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THE CHANDIGARH VARIABLE ENERGY CYCLOTRON

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Abstract.- The paper describes the operational characteristics of the variable energy cyclotron at Panjab University, Chandigarh (INDIA) operating since 1977. The various innovations in the machine to increase its stability, beam intensity and resolution are discussed in detail. The machine is operating at present with α-particles, Helium-3, Deuterons and protons. A few spectra, of gamma rays and charged particles, dipicting the quality of the beam, are presented alongwith the results obtained in various experiments already performed with the machine.

1. Introduction.- The variable energy cyclotron at Chandigarh has now been functioning for the last three years with resolved beam of protons, deuterons, alphas and He^{3++} at the main target chamber. The beams of protons of energy from 2 to 5 MeV, deuterons from 3.5 to 4 MeV, alphas 7 to 8 MeV, and He^{3++} 5 to 11 MeV have been obtained at the target. This paper describes the various features of this cyclotron and the characteristics of the accelerated particles. At present the Machine is being used for In-beam Nuclear Spectroscopy using protons and He^4 reactions. Few gamma rays and charged particle spectra are given to indicate the performance of the accelerator.

2. Main Features.- This machine at Chandigarh is adapted and built out of the components of the variable energy cyclotron at the University of Rochester,Rochester New York, USA. It is a single Dee classical cyclotron with arrangement for variable frequencies from 10 to 20 MHz, and the magnetic field upto a maximum of 14 K G. This permits the variability of the energy of the various accelerated ions. The layout plan of the whole set-up is shown in Fig. 1.

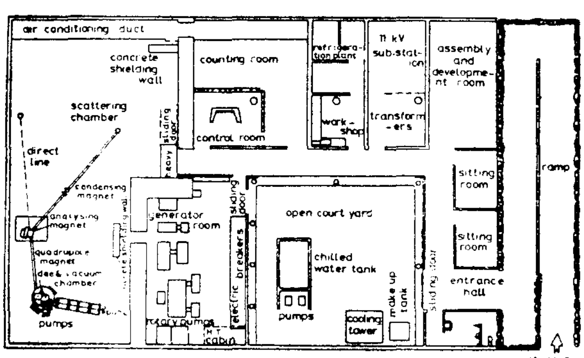

Fig. 1: General layout plan of the cyclotron laboratory.

3. The Main Magnet.- The stability of the magnetic field is better than 1 in 10^5. The radial fall-off of the field is shown in Fig. 2a. The field index varies from zero at the centre to 0.1 at the extraction radius of 28.0 cm. It is thus a weak focussing machine. The azimuthal variation of the magnetic field at different radie is shown in Fig. 2b. The pole faces are so aligned that the contribution of the first harmonic is less than 10 Gauss upto the extraction radius as shown in Fig. 2c.

Therefore, no appreciable shift in the beam centre was noticed.

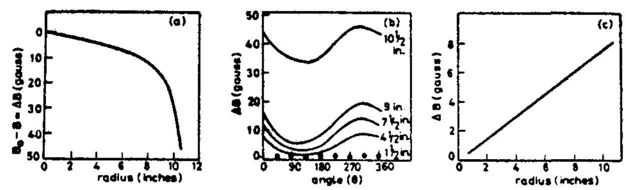

Fig. 2: Variation of the magnetic field of the main magnet in the chamber.

4. The Oscillator.- The oscillator is driven by a RCA 5771 tube with a dissipation power of 25 kVA and a water cooled anode as shown in Fig. 3. A cavity, 250 cm long and 65 cm outer diameter with a Dee stem of 7.5cm diameter forms the tank circuit of the oscillator tube. The oscillator operates in $\lambda/4$ mode. The high Q of the oscillator circuit ($\sim$1000) takes care of the stability of the frequency and the Dee voltage. The performance of the oscillator was greatly improved when the Dee cavity was directly coupled with the main accelerating chamber. In the original design this connection was provided only by a press contact which used to create excessive local heating.

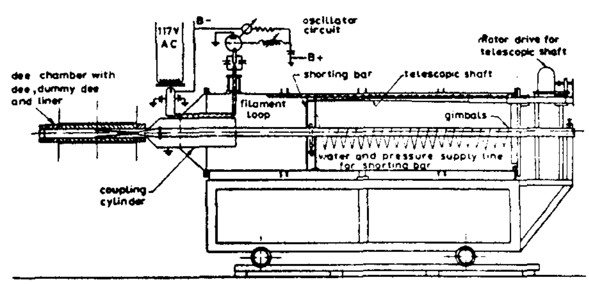

Fig. 3: Coupling of the oscillator cavity with Dee.

5. The Ion Source.- The machine was provided with a hooded arc ion source whose physical design was somewhat modified by providing an anticathode at the head for better performance and flexibility of movement.

Fig. 4 illustrates the final design of the ion source.

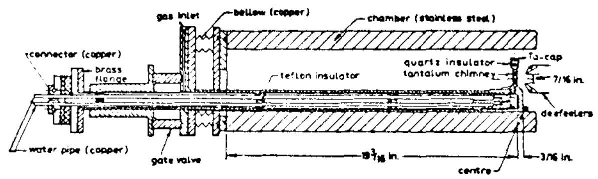

Fig. 4: Ion source assembly and the chimney.

6. The Deflector.- The deflector is of a simple electrostatic type with provision for a maximum DC voltage of about 70 kV. The deflector blade with the oil-cooling arrangement is made of copper, and the septum is made of very thin tungsten plate. The positions of the blade and the septum may be controlled remotely from the control desk.

7. Vacuum System.- The vacuum inside the machine is created by four 15 cm and one 23 cm diffusion pump. The forevacuum to diffusion pumps is provided by a Kinney rotary pump. The addition of the 23 cm diffusion pump to the oscillator cavity helped to improve the vacuum in the cavity by a factor of two when compared to the Rochester values. This increased the stability of the oscillator many times.

8. Beam Characteristics.- Fig. 5 shows the variation of the typical beam currents of the various ions at different radii in the main Dee chamber. In runs under the most optimized conditions, we have recently obtained internal beams of protons upto 100 μA at 20 cm radius and upto 50 μA at full radius. The currents for He^{4++} and He^{3++} are down by a factor of ten as compared to the protons.

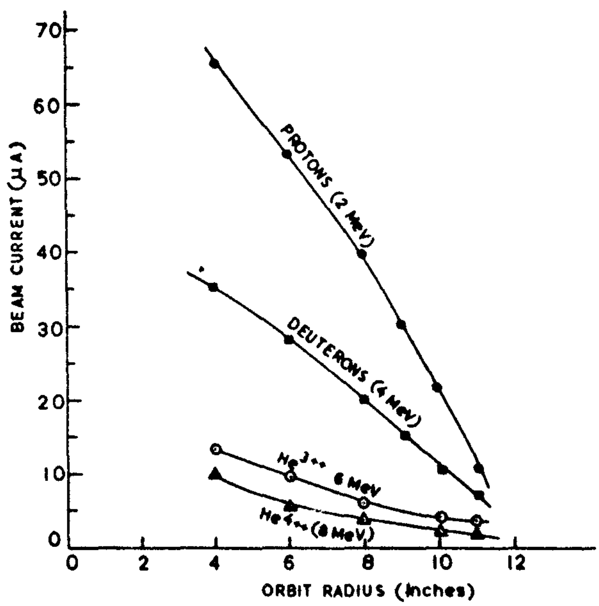

Fig. 5: Variation of the internal beam currents inside the chamber.

9. Energy Calibration and Resolution of the Beam.- Fig. 6 shows the charged particle spectra arising from the Al target with protons of 3.5 MeV. The thickness of the target was 5 keV for protons. The peaks due to inelastic scattering of protons and α-particles are clearly identified. From this, one obtains a beam resolution of 30 keV for protons.

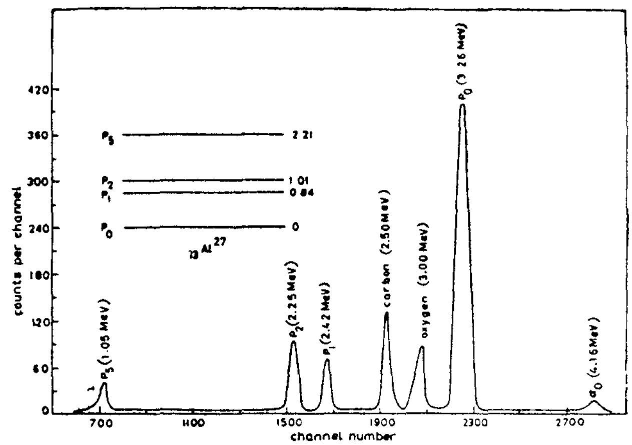

Fig. 6: Proton spectrum from $^{27}Al\ (p,p'\gamma)$

10. Experiments with the Machine.- At present three types of experiments are being carried out, these are described below :

(i) In-beam spectroscopy using proton and He^4 induced reactions.

In these experiments, we have studied the angular distribution of resulting γ-rays from the excited nuclei formed by (pp'γ), (p,nγ), (p,γ) and similarly with alphas by (α,pγ), (α,nγ) and (α,α'γ) reactions.

Fig. 7 and 8 show the gamma-ray spectra taken with protons and He^{3++} as projectiles on the ^{27}Al target.

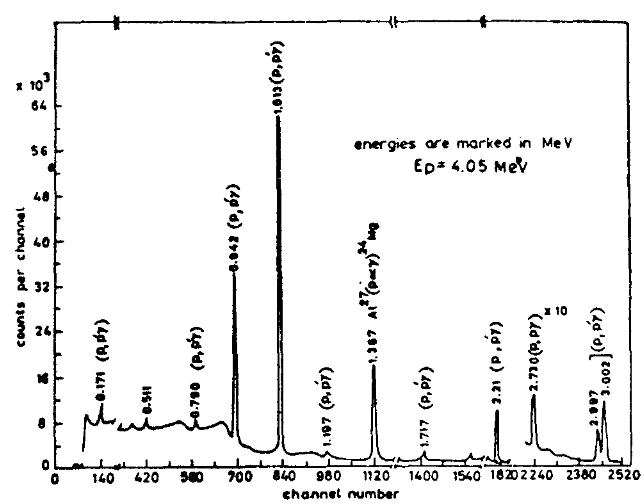

Fig. 7: Typical gamma rays spectra due to $^{27}Al(p,p'\gamma)$ at E_p = 4.05 MeV.

These two spectra show that there is no appreciable contribution from the background and all the gamma-rays can be attributed to reactions from aluminum. All these spectra were taken at 90° to the beam direction with the help of 50cc. Ge(Li) detector to avoid broadening of the peaks due to Doppler shift. The angular distribution of the γ-rays was recorded between 0° to 90° at 15° interval. A typical angular correlation data for 685 keV γ-ray in case of ^{93}Mo is shown in Fig. 9 alongwith the least square fit curve to determine the spin and mixing ratio.

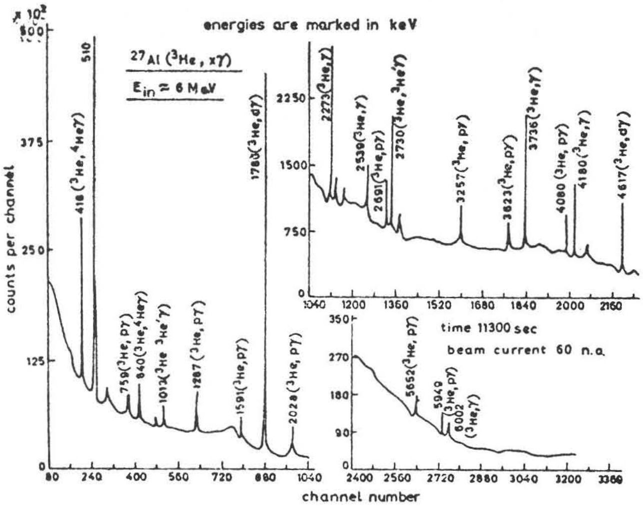

Fig. 8: Typical gamma rays spectra due to ^{27}Al (He^3,Xγ).

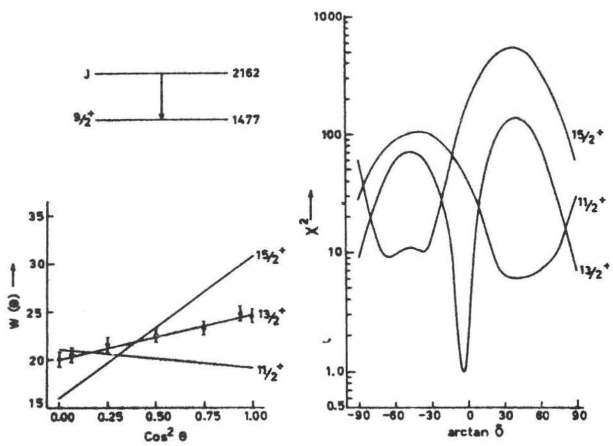

Fig. 9: Gamma ray angular distribution and χ^2 curve for decay from 2162 keV level in ^{93}Mo.

We have also measured the Doppler shift in the energy peaks at different angles in ^{27}Al (p,γ)^{28}Si reaction, which gives the life-time of the levels using the DSAM techniques. Fig. 10 shows typical shifts obtained from ^{27}Al (p,γ) reactions. The measurements of shift of a few keV upto 11.8 MeV shows the stability and reliability of the experimental set-up. Many other nuclei have also been studied.

(ii) Coulomb excitation :

Many cases of Coulomb excitation have been studied using protons as projectiles.

Fig. 11 gives the typical excitation function of some of the levels of ^{197}Au, by Coulomb excitation with protons, alongwith the theoretically expected values. Coulomb excitation on many nuclei have been studied.

(iii) Shortlived radio isotopes using the cyclotron :

The shortlived isotopes have been produced using the proton and He^4 beam of the machine. A typical case is that of ^{63}Zn, produced by ^{63}Cu (p,n) ^{63}Zn at 4.5 MeV of proton energy.

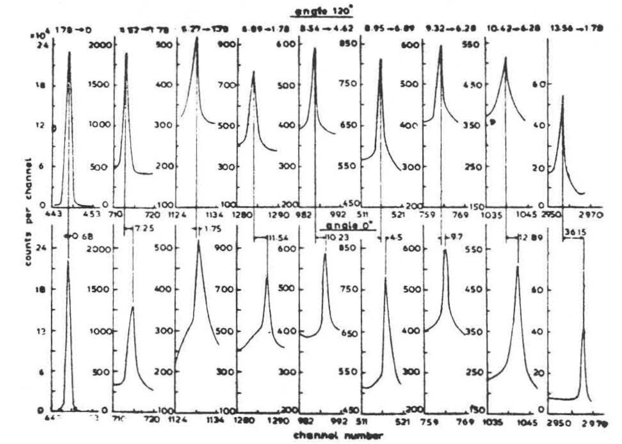

Fig. 10: Doppler shift of the gamma-rays spectra from ^{27}Al (p,γ) reaction at E_p = 2.03 MeV.

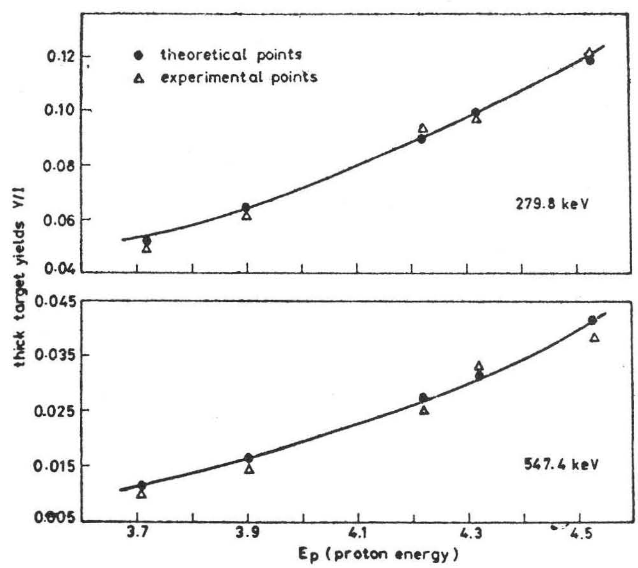

Fig. 11: Excitation functions of the reaction (p,p'γ), and its comparison with theoretical values based on Coulomb excitation.

Besides the above mentioned experiments, many workers in our laboratory and outside, have shown interest in this machine for other experiments, which may be broadly categorized as follows.

(i) Study of reaction mechanism in He^3 and deuteron-induced reactions, especially in the sub-coulomb region.

(ii) Study of nuclear spectroscopy through He^3 and deuteron-induced reactions. These studies will involve measurement of both particle spectra and gamma-rays.

(iii) Nucleo-solid experiments, for example,

(a) perturbed angular distribution
(b) channelling studies
(c) studies of radiation damages.

(iv) Proton-induced X-rays for non-destructive analysis. Some of these experiments are already being planned.

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