PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 57, No. 1
July 2001
pp. 5–9

Evolution of nuclear spectroscopy at Saha Institute of Nuclear Physics

P MUKHERJEE
Formerly of Saha Institute of Nuclear Physics, Kolkata 700 064, India
Present Address: 85 Block A, Bangur Avenue, Kolkata 700 055, India

Abstract. Experimental studies of nuclear excitations have been an important subject from the earliest days when the institute was established. The construction of 4 MeV proton cyclotron was mainly aimed to achieve this goal. Early experiments in nuclear spectroscopy were done with radioactive nuclei with the help of beta and gamma ray spectrometers. Small NaI(Tl) detectors were used for gamma–gamma coincidence, angular correlation and life time measurements. The excited states nuclear magnetic moments were measured in perturbed gamma–gamma angular correlation experiments. A high transmission magnetic beta ray spectrometer was used to measure internal conversion coefficients and beta–gamma coincidence studies. A large number of significant contributions were made during 1950–59 using these facilities. Proton beam in the cyclotron was made available in the late 1950's and together with 14 MeV neutrons obtained from a C-W generator a large number of short-lived nuclei were investigated during 1960's and 1970's. The introduction of high resolution Ge gamma detectors and the improved electronics helped to extend the spectroscopic work which include on-line $(p, p'\gamma)$ and $(p, n\gamma)$ reaction studies. Nuclear spectroscopic studies entered a new phase in the 1980's with the availability of 40–80 MeV alpha beam from the variable energy cyclotron at VECC, Calcutta. A number of experimental groups were formed in the institute to study nuclear level schemes with $(\alpha, xn\gamma)$ reactions. Initially only two unsuppressed Ge detectors were used for coincidence studies. Later in 1989 five Ge detectors with a large six segmented NaI(Tl) multiplicity-sum detector system were successfully used to select various channels in $(\alpha, xn\gamma)$ reactions. From 1990 to date a variety of medium energy heavy ions were made available from the BARC-TIFR Pelletron and the Nuclear Science Centre Pelletron. The state of the art gamma detector arrays in these centres enabled the Saha Institute groups to undertake more sophisticated experiments. Front line nuclear spectroscopy works are now being done and new informations are obtained for a large number of nuclei over a wide mass range. Currently Saha Institute is building a multi-element gamma heavy ion neutron array detector (MEGHNAD), which will have six high efficiency clover Ge detector together with charged particle ball and other accessories. The system is expected to be usable in 2002 and will be used in experiments using high energy heavy ions from VECC.

Keywords. Radioactivity; accelerators; in-beam spectroscopy; detector arrays.

PACS Nos 21.10.-k; 23.00

1. Introduction

In early 1940's the decay schemes of a large number of radioactive nuclei were studied in various laboratories of Europe and U.S.A. The nuclear level schemes obtained in these works posed a great challenge to nuclear spectroscopists. There was a great deal of confusion as these nuclear level schemes showed no regularities and the theoreticians were struggling to unravel the meaning of these spectroscopic data. Commenting on the lack of understanding of nuclear level schemes M N Saha, the founder of Saha Institute of Nuclear Physics, Calcutta, remarked:

"It appears that our position with regard to the nucleus is much the same as was the position with respect to the atom about the latter part of the nineteenth century" (M N Saha, 1950).

This situation changed remarkably during 1952–1953 when the foundation of nuclear structure theory was laid by the Copenhagen School (A Bohr and B R Mottelson). They, together with a large number of theoreticians, showed that the interplay of collective and single nucleon motions can quantitatively account for most of the observed spectra.

Against this background Institute of Nuclear Physics (as it was called then) started building equipments to investigate the level structure of atomic nuclei. Three laboratories of the institute were involved in this work: (1) the beta-gamma ray spectroscopy laboratory, (2) the cyclotron laboratory and (3) the 14 MeV neutron generator laboratory. We shall briefly describe the early activities of these laboratories.

2. Beta and gamma ray spectroscopy

During the initial stage the emphasis was on the fabrication of good quality NaI(Tl) gamma ray detectors, as these detectors were not available at that time commercially. Good quality NaI(Tl) crystals were grown (approximate size of these crystals were 2 cm dia. and 3 cm long). These were cut and polished in moisture free environment and canned in aluminium containers with appropriate reflectors. Fairly stable performance of these gamma ray detectors were obtained. It was only in 1954 that the first commercially available NaI(Tl) detectors were purchased for the laboratory.

Together with the detectors all the electronic equipments, viz., high voltage supply, linear amplifiers, scalars, pulse-height analyser, slow-fast coincidence circuits were designed and fabricated by the laboratory workers.

The first significant contribution in gamma ray spectroscopy was by S Chatterjee and A K Saha, who for the first time in 1953 showed the importance of finite solid angle in gamma–gamma angular correlation experiments.

In parallel with the gamma-ray work the complementary spectroscopic studies using beta ray spectrometer were also initiated in early 1950's. In 1953, M K Banerjee and A K Saha showed theoretically the remarkable improvement in energy resolution in a lens type beta ray spectrometer by placing a continuous baffle system at the intermediate image position. Following this idea an improved short-lens beta ray spectrometer was designed and made operational by P N Mukherjee, M K Pal, M K Banerjee and A K Saha (1956).

In 1958 a state-of-the-art beta ray spectrometer (Siegbahn-Slatis spectrometer) having good energy resolution and very large transmission was purchased from Sweden. This instrument became an important tool for the spectroscopy work of a large number of nuclei. During the same time a gamma ray spectroscopy laboratory was set up by R L Bhattacharyya and A K Sen Gupta.

The first complete spectroscopic work done using these facilities was the study of the decay of 12.5y ^{152}Eu leading to ^{152}Sm and ^{152}Gd (P N Mukherjee, I Dutt, A K Sen Gupta and R L Bhattacharyya (1958–59)). In this study measurements were made using the Siegbahn-Slatis beta ray spectrometer and gamma–gamma coincidence and angular correlations. The beta-ray spectrometer was modified so that beta–gamma and conversion electron–gamma coincidence experiments can be undertaken. The NaI(Tl) detector data (energy resolution 9$\%$ at 661 keV) was supplemented by external conversion data using uranium radiator in front of the radioactive source in the beta-ray spectrometer. The improved energy resolution (2$\%$) gave additional informations about a large number of gamma rays in the decay of ^{152}Eu.

From 1960 onward the level structure of a large number of nuclei was investigated using long-lived radioactive isotopes. Notable contributions were made in understanding the basic dynamics of single particle and collective modes in different nuclear regions.

With the introduction of high resolution Ge(Li) gamma detectors in 1966 the spectroscopy work received a boost and very precise data were obtained for many of the nuclei already studied earlier and the investigations on the level schemes were expanded for more difficult and complicated decay schemes. An important contribution was the measurement of electric monopole transition matrix elements in the beta and gamma vibrational bands in ^{152}Sm (P Mukherjee and I Mukherjee, 1969). Another new contribution is the measurement of K-capture rates (P_K) using summing technique in a single Ge(Li) detector (B K Dasmahapatra and P Mukherjee).

In 1967 a perturbed angular correlation set-up was installed in the gamma ray laboratory for the measurement of magnetic moments of nuclear excited states (R L Bhattacharyya and B K Sinha). This facility was extensively used for the measurements of magnetic moments of a large number of nuclei like ^{181}Ta, ^{152}Sm, ^{177}Hf, ^{144}Pr, etc (A K Nigam, R L Bhattacharyya and B K Sinha). Later in 1988, BaF_2 detectors having good timing properties were used for similar work (C C Dey, B K Sinha and R L Bhattacharyya).

3. The 38$''$ Calcutta cyclotron and nuclear spectroscopy work with 4 MeV proton beam

The cyclotron was modelled after the original 38$''$ cyclotron at Berkeley, U.S.A. The proposal for the cyclotron was placed before the then British Government by Professor M N Saha in 1942, who initiated nuclear science research in the Palit laboratory of Calcutta University. The magnet for the cyclotron and the vacuum equipments were imported. Rest of the components were fabricated in the workshop of the Palit Laboratory. The major equipments fabricated were:

(a) High power oscillator, 50 KW, 10.8 MHz.
(b) A low voltage hooded arc discharge ion source heated by 1 KW 100 KHz rf supply.
(c) The rf resonating system – a transmission line with improved Q by using an elliptical cross section of the line.
(d) Magnet coil with stabilized current supply.
(e) Control circuits.

The team of workers who built the cyclotron consisted of: B D Nag Chowdhury, B M Banerjee, S K Mukherjee, S Sen, S Chatterjee, A P Patro, B Basu, P K Dutta, S B Karmohapatro, S K Majumdar, B B Baliga and R Rama Rao together with a band of dedicated technicians and workshop personnel.

Although the cyclotron fabrication was completed by 1953 it took another six years to obtain internal stable beam of proton (50 μA). External proton beam (4 MeV, 0.05 μA) was obtained in 1965. The extracted proton beam was transferred to a separate beam hall having two beam lines at 0° and 20° respectively. Two Ge(Li) detectors were installed at 0° port for gamma–gamma coincidence and angular correlations of short-lived nuclei produced by 4 MeV proton. A separate gamma ray angular distribution table was also installed for doing online $(p, n\gamma)$ and $(p, p'\gamma)$ experiments.

In early 1960's the internal beam was used to produce several short-lived nuclei and the decay schemes were studied with conventional gamma ray spectroscopy (A P Patro and B Basu). These studies include the following nuclei: ^{51}Mn, ^{85}Y, ^{96}Te, ^{96}Nb, ^{97}Rh, ^{100}Rh, ^{103}Ag, ^{107}In and ^{113}Sb.

Several online $(p, n\gamma)$ and $(p, p'\gamma)$ experiments were undertaken by A P Patro and S K Basu in early 1970's which include spectroscopy of ^{96}Mo and ^{85}Sr. In collaboration with V Paar theoretical interpretations of the level schemes were given.

In a parallel investigation by A P Patro and P Sen during the same period (1970) a time resolution of 135 ps was achieved for ^{60}Co with plastic phosphor, which was the best reported time resolution at that time. Using this timing set-up the behaviour of ortho-positronium in metallic oxides were studied for the first time in India.

4. Experiments with 14 MeV neutrons

A 200 keV C-W generator was built during (1956–58) by S K Mukherjee, N K Majumdar and A K Ganguly. 14 MeV neutron was made available from 1960 onward. Here also a large number of short-lived nuclei were produced and their decay schemes were established by gamma ray spectroscopy. Earliest (1964) measurements include spectroscopy of ^{93}Y, ^{183}Ta and ^{162}Dy by H Bakhru and S K Mukherjee. A noteworthy contribution is the decay of 46.6 s isomer of ^{75}Ge by P Bhattacharyya, R K Chattopadhay and B Sethi (1976).

5. Nuclear spectroscopy work at the national facilities

5.1 *Variable Energy Cyclotron Centre, Calcutta*

The experience gained by the scientists of Saha Institute of Nuclear Physics during 1950 to 1970 became useful with the commissioning of the variable energy cyclotron in early 1980's. A number of groups were formed to undertake nuclear spectroscopy work as well as nuclear reaction work using the 30–80 MeV alpha (^{4}He) beam from the cyclotron. We shall only describe the work in the field of gamma ray spectroscopy with (α, xn) reaction on various nuclei. Two 130 cm^3 N-type Ge detectors together with adequate electronics were purchased and a gamma–gamma two parameter system was made operational in 1983. Since the alpha beam from the cyclotron is pulsed (5 ns beam width and about 140 ns interval), both rf prompt and rf-delayed spectroscopy are routinely done. Important and new results are obtained (1984) in several At nuclei from ^{209}Bi$(\alpha, xn\gamma)$ reaction (P Mukherjee, P Sen, I Mukherjee and C Samanta). The high spin states (up to 43/2$\hbar$) in ^{211}At identified for the first time are correlated with the aligned three proton states outside the closed shell at $Z = 82$. In another experiment done in 1988 the band structure in ^{95}Ru and ^{104}Ag are studied with ^{94}Mo $(\alpha, 3n\gamma)$ and ^{103}Ru $(\alpha, 3n\gamma)$ reactions respectively

(A Goswami, M Saha, P Basu, P Banerjee, P Bhattacharya, S Bhattacharya, M L Chatterjee, B Dasmahapatra and S Sen). Among the important work completed in 1989–90 are the study of ^{149,151}Sm nuclei with ^{150}Nd $(\alpha, xn\gamma)$ reaction (J Chatterjee and Somapriya Basu) and the spectroscopy of ^{123}I with ^{121}Sb $(\alpha, 2n\gamma)$ reaction (R Goswami, B Sethi, P Banerjee and R K Chattopadhyay).

During the same period (1989–90) a sum and multiplicity spectrometer system consisting of a large six-segmented NaI(Tl) cylindrical detector completely surrounding the target and five Ge detectors (of which two are Compton-suppressed) are used to study the level scheme of ^{198}Tl with ^{197}Au $(\alpha, 3n\gamma)$ reaction. With proper multiplicity gate a clear separation of 3n reaction channel is obtained and many new levels in ^{198}Tl are found (P Mukherjee, P Sen, I Mukherjee and B Sethi).

The above are a cross section of the experiments done during 1983 through 1990 with the variable energy cyclotron. Till date a large number of investigations have been completed and published by several groups from Saha Institute of Nuclear Physics together with the scientists from other centres like VECC, TIFR, BARC etc.

5.2 *BARC–TIFR Pelletron, Bombay and Nuclear Science Centre Pelletron, New Delhi*

Nuclear spectroscopy work entered a new phase with the availability of medium energy heavy ion beam from the above centres. One of the first spectroscopic studies undertaken by Saha Institute at BARC–TIFR Pelletron was the spectroscopic study of ^{216}Ra from ^{209}Bi(^{11}B, $4n\gamma$) reaction (P Mukherjee, B Sethi, I Mukherjee, P Sen in collaboration with M G Betigeri and his group at BARC, 1990). The work is essentially an extension of the earlier work in At-region to identify the high spin aligned single proton states. With the availability of gamma detector array system (six compton-suppressed Ge detector) at Nuclear Science Centre, New Delhi further work on several Ra nuclei is continued (1992–95) in collaboration with R K Bhowmik and his group at NSC.

Several other groups from Saha Institute are actively engaged in these two heavy ion facilities and a large number of spectroscopic studies are completed during 1992 to date. Out of the numerous publications, mention could be made of two very interesting work: rotational band structure in ^{111}Sn (S Bhattacharya, B Dasmahapatra and S Sen in collaboration with R L Bhattacharya and his group at Calcutta University and R K Bhowmik and his group at NSC, 1995). They observed for the first time a negative parity rotational band up to 43/2 in the reaction ^{103}Rh (^{12}C, $p3n\gamma$). During 1992–94, J M Chatterjee, S Basu, in collaboration with S S Ghugre, Bombay University and R K Bhowmik and his group at NSC found convincing evidence for octupole collectivity in the Sm region from ^{148,150}Nd (^{7}Li, $xn\gamma$) reaction leading to ^{150,153}Eu.

Only a few out of the many investigations carried presently by various groups from Saha Institute of Nuclear Physics are presented here. The richness and variety of work done at the two heavy ion machines assure a continuity of spectroscopy work for several years to come. It is hoped that more energetic heavy ions will be made available soon from VEC and the two Pelletrons, which will expand the spectroscopic studies to regions of nuclei far removed from the beta stability line. These exotic nuclei may show completely new properties throwing new challenge to understand their spectra. Also new spectroscopic tools are being developed, both at Saha Institute of Nuclear Physics and other national laboratories. It is hoped that the present decade will enable us to enter the very frontier of nuclear spectroscopy research.