in the most important region of energies of the scattered quanta. Any errors due to failure of the Born approximation will be in the direction to make (14) an overestimate. The approximation to (7) by the use of (13) must be regarded as the first term in a purely analytical development not involving the question of the validity of the Born approximation in the limit $\sigma=\nu-2$.

For the Th C″ radiation with $\nu=5.15$, the inelastically scattered radiation ranges from $\sigma=0$ to $\sigma=3.15$, with the intensity falling rapidly towards the high energy side. The more energetic scattered quanta are strongly concentrated within a small angle $\sim 1/\nu$ (see Fig. 1), as is evident from the presence of the denominator $(\nu-\sigma)^8$ in (13).

The estimate (14) shows that in pair production the ratio of the cross section with inelastic scattering to that with simple photoelectric absorption ($\varphi=0.67\alpha Z^2(e^2/mc^2)^2$) is less than 1.2×10^{-4} for Th C″ gamma-rays; the contribution of the inelastic scattering is clearly negligible, both to absorption, and to the production of the gamma-radiation observed to come from heavy elements exposed to high energy quanta. The only simple possibility for observing the effect discussed here would be in a cloud chamber containing a heavy gas, or a thin metallic foil, exposed to hard monochromatic gamma-rays. With this arrangement the appearance of pairs with total energies less than the incident energy would be attributable to the inelastic scattering.

AUGUST 15, 1935 PHYSICAL REVIEW VOLUME 48

Carbon Radioactivity and Other Resonance Transmutations by Protons

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(Received June 10, 1935)

By observations with direct-current potentials of from 200 to 900 kv and currents of protons and deuterons up to 10 microamperes, it is shown that: (1) The induced radioactivity from the reaction ($C+H^1$) is produced by a resonance process with two resonance lines at about 400 and 480 kv indicated, whereas the efficiency of the corresponding process for ($C+D^2$) increases approximately exponentially throughout the voltage range covered; (2) the gamma-rays emitted in the reaction ($Li+H^1$) show resonances at 450 kv and 850 kv; (3) the gamma-rays from ($F+H^1$) suggest resonances at 320, 700 and 800 kv; (4) the gamma-rays from ($Be+H^1$) do not appear to be produced by a resonance process.

INTRODUCTION

THIS paper gives a more detailed report of the experiments on which recent Letters to the Editor[1] from the Department of Terrestrial Magnetism of the Carnegie Institution of Washington were based.

I. EXPERIMENTAL TECHNIQUE

High voltage equipment

The concentric one- and two-meter Van de Graaff installation at the Department, shown schematically in Fig. 1, was used in this work.

A maximum of 1300 kv is available with this apparatus, but it was limited to about 900 kv in this work by sparking to ground along the paper charging belt which had been in use nearly eight months and was in bad condition. While replacement of the belt is a relatively minor operation, it was postponed until the present work was finished to avoid possible extraneous delays.

Charging currents

Under best conditions a charging current of 750 microamperes has been obtained with this department's equipment, but all the work reported here was done with reduced belt speed and with charging currents of about 300 microamperes. Some of the observations reported were made in August 1934 with the relative humidity as high as 71 percent.

Voltage calibration

At the higher voltages it was possible to obtain range measurements on the primary beam, but

[1] Hafstad and Tuve, Phys. Rev. **47**, 506 (1935).

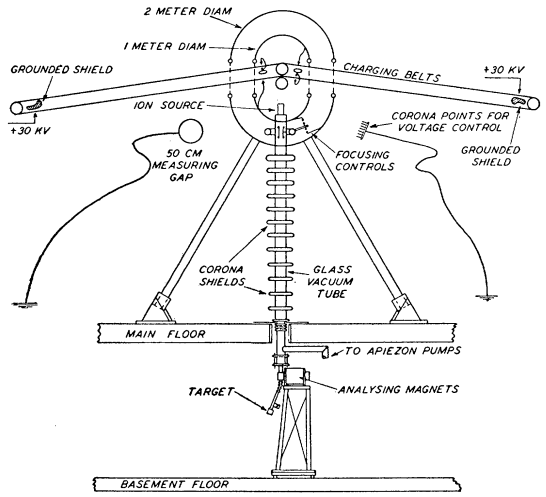

FIG. 1. Schematic diagram of concentric Van de Graaff generator.

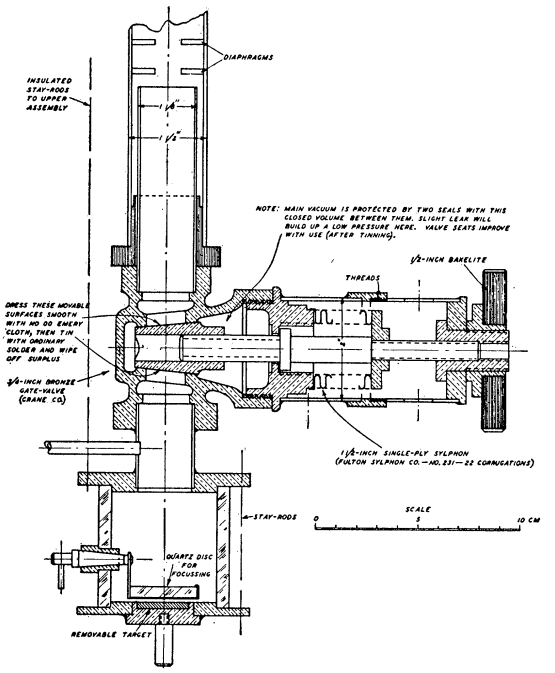

FIG. 2. Sylphon gate value and target assembly with Faraday cage.

below 500 kv (thinnest available metal window) it was necessary to resort to sphere gap voltage indications. The problem was further complicated by the concentric sphere design, since the gap responds only to the voltage on the outside sphere, so that the voltage between spheres must be added separately. However, by taking direct range measurements on the primary beam at 750, 700, 600 and 525 kv, and by measuring (with 25-cm sphere gap) the voltage between the spheres for the focusing voltage settings used in the present work, enough points were obtained on the absolute voltage curve so that intermediate points could be obtained by interpolations without large errors. The greatest uncertainty lies in the range *versus* energy relation for low energy protons which as yet is not definitely established.[2] We have assumed as a compromise value a range of 10 mm for 500 kv protons [36 mm for 1200 kv].

Voltage variation

Voltage variation during most of this work was obtained by setting the sphere gap for some desired voltage and then adjusting the position of grounded corona points until the gap just failed to spark. This index was chosen because the sphere gap response is sharp and reasonably repeatable over many trials. In the latter part of the work when very exact voltage settings had been shown to be necessary, a different method of holding the voltage at the sphere gap setting was used which will be described below.

Ion source

The ion source used was the old low voltage arc previously used at the Department of Terrestrial Magnetism but modified by the use of an oxide coated filament of platinum and the use of picein instead of Apiezon "Q" for all joints, thus eliminating slow leaks and permitting the hydrogen or deuterium to be kept relatively free of air or foreign vapors. This purity is apparently an important requirement, for with a small amount of air in the arc not over 0.2 microampere could be obtained in the magnetically resolved proton beam whereas with pure H_2 (or mixed with He) up to 12 microamperes has been obtained, though this required a large gas flow. Most of the work here reported was done with target currents of 5 to 10 microamperes, measured in a deep Faraday cage at the target..

The use of a low voltage arc in this work has proved to be a distinct advantage for the velocity spread in the beam is very small even compared to voltage increments used in investigating the voltage variation near points of resonance.

[2] Cockcroft and Walton, Nature **129**, 242 (1932); Blackett and Lees, Proc. Roy. Soc. **A134**, 665 (1932).

Most of the data on which this paper is based were obtained on a single oxide coated filament of platinum installed December 17, 1934, and burned out by accident on February 14, 1935.

Target assembly

In order to permit the removal of activated targets, the target assembly shown in Fig. 2 was used. The valve and target holder, being insulated from the rest of the system, form an excellent Faraday cage, and, since the beam is limited by the diaphragms above the valve, one can be certain that all current measured actually strikes the target. The movable quartz disk just above the removable target permits the beam to be brought into a stable focus before the target is actually exposed. Any wandering of the spot thereafter makes itself evident by a decrease in the measured target current, which was continuously observed throughout the time of bombardment.

A magnetic field sufficient to give a separation of about 5 cm between the mass one and mass two spots at the target was used in these experiments. When sharply focused, the spots were 5 mm or less in diameter. In practice the spots were deliberately defocused slightly in order to cover the targets more uniformly.

Measuring instruments

The present investigation was undertaken in order to clarify discrepancies between the observations obtained at Washington and Pasadena on the radioactivity produced in carbon by protons and deuterons. By the use of one of Professor Lauritsen's own electroscopes, kindly loaned to us at our request, for most of these observations, we were able to eliminate one important experimental variable and to make our later measurements entirely comparable to his. Our earlier measurements had been made using a Geiger point counter and an ionization chamber connected to a vacuum tube electrometer (FP-54), so a series of intercomparisons was made between these instruments and the Lauritsen electroscope and Geiger tube counters as used by other workers. These comparisons will be discussed in connection with the question of absolute yield.

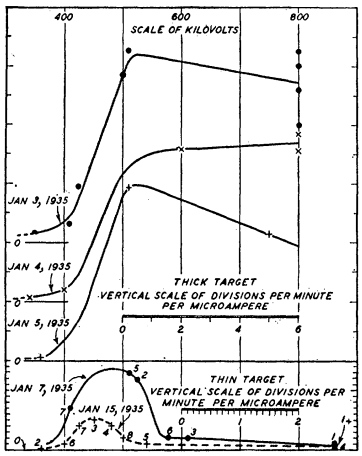

FIG. 3. Excitation functions for induced radioactivity from carbon (thin and thick targets).

II. CARBON RADIOACTIVITY

Excitation function for $(C+H^1)$

The upper two curves shown in Fig. 3 for thick Acheson graphite disks were taken with relatively small target currents and imperfect voltage control, but both suggested strongly an abrupt rise between 400 and 600 kv and no great change at higher voltages as might be expected only from a resonance effect. The points for January 5, 1935, were taken with improved voltage control and target currents raised to 7 to 10 microamperes in preparation for the verifying thin target observations to follow.

The thin targets used for the observations on January 7 were prepared by smoking clean copper disks over a candle flame. The points are numbered in the order of the observations, a separate target being used for each point, and, as will be surmised, point 7 was taken with every expectation of finding it well below the resonance point. The high value of point 7 was the first hint of a peculiarly broad resonance. The total intensity observed being only one-fifth of that for a solid target, it appeared difficult to ascribe this width to target thickness but equally difficult to account for it in any other way.

After considerable experimentation a new set of thin targets was made by slowly evaporating a suspension of colloidal carbon in water (aquadag) onto a set of clean copper disks which had been washed in alcohol just before being dropped into the carbon suspension. This process gave an

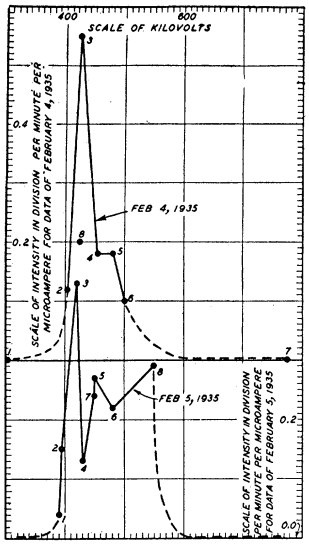

FIG. 4. Excitation function for induced radioactivity from carbon (thin target).

extremely thin and fairly uniform layer of carbon. The results of observations made on these targets are shown in the curve for January 15, 1935. It will be noted that the intensity of the effect was still further reduced so that the total stopping power of the film might be estimated, by comparison with the thick target intensity, as about one-twentieth of the resonance width. From these curves it seemed safe to conclude that a resonance "half-width" of about 50 kv must be assigned to the nucleus.

After correspondence with Professor Breit regarding the above results it appeared highly desirable to obtain some indication as to the exact shape of the resonance curve, and it seemed, in view of the consistency of the points obtained January 15, that with special care this might be barely possible. A new set of thin targets was prepared with even more care than before. A weighed quantity of aquadag was used in the suspension, and from the area covered on evaporation the weight of carbon per square centimeter could be determined and a corresponding average stopping power estimated. This was approximately one-tenth millimeter (air equivalent) for the targets used.

With the new set of targets the curves shown in Fig. 4 were obtained. While one might expect a "tailing" on the high voltage side of a resonance peak produced by thick spots in the targets, a second maximum as suggested in these curves hardly can be dismissed as being produced in this way. On the other hand, to prove the existence of a double maximum from thin target observations is also very difficult. Either a set of targets must be first proved to be of uniform thickness at *all* points in some way, or else one single target must be used throughout the investigation, allowing ample time for decay between activations. Unless voltage settings are reproducible with great accuracy, the latter method is impracticable. In either case it would also have to be demonstrated that the ion beam was truly homogeneous and free of appreciable "tailing" of ions with velocities below the maximum. We consequently chose to return to thick target observations to test for the existence of a step or steps in the excitation curve, which must exist if the multiple resonances were real. In a series of three curves strong indications were obtained for such an effect, but the observed points failed to repeat sufficiently well to permit a definite conclusion to be drawn. Finally, however, by arranging a convenient control for the charging current we were able to force the gap to spark approximately every 30 seconds and thus hold the voltage "up against the sphere gap limit" with assurance that voltage could be neither high nor low for any appreciable period. The two final curves obtained under these conditions are shown in Fig. 5. It is felt this evidence forces us to conclude that this proton resonance on carbon is not due to a single resonance line but to a doublet or to a multiplet of which two components are clearly indicated between 400 and 500 kv.

This conclusion does not appear to us to contradict the results of Cockcroft, Gilbert and Walton,[3] for the existence of two close resonance peaks, plus the possible spread in energy among the ions of their beam produced by a 20-kv canal-ray source, would tend to give a slowly rising curve such as they observed.

Absolute yields

Our values for absolute yields for the $(C+H^1)$ reaction have now been obtained by several methods which show a reasonable agreement with each other as well as with the recent quantitative

[3] Cockcroft, Gilbert and Walton, Proc. Roy. Soc. **A148**, 225 (1935).

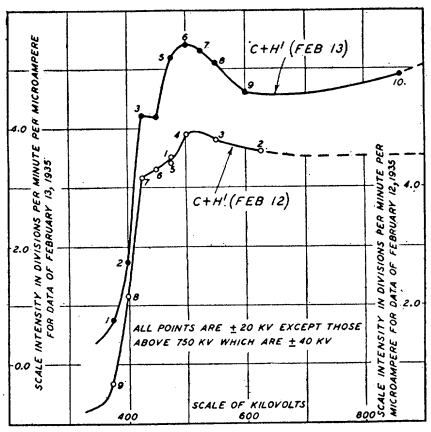

FIG. 5. Excitation function for induced radioactivity from carbon (thick target).

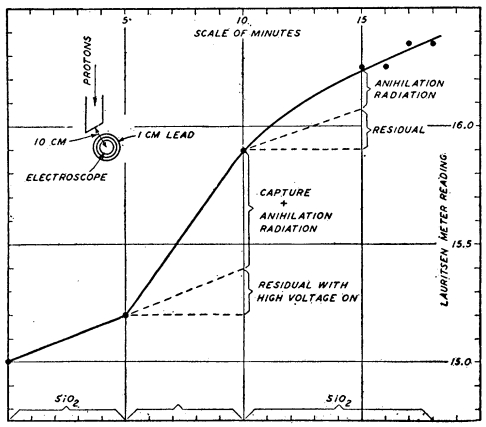

FIG. 6. Gamma-rays from C+H¹, January 16, 1935.

measurements on this point by Cockcroft, Gilbert and Walton.

Our first observations on induced radioactivity were made with a point counter, but this was used only as an indicator, being discarded for the more convenient as well as more quantitative measurements with a vacuum tube electrometer after it had been found repeatedly that a counting rate of about two counts per minute on the point counter corresponded to a 1-cm deflection of the galvanometer spot. Since in our early observations we failed to observe a (C+H¹) effect with this apparatus but later (after being informed by Cockcroft that a proton effect persisted even after magnetic analysis had been introduced in their experiments) measured the effect with the same apparatus, it is important to record that in the original experiments a disk of graphite was bombarded through a valve with a relatively long and small bore so that an unknown part of the current was lost to the walls. Since this effect should be about the same for either proton or deuteron beams, no correction was made for this effect in our *ratio* determinations. As soon as it was apparent that the discrepancy between different laboratories involved the absolute magnitude of the effect, the smaller cock was replaced with the one shown in Fig. 2 after which the magnitude of *both* the proton and deuteron effects was considerably increased.

From a measurement made in August 1934 with the vacuum tube electrometer, we estimated the absolute yield of the (C+H¹) reaction to be of the order of one disintegration per 10^{10} incident protons. This value might vary by a factor of 3 or 4 because of uncertainties in the estimates of solid angles and the average number of ions produced by each positron entering the ionization chamber from the activated target.

In measurements made recently using Lauritsen's electroscope we have consistently found a discharge rate of about 4 divisions per minute per microampere. Assuming 2×10^6 ions per division, 500 ions per positive electron, and a solid angle of $4\pi/4$, we get a yield of 1 per 2×10^{10} incident deuterons. The probable error is, however, greater than for the electrometer measurement above since in the latter case the absolute sensitivity of the instrument is accurately known.

Finally using a tube counter with a 6-mm diameter window covered with cellophane on a 50 percent gauze, we observed 16, 33 and 43 counts per minute per microampere, with the activated carbon disk at 10, 4 and 2 cm, respectively, from the window. At the closest position our amplifier was obviously paralyzed (improvised output circuit), but the 10- and 4-cm positions give yields of 1 per 3×10^9 and 1 per 5×10^9, respectively, in rough agreement with the above observations as well as those of the Cavendish Laboratory. However, since in our counter observations the inverse square law is clearly not obeyed, and an indefinite but considerable fraction of the counts was produced by annihilation radiation, which was not corrected for, they are probably no more accurate than the

other determinations, so the original yield of 1 per 10^{10} will be retained as our value until a more quantitative estimate can be made.

Capture radiation

An important question in connection with the reaction $C^{12}+H^1 \rightarrow N^{13}+h\nu$ which is the most probable in this case is the detection of the gamma-rays indicated. Observations on this radiation, which we had assumed would be too weak to measure, were obtained in a control run during ($Li+H^1$) observations. To insure that the resonance gamma-rays from lithium, occurring at nearly the same voltage as the carbon resonance, were not due to carbon contamination, the thin lithium target was replaced by a solid graphite target, with the result for thick targets of C and SiO_2 bombarded with 4.4 microamperes of protons as shown in Fig. 6. From these observations it appears that there is a very small effect of less than 0.1 division per minute which may be ascribed to the "capture" radiation. Since there should be one quantum emitted per capture, and the number of captures is fairly well established as of the order of one capture per 10^{10} incident protons, it should be possible to obtain a check on this process. For a current of 4.4 microamperes of protons to a solid carbon target we should expect, therefore, approximately 3000 quanta per second. A comparison of this expectation with the observed discharge rate of 0.1 division per minute can be obtained by the following crude but plausible assumptions:

(1) That the capture radiation is predominantly of high energy as deduced from the energy balance of the equation, giving essentially the same discharge rate through 1 cm of lead as through 3 cm, and that it has an ionizing power equal to that of the hard quanta from radium.

(2) That for radium the ratio of hard quanta to the total number is given approximately by the ratio of the measured discharge rates through 3 cm of lead and through about 3 mm of glass, respectively.

(3) That a measurement for radium at 25 cm can be adjusted to a target distance 10 cm by the inverse square law without introducing appreciable errors.

By assumption (3) we get a value of 15 divisions per minute for 1 mg radium at target distance through 3 cm of lead. By assumption (2) we obtain a ratio less than 1/23 for hard to total quanta under the conditions of our experiment. Finally, taking 7×10^7 as the total number of quanta emitted from 1 mg of radium, we get 0.1 division per minute $\leq$20,000 quanta per second, to be compared with the 3000 quanta per second which was to be expected. There is thus a fair agreement as to the order of magnitude of the effect and we believe this can be taken as further evidence for the reality of the capture-process. The effect here observed is too small to justify attempts to improve the measurements, especially since much more intense ion beams will soon be available.

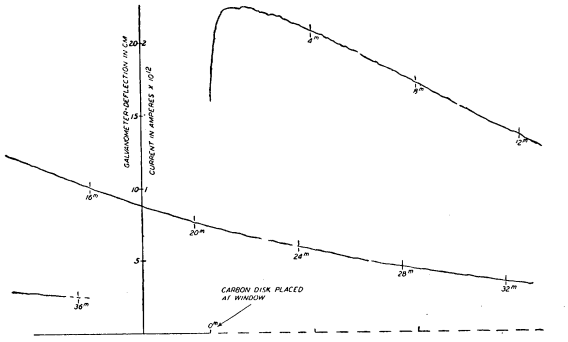

FIG. 7. Decay curve for (C+D) radioactivity.

Decay periods

Numerous measurements have been made of the decay periods of both the ($C+H^1$) and ($C+D^2$) effects, but the values obtained fluctuate too much to permit any accurate value to be given. In our experience tube counters are found to show an apparently increased sensitivity after short periods of fast counting which gradually settles down to the normal value, thus giving a spurious decay even for sources presumably constant. Our best values are those obtained from photographic records taken with the vacuum tube electrometer of which an example is given in Fig. 7. This curve for ($C+D^2$), which was started within three minutes after activation, gives a half-period of 10.2 ± 0.5 minutes by a least-square adjustment.

Equally good determinations have been obtained from other records, but the values often fell outside the limit of errors for previous measurements. For example, from a record on

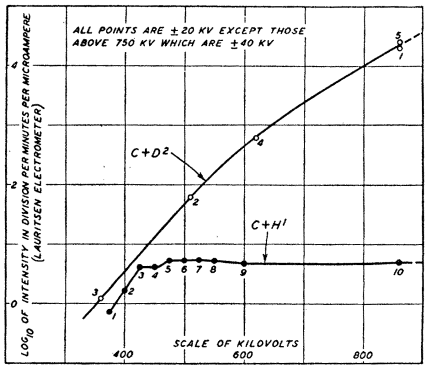

FIG. 8. Excitation function for induced radioactivity from carbon.

another target begun an hour after activation a value of 11.1±0.3 minutes was obtained. This value is the highest we have observed, all of the others falling between 10 and 11 minutes, so that on the basis of all of our measurements we would give 10.5±0.5 minutes as a present estimate of the decay period for the radioactive substance produced in this reaction. The reason for the fluctuations is not known, but may be connected either with a slow escape of the radioactive gas or with the presence of some contamination with a longer period.

The (C+H¹) period appears to be the same as that for deuterons within the limits of accuracy of our measurements.

These results are in agreement with the values for the decay period of radio-nitrogen produced from boron by alpha-particle bombardment as given by recent work.[4]

Excitation function for (C+D²)

The results obtained for (C+D²) are shown, compared to the (C+H¹) effect, in Fig. 8. As in the case of (C+H¹), the intensity was measured by means of the Lauritsen electroscope, waiting for the activity to decay until a convenient discharge rate was obtained, and then calculating the initial activity using a half-period of 10.5 minutes, as determined above.

The curve for (C+D²) shows a continuous rise which is approximately exponential throughout the voltage-range covered, in contrast to the resonance for (C+H¹). This difference may

[4] C. D. Ellis and W. J. Henderson, Nature **135**, 429 (1935); H. Fahlenbrach, Zeits. f. Physik **94**, 607 (1935).

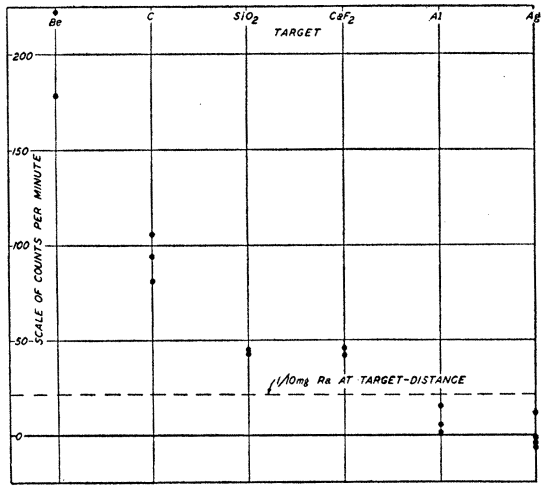

FIG. 9. Gamma-rays by ~0.5μA of ~1200-kv deuterons with 1/2-inch lead shielding (April 1934).

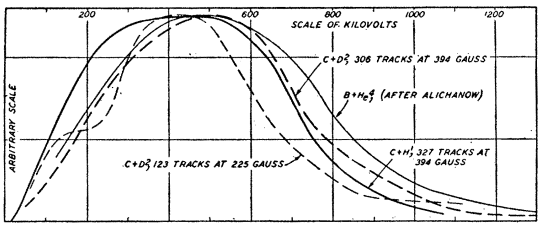

FIG. 10. Energy distribution of positrons.

account for the observation reported by Cockcroft, Gilbert and Walton[3] that a carefully cleaned target (therefore, thin film of contamination) bombarded at 550 kv gave 300 counts per minute for deuterons but no observable effect for protons of this energy which is above that for resonance.

From the ratio of the two effects at 900 kv and the known yield for protons one gets immediately an efficiency of about 5 in 10^7 for the deuteron reaction involving the production of N^{13}.

Gamma-rays from (C+D²)

By a comparison of the intensity of the radiation from (C+D²) with that from radium as measured by the Lauritsen electroscope through one-half inch of lead, we obtained a value of about 2 mg radium equivalent per microampere of deuterons at 900 kv. This agrees well with the high value we reported at the Washington meeting of the American Physical Society in April 1934, based on Geiger tube counter obser-

vations as shown in Fig. 9. A rough estimate of the yield from these observations is of the order of one disintegration per 10^6 incident deuterons. Accurate estimates are difficult due to the presence of neutrons.

Energy distribution of positive electrons

Measurements on the energy distribution of the positrons emitted from an activated disk have proved to be time consuming, for relatively few of the tracks photographed are measurable. By measuring only the best tracks, different observers here were able to get repeatable results on any single run, but so few tracks were obtained that the statistical fluctuations were very large and successive runs would give contradictory results. Pending the acquisition of a sufficiently large number of measured tracks to eliminate statistical "humps," the best representation of our present results is perhaps given by a summation of all of our observations on all measurable tracks, smoothed by the usual formula $(a+2b+c)/4$. Such curves are given in Fig. 10 in which the curve of Alichanow[5] for radio-nitrogen is included for convenient comparison.

III. Other Resonance Transmutations Under Proton Bombardment

Gamma-rays from (Li+H¹)

The existence of resonance in the (C+H¹) reaction suggested that a similar behavior might be expected in other proton reactions. The (Li+H) reaction was particularly interesting in view of the failure of Oliphant and Westcott[6] to observe gamma-rays at 400 kv where the workers at the California Institute of Technology at Pasadena had found an easily observable effect at 600 kv. The probable existence of a resonance for this reaction had been suggested by Lauritsen at the Berkeley meeting.

In order that direct comparisons with results of both the Cambridge and Pasadena investigators might be possible, preparations were made to observe simultaneously with the Lauritsen electroscope and a Geiger-Müller tube counter

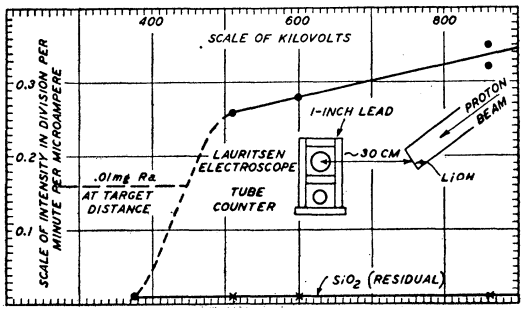

FIG. 11. Excitation function for gamma-rays from Li+H¹, January 11, 1935.

(2×10 cm), as shown in the sketch in Fig. 11. After parallel observations had been obtained at the two lowest points on the curve, a breakdown occurred in the tube counter amplifier so that a complete comparison could not be obtained. However, the following figures for 510 kv will give an indication of the relative sensitivities. For 5.5 microamperes of protons on SiO_2 the electrometer gave 0.1 division per minute and the counter 30 impulses per minute. For the same current on LiOH, the electrometer gave 1.4 divisions per minute compared to 210 for the counter. The residuals with the high voltage cut off were 0.05 division per minute and 10 counts per minute for the electroscope and counter, respectively. The effect was therefore easily observable with either detecting instrument. As may be seen from Fig. 11, the magnitude of the effect is roughly 0.02 mg radium equivalent per microampere of incident protons, which is within a factor of two of that reported by Lauritsen in his original observations.

A thin target curve for the gamma-rays from (Li+H¹) was given in our letter showing a sharp resonance at 450 kv and a suggestion of a second resonance at a higher voltage. A more complete curve verifying the existence of the second resonance at about 850 kv has now been obtained and is shown in Fig. 12.

Alpha-particles from (Li+H¹)

If the energy of the gamma-rays is deducted from total energy available in the (Li+H¹) reaction, the remainder should give the energy of any alpha-particles which might be emitted. Two strong gamma-ray components have been reported from Pasadena for the (Li+H¹) reac-

[5] Alichanow, Zeits. f. Physik **93**, 350 (1935).
[6] Oliphant and Westcott, Int. Conf. Phys., London, 1934, p. 144.

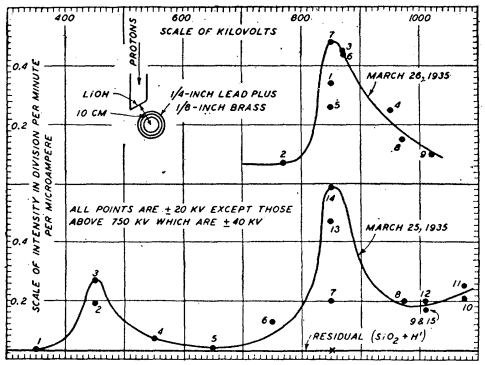

FIG. 12. Excitation function for gamma-rays from Li+H¹.

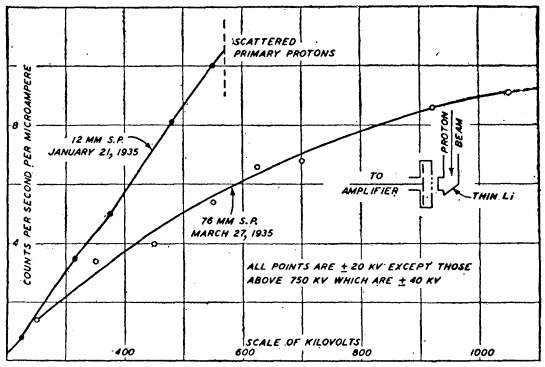

FIG. 13. Excitation function for alpha-particles from very thin Li+H¹.

tion,[7] either of which might be associated with the 450-kv resonance. Efforts to find either of the two predicted alpha-particle groups were unsuccessful, as were efforts to detect the emission of beta-particles either during or subsequent to the bombardment. From these observations we must conclude that if alpha-particles are emitted, their range must be less than 9 mm and the gamma-radiation therefore must be of greater energy than 14 MEV. This is in agreement with later observations by Crane and Lauritsen.[8] Corresponding observations have not yet been made at the 850-kv resonance point.

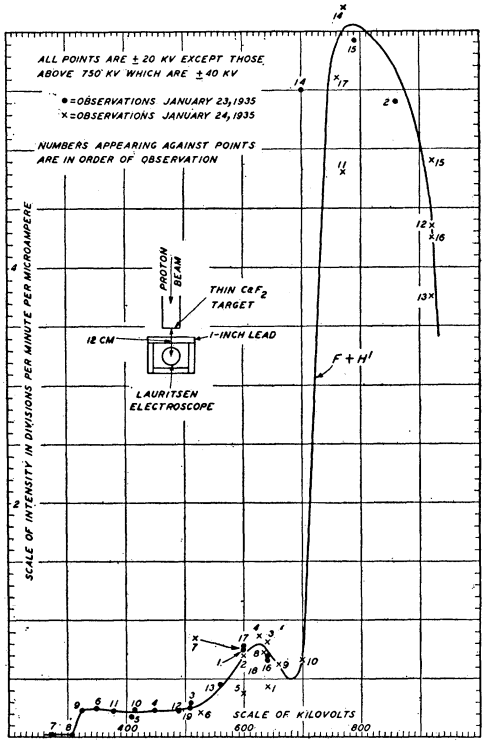

FIG. 14. Excitation function for gamma-rays from fluorine (moderately thin target).

Having satisfied ourselves that no new alpha-particle group appeared at the 450-kv resonance, we investigated the variation of the known groups with voltage. Fig. 13 shows the curves obtained for the very thin LiOH target previously used in the gamma-ray resonance observations. It will be noted that neither of these curves shows any discontinuity at the resonance voltages, so that the corresponding alpha-particle groups must be due to completely independent processes.

It is also of interest to remark that for this very thin lithium target the yield for the long range particles is still rising at 1000 kv, in disagreement with the early results reported by Henderson[9] which indicated that the top of the potential barrier for this process was about 400 kv.

Gamma-rays from (F+H¹)

Observations were made on two days only on the (F+H¹) reaction, but the results are sufficiently significant to report at this time. In Fig. 14 the readings obtained on a Lauritsen electroscope placed 12 cm from the target and shielded with one inch of lead are plotted against the accelerating voltage. The most correct interpretation will be obtained by noting the sequence of points, for, while small increments of voltage in a

[7] Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **46**, 531 (1934).

[8] Crane and Lauritsen, Phys. Rev. **47**, 420 (1935).

[9] Henderson, Phys. Rev. **43**, 98 (1933).

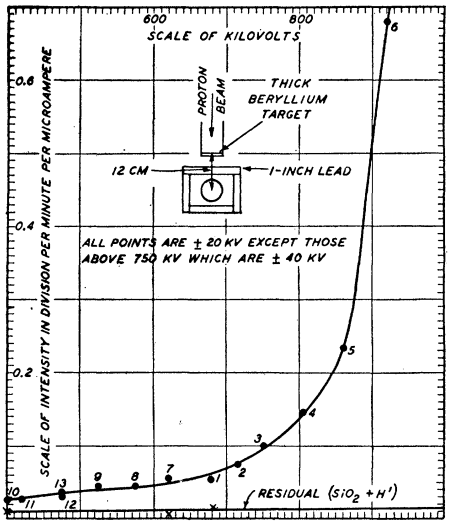

FIG. 15. Excitation function for gamma-rays from Be+H¹.

single sequence have proved to be dependable, any large changes in voltage depend on the absolute voltage scale and are less accurate. Thus several resonance voltages are clearly shown, although the absolute voltages for the resonance lines are not well determined.

A rough indication of the intensity can be obtained from the radium calibration cited above, namely, one mg radium at 10 cm gives 15 divisions per minute through 3 cm of lead. Note, however, that the points plotted are for a "moderately thin target," which is thick for 500-kv protons, but thin for 900-kv particles as shown by the curves.

Gamma-rays from (Be+H¹)

While this does not appear to be a resonance process, such observations as we have made may well be reported at this time. These are given in Fig. 15. The experimental conditions were the same as for the fluorine observations, except that a thick target was used. The beryllium was known to contain one percent iron, with other impurities under 0.05 percent.

ACKNOWLEDGMENT

We are grateful to Professor Lauritsen for the electroscope he very kindly sent us, which has proved to be exceedingly convenient in this work. We also wish to thank Professors Breit and Gamow for their enthusiastic interest in the problem of radiative capture, and Messrs. Brown and Dahl for invaluable technical assistance.

AUGUST 15, 1935 PHYSICAL REVIEW VOLUME 48

High Voltage Technique for Nuclear Physics Studies

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(Received June 10, 1935)

A description is given of experiments at the Department of Terrestrial Magnetism, Carnegie Institution of Washington, during four years in which two electrostatic generators and several multiple-section high voltage tubes have been used for the production of high speed protons and deuterons, as required for studies of nuclear transmutations. A 1-meter diameter generator of the type designed by Van de Graaff reaches usable steady potentials up to 600 kilovolts (positive). A generator comprising concentric 1-meter and 2-meter shells, charging current 0.75 milliampere, reaches practical limitations at 1300 kilovolts (positive) in a special room of large size. Voltages below the maximum are steady to within several percent. Details of design and operation are discussed.

Multiple-section high voltage tubes of the Coolidge "cascade" type, giving complete focusing of positive ion currents of 20 microamperes at voltages up to 1200 kilovolts, offer no difficulties in construction or operation. No reasons have yet appeared for expecting any special troubles if this technique were to be extended to much higher voltages and currents.

A. INTRODUCTION

IN response to numerous requests for a comprehensive description of the high voltage technique which has been developed during a period of years in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington[1] and which has been used for studies of

[1] The development of these experiments is described chiefly in the Annual Reports of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, 1926 to date. Early work is covered by: G. Breit, M. A.