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EXPERIMENTAL OBSERVATION OF DOUBLE COULOMB EXCITATION

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EXPERIMENTAL OBSERVATION OF DOUBLE COULOMB EXCITATION*

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In regions of the periodic table where nuclei have large spheroidal deformations, it is well known that there are associated with the ground states of even-even nuclei rotational bands in which the members have spins and parities of 0+ (ground), 2+, 4+, 6+, etc.[1] The 4+ state belonging to this rotational band can be Coulomb excited either by a direct E4 excitation or by a double E2 process via the 2+ member of the band.[2] (Other intermediate states can also give a contribution, but that from the 2+ state is likely to predominate.) When heavy ions are used as bombarding particles, the probability for the double E2 process is expected to become high, and to exceed considerably that for the E4 excitation.

In order to observe double E2 Coulomb excitation we bombarded thick targets of natural tungsten with oxygen ions from the Berkeley heavy-ion linear accelerator. Natural tungsten consists almost entirely of the three even-even isotopes, W^{182}, W^{184} and W^{186}, and of the odd-mass isotope W^{183} in 14% abundance. These nuclei are known to be highly deformed and to have rotational bands. The gamma rays arising from the decay of the excited states were observed with 1" x 1-1/2" diameter NaI(Tl) crystals together with a 50 channel and a single channel pulse-height analyzer.

The pulse-height spectrum showed two broad peaks, having mean energies of 114 and 250 kev. The lower energy peak arises almost completely from the decay of the known first excited states of W^{182}, W^{184}, and W^{186}, which have energies of 100.07 kev, 111.13 kev, and 122.48 kev respectively.[3] We believe that the second broad peak arises from the decay of the 4+ to the 2+ states of the even-even nuclei,

1. A. Bohr and B. R. Mottelson, Dan. Mat. Fys. Medd. 27, No. 16 (1953).
2. K. Alder, A. Bohr, T. Huus, B. Mottelson and A. Winther, Rev. Mod. Phys. 28, 432, (1956).
3. E. L. Chupp, A. F. Clark, J. W. M. Du Mond, F. J. Gordon and H. Mark, Phys. Rev. 107, 745 (1957).

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† At present on leave of absence from AERE, Harwell, England.

and from the decay of the 292 kev level in W^{183}.[4] The energies of the 4+ to 2+ transitions in W^{182} [5] and W^{184} [6] are known to be 229.07 and 252.8 kev, and that in W^{186} is expected to be about 280 kev. The intensity arising from the excitation of the 292 kev state in W^{183} can be calculated from the measured B(E2).[4] In order to verify that most of the 250 kev peak was in coincidence with a transition of about 114 kev, coincidence measurements were made with a resolving time $2\tau = 10^{-7}$ sec. The results indicated that at 66 Mev bombarding energy essentially all the 250 kev peak was in coincidence with such a transition.

The excitation functions for the two peaks were also measured using bombarding energies between 30 and 80 Mev. The excitation function for the 114 kev peak is shown in Fig. 1, where it is compared with a theoretical thick target excitation function for exciting a state at 114 kev.[2] The range-energy curves of Barrett[7] were used in calculating the theoretical curve. The normalization of the curve to the experimental points is arbitrary; nevertheless, the experimental thick target yield of $(5.7\pm0.8) \times 10^6$ photons/μcoul. at 40±2 Mev bombarding energy is consistent with that of 5.8×10^6 photons/μcoul. calculated from the previously measured B(E2) values for the tungsten isotopes.[8,2] This corresponds to a cross section of 0.57 barns for the production of photons or, since the average conversion coefficient is about 2.3,[2] to an average cross section for exciting the 2+ states of about 1.9 barns. It can be seen that the points deviate from the theoretical curve by almost as much as a factor of two at the highest energy, which is close to that of the Coulomb barrier. The process of Coulomb de-excitation, estimated from a naive point of view, is too small to account for this deviation. Such a deviation from the theoretical curve at the highest energies is not particularly surprising since the

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4. P. H. Stelson and F.K. McGowan, Phys. Rev. 99, 112 (1955).
5. J. J. Murray, F. Boehm, P. Marmier, and J. W. M. Du Mond, Phys. Rev. 97, 1007 (1955).
6. C. G. Gallagher, Jr., D. Strominger, and J. P. Unik, Phys. Rev. (1958) to be published.
7. R. Barrett, private communication (1957), recalculated from Aron, Hoffman, and Williams, AECU-663 (1949) unpublished.
8. C. McClelland, H. Mark, and C. Goodman, Phys. Rev. 97, 1191 (1955).

probability for excitation is so high that the perturbation method used in the theoretical derivation is hardly a valid procedure.

The excitation function for the 250 kev radiation is shown in Fig. 2. The calculated intensity of the 292 kev gamma ray of W^{183} is also shown, and this contribution has been subtracted from the experimental points before plotting. The resulting points are compared with an approximate theoretical excitation function for the double E2 process of the form:[2]

$$\sigma_{E2-E2}\ (0 \rightarrow 4) = \alpha\ a^{-2}\ \sigma_{E2}\ (0 \rightarrow 2)\ \sigma_{E2}\ (2 \rightarrow 4), \qquad (1)$$

where α is a constant and 2a is the distance of closest approach in a head on collision. It can be seen that the agreement between this curve and the experimental points is good except at the highest energies where the points fall below the curve. This deviation is rather similar to that observed for the 114 kev peak, and it seems likely that the two are related.

If the theory of double E2 excitation were well established, we could in this case use it, together with the measured cross sections, to give a value for $B_{E2}\ (2 \rightarrow 4)$. We could then see whether that value was consistent with that expected from the theory of rotational states:

$$\frac{B_{E2}\ (2 \rightarrow 4)}{B_{E2}\ (0 \rightarrow 2)} = \left\{\frac{\langle 2200 \mid 40 \rangle}{\langle 0200 \mid 20 \rangle}\right\}^2 = \frac{18}{35} \qquad (2)$$

Since the theory of double E2 excitation is not yet well established, we shall use the reverse procedure and, assuming that relation (2) is valid, compare our measured yield with that calculated from (1) using the theoretical value of 0.0272 for α.[9] Our yield of $(1.10 \pm 0.17) \times 10^5$ photons / μcoul. at 40±2 Mev bombarding energy compares well with the value of 1.19×10^5 photons / μcoul. obtained on the basis indicated above. This yield corresponds to an average cross section of 25 millibarns for the double excitation process. It should be noted here that in order to obtain this cross section from E4 excitation the B_{E4} would have to be about 5000 times the single particle value.[2] This does not seem to us very likely. It appears then that the present theory of double E2 excitation is not seriously in error.

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9. Private communication from K. Alder to G. Breit of a correction to the formula in Reference 2.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Fig. 1. Yield of 114 kev radiation from natural tungsten as a function of oxygen ion (charge +8) energy. The points are the experimental yields, and the line is the theoretical curve for E2 excitation of a 114 kev state in tungsten, arbitrarily normalized.

Fig. 2. Yield of 250 kev radiation from natural tungsten as a function of oxygen ion (charge +8) energy. The light line is the theoretical yield curve for excitation of the 292 kev state in W^{183} using the B_{E2} of Reference 4. The heavy line is the theoretical yield curve for double E2 excitation in natural tungsten arbitrarily normalized. The points are the experimental yields with the 292 kev contribution from W^{183} subtracted.

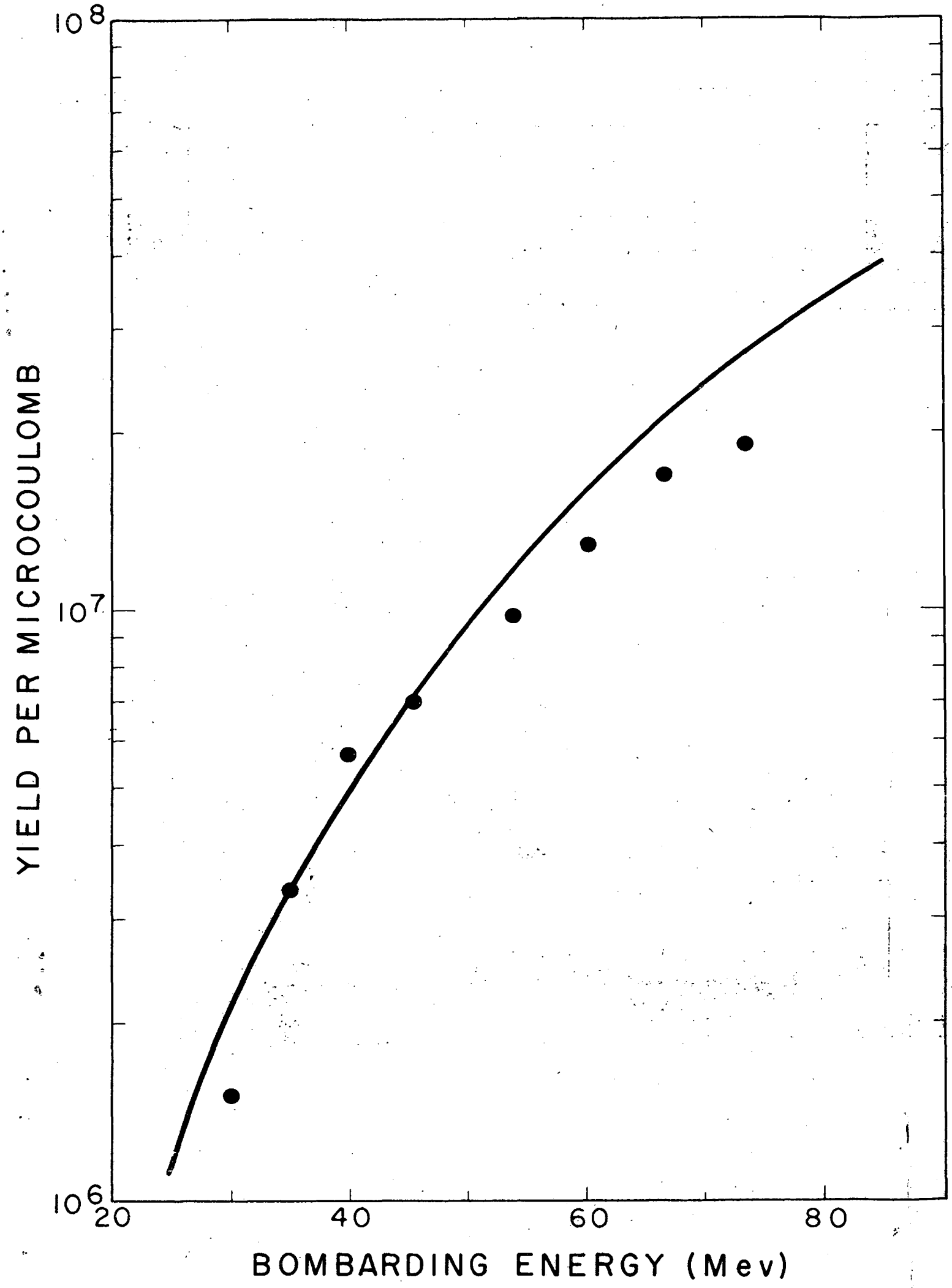
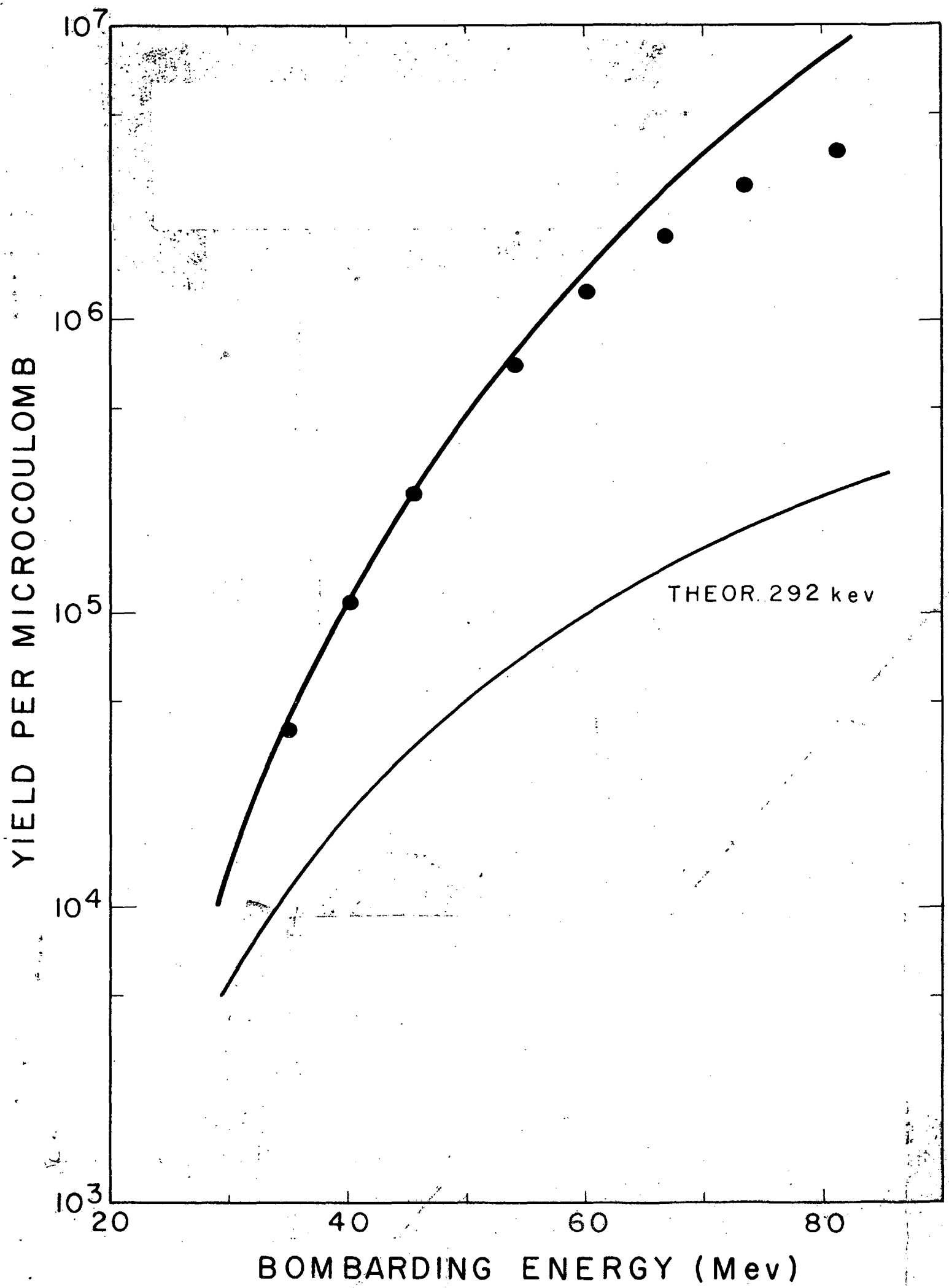

10^8
10^7
10^6
YIELD PER MICROCOULOMB
20
40
60
80
BOMBARDING ENERGY (Mev)

Fig 1

50 903-


10^7
10^6
10^5
10^4
10^3
YIELD PER MICROCOULOMB
THEOR. 292 kev
20
40
60
80
BOMBARDING ENERGY (Mev)