The quadrupole moment of nucleus is one of the fundamental properties of the nucleus. Its determination has enabled the atomic and nuclear physicists to determine the non-spherical shape of the nuclear charge distribution. From the quadrupole moment study, some of the intrinsic properties of the nuclear forces were thus discovered. The most outstanding cases were (1) The discovery of the non-central nuclear forces by the precision measurements of the quadrupole moment of deuteron\(^1\) and (2) The understanding of the collective motion of the nucleons in the strongly deformed nuclei\(^2\) by the observation of the anomalously large quadrupole moments and the \(E2\) transitions of these deformed nuclei. However, to extract the quadrupole moments from ordinary atomic h.f.s. or other methods is difficult because of the uncertainties in the calculations of the electric field gradients or the excited virtual states in reorientation methods, etc. Dr. Powers has just presented an excellent review on how to make precision determination of the \(E2\) (and \(E4\)) moments in strongly deformed nuclei to an accuracy of 1-2\% by the study of the h.f.s. in the muonic or pionic X-rays.

Recently, the Columbia's 550 MeV proton Cyclotron began to produce an external proton beam of a fraction of \(1\%\). As starting-up experiments, we have obtained some rather satisfactory results of the \(\pi\)-X-rays and the rotational \(\gamma\)-rays of pionic atoms formed with the strongly deformed nuclei\(^{165}\)Ho and \(^{181}\)Ta.

Here I wish to present only the results on the study of the quadrupole hyperfine structure in pionic atoms.

As Dr. Powers pointed out in his talk that the E-M interaction between the \(\pi\) and the nucleus may be treated exactly the same way as in the case of the \(\mu\)-atom. However, there are two distinctive differences between them. Firstly because of the zero spin of \(\pi\), the solutions of the Klein-Gordon equation have to be used instead of the Dirac wave functions. Secondly, the strong interactions between the \(\pi\) and the nucleons have to be taken into account particularly in a strongly deformed nuclei, this strong interaction affects not only the positrons of the unsplit levels, it may also affect the quadrupole hyperfine splittings in a pionic atom in a measurable way. The non-spherical contributions of the strong interaction result in different amounts of level shifts and broadenings for the various components of the h.f. multiplet. The reason for this is rather simple. The different hyperfine states \((F_i = I + \ell_i)\) reflect simply different coupling of the nuclear spin \((I)\) and the plane of the atomic orbit \((\ell)\). Clearly, for a deformed nuclear spheroid, the ends of the major axes are much closer to the circular orbit of the atomic particles \((\pi)\) if the elongated spheroid lies in the plane than if it is perpendicular to it. The strong interaction quadrupole level shifts \(\Delta \gamma_2\) and width \(\Gamma_2\) are therefore bigger in the first case. This type of investigation not only yields precision determination of the quadrupole moment of certain nuclei, it also offers a novel means to study the strong interaction in the h.f.s. splitting. Therefore, there are two ap-
approaches to this type of investigation:

I. The quadrupole effect due to the strong interaction may be observed by combining a precise measurement of the h.f.s. of the pionic atom with that of the corresponding μ-atom. The difference between the effective h.f.s. constant \( A_\text{eff} \) of pionic atom and the E-M h.f.s. constant \( A_\mu \) calculated by using the spectroscopic quadrupole \( Q \) extracted from the muonic atom method must be attributed to the quadrupole effect of the strong interaction.

II. If the accurate spectroscopic quadrupole moment \( Q \) is not available, one might proceed the analysis of the h.f.s. in pionic atoms in a reverse direction. As it is known, the quadrupole effect due to the strong interaction is only a few percent of the total effect. Furthermore, the ratios of level shifts \( \epsilon_2/\epsilon_0 \) (where \( \epsilon_2 \) is the strong interaction quadrupole shift and \( \epsilon_0 \) the monopole shift) and level broadening \( \Gamma_2/\Gamma_0 \) of the various components in a multiplet due to the strong interaction have been estimated theoretically by F. Scheck. The h.f. contribution due to the strong interaction can be taken account by using the theoretical corrections and then extract the spectroscopic quadrupole moment \( Q \) from the measured total quadrupole splitting \( (Q_{\text{eff}}) \).

We used the second approach to extract the quadrupole moments of \(^{155}\text{Ho}\) and \(^{181}\text{Ta}\) from our pionic atom results and the \( Q \) values (Table 3) are in excellent agreement with that from the muonic atoms (\(^{155}\text{Ho}\) and \(^{181}\text{Ta}\)) by Powers et al. \(^4\) \(^5\) and from the pionic atoms (\(^{155}\text{Ho}\)) by Ebersold et al. \(^6\).

Experimental Arrangements:

The external proton beam incidents on a thick Be target and the generated pions coming out at 90° are focussed and analyzed in a magnetic Channel #1. The X-rays and the γ-rays are detected by two Ge(Li) detectors which are in coincidence with the conventional \( \pi \) stop-signals as in Fig. 1. The electron contamination of the pion beam is almost totally suppressed by the Lucite Cerenkov counter \( S \), while the loss of pions is kept at less than 5%. The data-acquisition system has the ADC'S interfaced to a PDP-8 computer for collection of digitized data and stabilization of the ADC'S. The long time stability is \(< 1/2 \) channel out of 8000 channels.

![Figure 1. Experimental Beam Telescope](image-url)