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V.g. Coulomb Excitation of ^{208}Pb with Heavy Ions

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(Presented by A. R. Barnett)

The static quadrupole moment of the 2.6 MeV 3^- state of ^{208}Pb is being remeasured by a γ-ray method. So far beams of ^{12}C, ^{20}Ne, ^{32}S, and ^{40}Ar have been used, with the result $Q(3_1^-) = -0.9 \pm 0.4$ b. This value depends weakly on $Q(2_1^+, {}^{206}\text{Pb})$ and it agrees with the earlier determination of -1.3 ± 0.6 b. It also agrees with the finite-Fermi-system calculation of Krainov.

Recent calculations[1)] of the quadrupole moment of the collective octupole state in ^{208}Pb, $Q(3_1^-)$ have failed to reproduce the result obtained in an earlier experiment.[2)] In that work both the quadrupole moment (-1.3 ± 0.6 b) and the B(E3) (0.58 ± 0.04 e^2b^3 = 32 spu) for the transition were extracted from absolute differential cross section measurements of the inelastic scattering of ^{4}He and ^{16}O off thin targets of ^{208}Pb. It is important both for the theories of the doubly-magic Pb nucleus and for the understanding of possible sources of error in that experiment, that this discrepancy be resolved. In this note we report on the first results of a remeasurement of $Q(3_1^-)$ by a technique which compares the thick-target, total γ-ray yield following Coulomb excitation of the ^{208}Pb 3_1^- state to that for exciting the 2_1^+ level in ^{206}Pb. This method should be less sensitive to possible interfering amplitudes in the small excitation probability of the 3_1^- level than the earlier work, since the yields are averaged over both energy and angle.

Targets of natural lead, 0.01 cm in thickness, were bombarded with 4.15 MeV/A beams

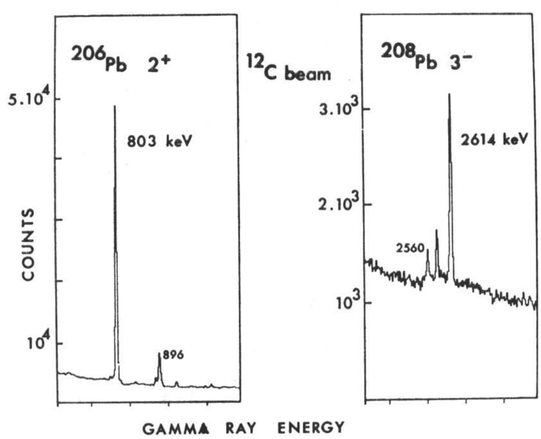

Fig. 1. The sum of fourteen spectra obtained with the ^{12}C beam on a natural Pb target. A 75 cm^3 GeLi detector was used.

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of ^{12}C, ^{20}Ne, ^{32}S and ^{40}Ar from the Manchester heavy-ion linac. The angular distributions of the 0.803 MeV and 2.614 MeV γ-rays, de-exciting the 2_1^+ level in ^{206}Pb and the 3_1^- level in ^{208}Pb respectively, were measured with a 75 cm^3 Ge(Li) detector at 7 cm from the target. A second detector was used as a monitor. Figure 1 shows the sum of fourteen spectra obtained with a ^{12}C beam in the region of the two gamma rays. Figure 2 shows the angular distributions for a ^{12}C beam together with theoretical fits to the shape obtained from Coulomb excitation theory. These shapes are essentially independent of the quadrupole moments. The results and fits for a ^{32}S beam are given in Fig. 3; the comparison between theory and measurement is again seen to be good. Fits to the experimental distributions gave the relative thick-target total yields, after correcting for the relative efficiencies which were determined during each experiment. These experimental ratios are shown as a function of the adiabaticity parameter ξ of the 3_1^- state excitation in Fig 4.

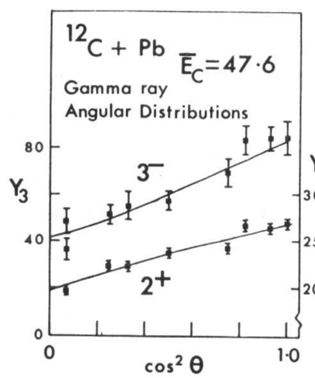

Fig. 2. Gamma-ray angular distributions for $^{12}C + ^{208,206}Pb$ and theoretical fits from Coulomb excitation theory with, $Q(3_1^-) = 0.9$b and $Q(2_1^+) = Q_R$. The ratio of the total γ-ray yields was used in the determination of $Q(3_1^-)$.

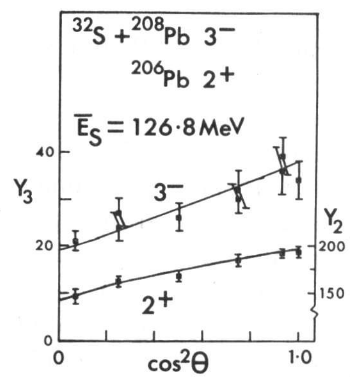

Fig. 3. Gamma-ray angular distributions following $^{32}S + Pb$ at a mean energy of 127 MeV. Theoretical fits are shown as in Fig. 2.

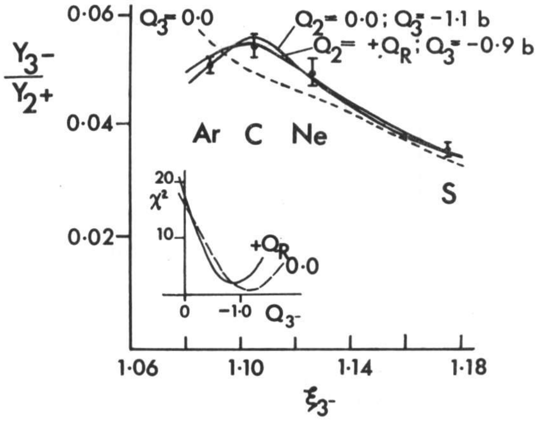

Fig. 4. Ratio of yields for exciting the 3^- state of ^{208}Pb to the 2^+ state of ^{206}Pb, with four projectiles. The curves are the best fits under the restrictions shown; the inset gives the variation of the fit for two assumed values of $Q(2_1^+)$. The dashed line shows the unacceptable fit if $Q(3_1^-) = 0.0$. Removing the Ar point does not alter the best fit $Q(3_1^-)$.

The theoretical relative yields of the two γ-rays for each of the projectiles were predicted with the usual coupled-channels calculation, using B(E3) and B(E2) values taken from the literature.[2,3] The sensitivity of the total 3^- cross section to $Q(3_1^-)$ ranges from 6% per barn for ^{12}C to 18% per barn for Ar; in the total 2^+ cross section the change for a rotor value change is only 4%. The sensitivity to $Q(2_1^+)$ is reduced because of the relatively much greater excitation of the 2^+ state. Thus the ratio of the relative yields for any two projectiles depends most strongly on $Q(3_1^-)$, and to a lesser extent on $Q(2_1^+)$. It is relatively insensitive to all other electromagnetic matrix elements. Using the data on Fig. 4, the most likely value of $Q(3_1^-)$ for $Q(2_1^+)$ equal to zero is -1.1 ± 0.4 b. For $Q(2_1^+)$ equal to $+Q_R$, where Q_R is the value deduced using the rotational model, $Q(3_1^-) = -0.9\pm0.4$ b. Hence, the lack of knowledge of $Q(2_1^+)$ does not introduce a serious uncertainty in $Q(3_1^-)$.

The preliminary results presented here are in agreement with the earlier measurement,[2] perhaps suggesting a slightly lower value of $Q(3_1^-)$. Figure 5 shows a comparison with theory. Krainov[4] has carried out finite-Fermi-system calculations and obtains $Q(3_1^-) = -0.79$ b, in excellent agreement with experiment. Both the B(E3) value and the g-factor are also given correctly. Recently several authors[1] have calculated Q to be between -0.07 and -0.20 b. Although the existing Coulomb excitation results are two standard deviations away from a quadrupole moment near zero there are two effects which may be influencing the interpretation. Without more experimental work one cannot be sure that the bombarding energy is sufficiently low that the interaction between the projectile and target is purely electric. The Ar energy is higher than current criteria for pure Coulomb excitation (established, however, for the differential cross sections to 2^+ states). However, if we exclude the Ar point from Fig. 5, the result is unchanged although the errors increase, so that the Ar data are completely consistent with the remainder. We intend to investigate this point further and to use beams of ^{24}Mg and ^{40}Ca in subsequent work.

Another source of uncertainty is the giant dipole resonance in Pb, whose parameters are not yet well enough known for our purposes; nevertheless a sensible estimate of the 1^- strength and its coupling to the octupole state suggests that the effect is quite small. In the case of the

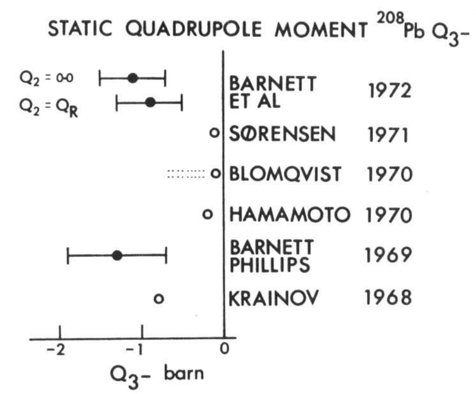

Fig. 5. Comparison of experimental and theoretical values for $Q(3^-)$. The recent result depends weakly on $Q(2_1^+$, ^{206}Pb) as shown and was obtained by a completely different method to the 1969 experiment. They are in agreement and also agree with the calculations of Krainov.

one-quadrupole-phonon 2^+ state at 4.09 MeV and the possible 0^+ and 2^+ two-octupole-phonon states, which we set at 3.7 MeV, we have better estimates of the coupling matrix elements and their effect is insignificant.

It is important for possible corrections to heavy-ion Coulomb excitation to calculate the effects of virtual nuclear tunnelling. It is also of interest to understand the origin of the large difference between the calculations of ref. 1 and ref. 4.

We conclude that the available data suggest that $Q(3^-)$ is close to -1.1 b with an error of ± 0.5 b, and it is in agreement with the calculations[4] of Krainov.

References

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2) A. R. Barnett and W. R. Phillips: Phys. Rev. **186** (1969) 1205.
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4) V. P. Krainov: Phys. Letters **27B** (1968) 341; and private communication.

Discussion

E. KANKELEIT (ITK-Darmstadt): The isomer shift of the 3^- state coupled to a particle has been measured in Tl and Bi muonic atoms. Using different models these shifts can be compared with your $Q(3^-)$ and turn out to be in reasonable agreement.