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RANGE OF 208 ± 4 MEV PROTONS IN G5 NUCLEAR EMULSION*

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ABSTRACT

A range curve was taken in G5 stripped nuclear emulsion of the external beam of the University of Chicago synchrocyclotron. The range of this beam in copper was also measured in order to determine its energy. Having a mean range of 41.1 ±.1 g/cm^2 of copper, the beam had an energy of 208 ± 4 Mev according to Aron's tables. The mean range of the same beam in G5 nuclear emulsion at 47 percent relative humidity was 41.3 ± .2 g/cm^2 which is about 1.2 percent longer than that from Heinz's measurements and about 1.3 percent short-

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er than that calculated by Vigneron. At 47 percent relative humidity the average density of the emulsion was measured to be 3.85 ± .01 g/cm^3, in good agreement with the calculations of Wilkins.

I. INTRODUCTION

Ilford G5 emulsion, because of its sensitivity to particles of minimum ionization, has many applications in high energy physics. It has been used extensively in cosmic ray and meson physics and has provided much information about nucleon-nucleon collisions at cyclotron and cosmotron energies.

In experiments in which nuclear emulsion is used if is often necessary to know the energies of the particles that take part in the observe phenomena. When the tracks of particles do not end in the emulsion one can get an estimate of the energies by measuring the grain densities of the tracks. But when a track ends in the emulsion it is possible to get a precise measurement of the energy by using the range-energy relation for the particle in emulsion. This gives considerable importance to the experimental determination of this relation.

There are many data for proton energies up to about 40 Mev.[1] This experiment, in which the range of 208 Mev protons was measured in G5 nuclear emulsion, was undertaken to extend the experimentally determined range — energy curve. At about the time this measurement was being done, however, Heinz's[2] results were published giving the range of 342.5 Mev protons in C2 emulsion as well as its specific ionization at energies ranging from 320 to 230 Mev. The two results are in substantial agreement. The compositions of G5 and C2 emulsion are so similar that ranges in them should not differ by more than .1 per cent.

II. EXPERIMENTAL LAYOUT

An external well-collimated monoenergetic beam of protons was scattered out of the Chicago 170-inch synchrocyclotron from an internal beryllium target at a 66 inch radius. The scattered protons were analyzed energy-wise by deflection in the fringing field of the cyclotron magnet, and then were defined as a beam by passing through two collimators in the heavy shield. The first collimator located inside of the synchrocyclotron room, was a 1/8 inch vertical slit obtained with stainless steel bricks. Twenty feet away, outside of the biological sheild, was a second collimator of 3/8 inch diameter. Following this the beam was deflected a second time with an auxiliary magnet.

The arrangement of the experiment is shown in Fig.1. The proton beam already analyzed in the fringing magnet field of the cyclotron enters the experimental area through the collimator A, is reanalyzed by the auxiliary magnet B, then passes through an auxiliary shield J used to avoid extraneous background.

The proton beam is defined by 2 monitoring telescope coincidence counters C, which also cout the number of protons in the incoming beam in a particular measurement. The beam traversing counters C then proceeds through a hole in a heavy steel shield D and reaches the absorbers.

The protons coming to rest in the absorbers, scattered out, or absorbed are counted by a large anticoincidence counter F. The preliminary alignment of the system was aided by a cathetometer H in the beam path at the end of the experimental area farthest from the cyclotron.

III. COUNTERS AND ELECTRONICS

The monitoring counters were circular counters made of plastic scintillator "Pilot B" of 1/8 inch thickness and 1 inch diameter. The anti-coincidence counter F is a large circular liquid scintillator, 9 1/4 inches in diameter and 1 inch thick.

This range determination was conducted as an auxiliary experiment to a measurement of total cross sections, as the setup was thought suitable. Thus only a brief description of the electronic equipment will be given here as this equipment is described elsewhere in detail[3].

Fast counting systems and fast resolving time coincidence circuits are necessary to obtain reliability with the counting rate used and in order to minimize background caused by accidental coincidences. The signal pulses from the monitor counters C1 and C2 (Fig. 2) were amplified by two and a half distributed amplifiers of 200 megacycles band width and a voltage gain of 10 each. The pulses were clipped to 8×10^{-9} seconds by shorted cables and fed into a two channel crystal diode coincidence circuit developed at the University of Chicago by J. Fischer.

The pulses from the two photomultiplier tubes of the anticoincidence counter F were amplified by three distributed amplifiers and connected without clipping to a diode coincidence-anticoincidence circuit which also received the pulses from the first two counters by parallel connection from the first coincidence circuit. The output of the coincidence-anticoincidence circuit was fed to a Hewlett-Packard 10 megacycle scaler. Both fast scalers were followed by slower scalers (scale of 1000) and mechanical registers. In order to correct for the time of flight of the particles and the transit time of signals in the tubes, amplifers, and connecting cables, the signals were transmitted through a 180 - line switch-box capable of giving integral time delays from 1 to 63 millimicroseconds.

IV. ABSORBERS

The absorbers consisted of 115 discs of Ilford G5 stripped emulsion, 5/8 inch in diameter and ranging in thickness from 1170 to 620 microns. The length of the stack was 11.30 cm. Maintained at a relative humidity of 47 per cent by geing kept in equilibrium with a saturated solution of potassium nitrite, the emulsion had an average density of 3.85 ± .01 g/cm^3. This agress, within experimental error, with the density predicted by Wilkins'[4] curve of density vs. relative humidity if one takes 4.18 g/cm^3 as the density of absolutely dry emulsion as published by Ilford[5].

The electrolytic copper absorbers used to establish the energy of the beam had a density of 8.91 ± .02 g/cm^3.

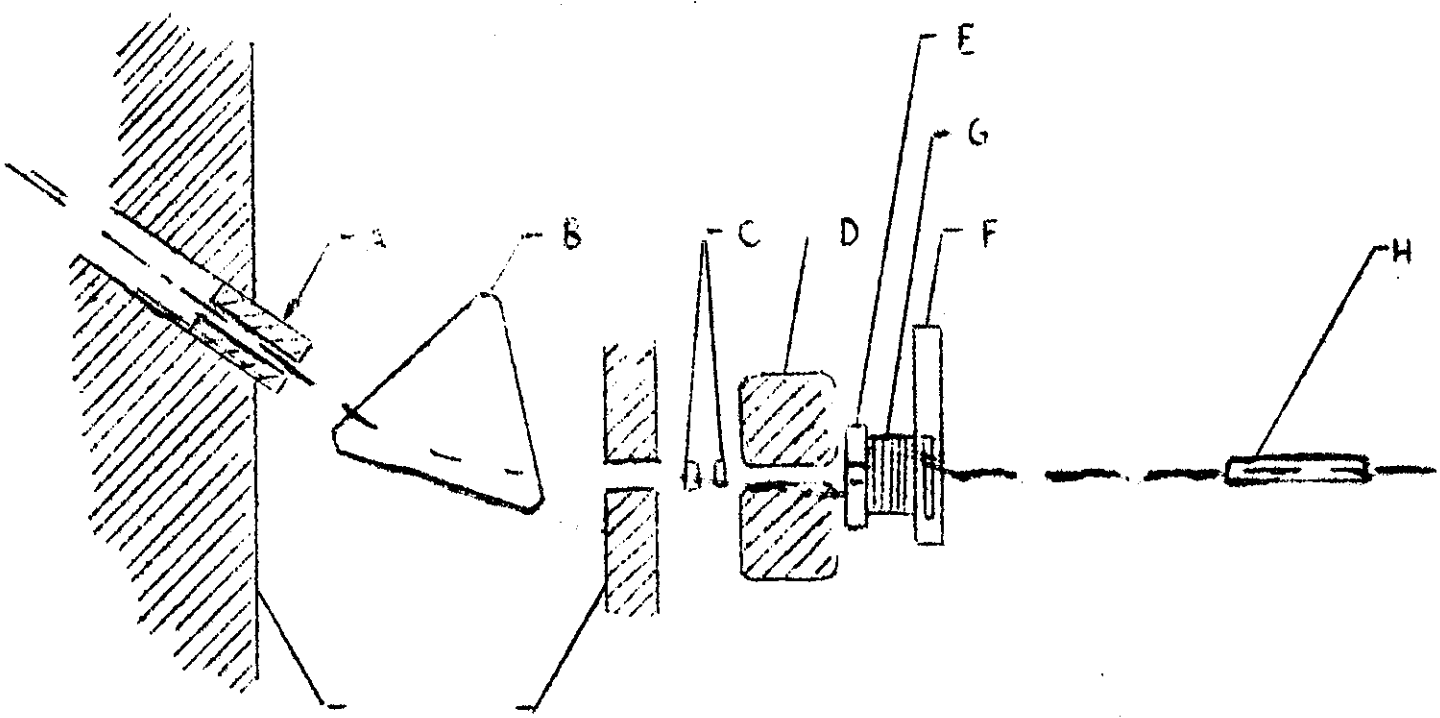
V. RESULTS

First the attenuation of the proton beam in copper was measured using the anticoincidence method, from which the integral range curve(Fig. 3) was drawn. In this curve the relative number of counts(coincidences minus anticoincidences)is plotted against range in g/cm^2. From the point of steepest slope of the curve the mean range R* was obtained. This range R*, measured to be 40.9 g/cm^2, is not the actual range along the trajectory but rather a projected range. The rectified range R, because of multiple scattering in the absorber, is somewhat longer and may be obtained by adding a small correction[6], which for protons is approximately given by $R-R^* = RZ/6400$ where Z is the atomic number of the absorber. The corresponding energy of the proton beam was found to be 208 ± 4 Mev from Aron's[7] range-energy tables for a mean range R of 41.1 ± .1 g/cm^2. The beam energy inhomogeneity, ± 4 Mev was calculated from the experimental straggling using the range extrapolation method.

The G5 nuclear emulsion mean range was measured by reducing the 1 inch diameter beam used for the copper measurement to a 1/8 inch diameter beam by the use of a copper collimator.

The mean range of the beam in G5 nuclear emulsion was determined in the same way as that for copper, and is also given in Fig. 3. The projected mean range was found to be 41.1 ± .2 g/cm^2. Applying the R-R* correction, one obtains 41.3 ± .2 g/cm^2 as the rectified mean range of 208 ± 4 Mev protons in G5 nuclear emulsion. This is about 1.2 percent longer than the value calculated from Heinz's results, using his measured range in C2 at 342.5 Mev and his measurements of dE/dx. The errors of the two values just overlap. The measured range in G5 of 208 Mev protons is about 1.3 percent shorter than that calculated by Vigneron (and extended to higher energies by Barkas). With respect to the range in copper of 208 Mev protons the measured range in emulsion is about .5 percent longer and Vigneron's calculated value is about 1.8 percent longer, whereas the range in emulsion calculated from Heinz's results is about .7 per cent shorter.

1. L. Vigneron, Journal de Physique 14, 145 (1953).
2. O. Heinz, UCRL-2458, January, 1954.
3. H. G. de Carvalho, "Total cross sections of light elements for 208 and 315 Mev protons", Phys. Rev., 96, 398, 1954.
4. J. J. Wilkins, AERE 664, Harwell, 1951.
5. Ilford Limited, Ilford, London, England.
6. R. Mather and E. Segré, Phys. Rev. 84, 191 (1951).
7. W. A. Aron, UCRL-1325, May, 1951.



A - COLLIMATOR
B - AUXILIARY MAGNET
C - MONITOR TELESCOPE COINCIDENCE COUNTERS
D - SHIELD
E - NARROW COLLIMATOR
F - ANTICOINCIDENCE COUNTER
G - ABSORBERS
H - CATHETOMETER
I - HEAVY SHIELD
J - AUXILIARY SHIELD

FIG. 1

COUNTING SYSTEM

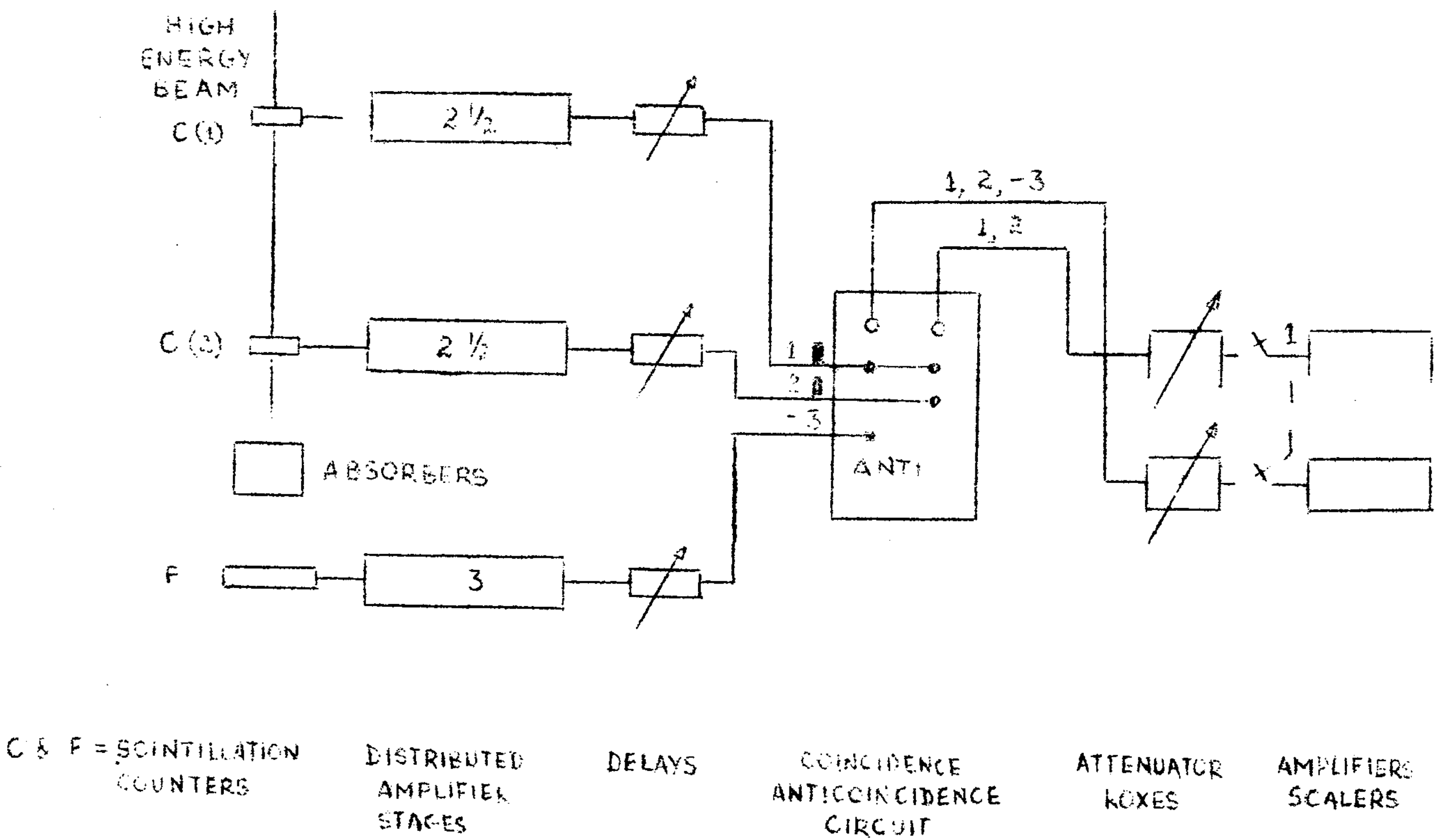
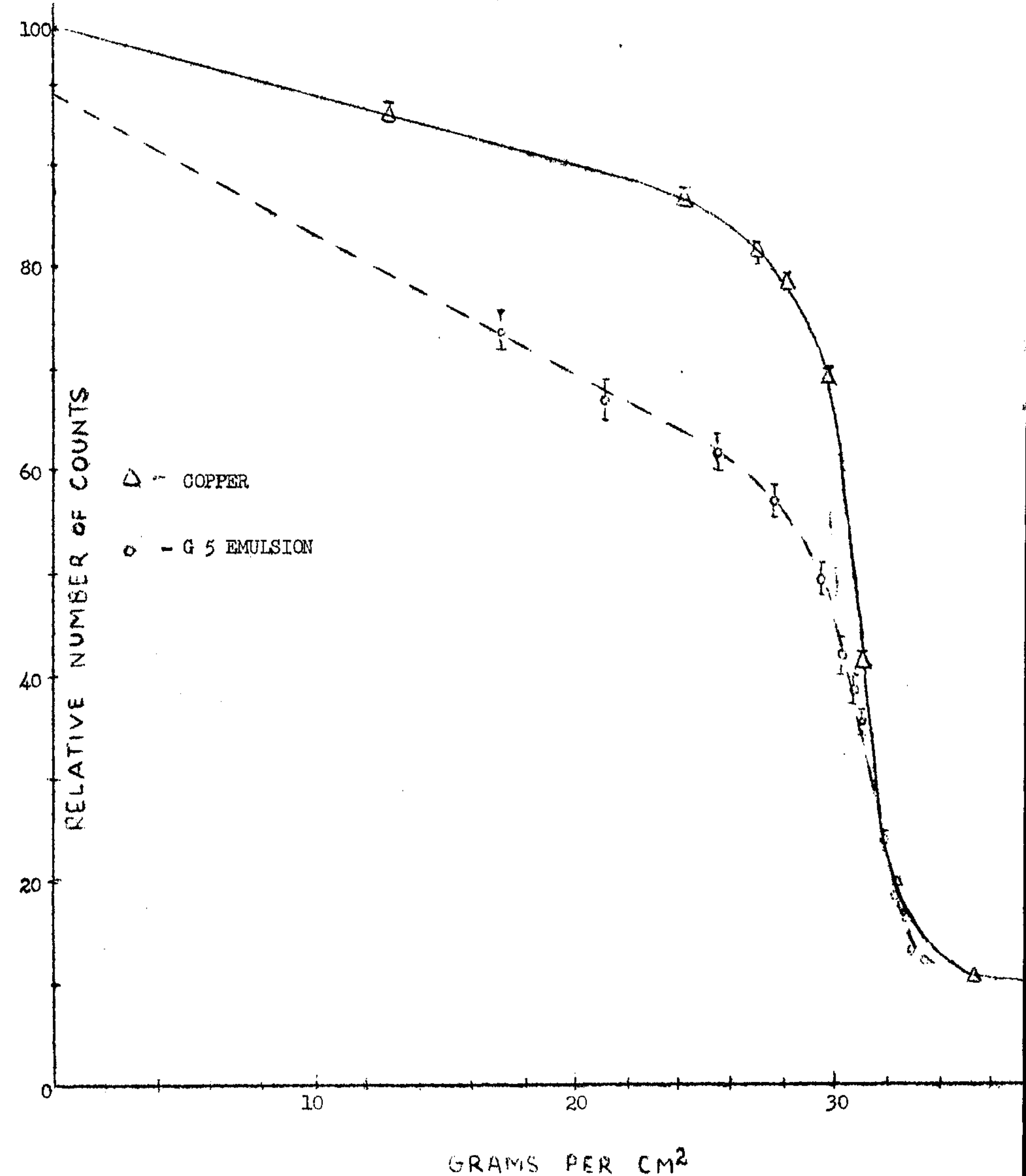


FIG. 2

F



100
80
60
40
20
0
10
20
30
RELATIVE NUMBER OF COUNTS
GRAMS PER CM2
Δ - COPPER
o - G 5 EMULSION

FIG. 3