must have to arrive at 45° from the zenith (and in a certain azimuth) while the upper curve gives that if it has a minimum energy of 540 millistörmers it may arrive from any direction within 45° of the zenith. Similarly 408 millistörmers is the least energy a particle must have to arrive at 30° from the zenith, while 510 millistörmers is the least energy required to arrive from any direction within 30° of the zenith. In addition the limiting energies for which the main cone is completely open is given by the uppermost curve. This curve consists of two parts: first, the locus of the vertices of the periodic orbits (cf. Fig. 1) and then the limiting energy for the limit $\gamma_1=0.78856$ for which periodic orbits disappear. This curve takes into account only the trajectories of the first kind.[16] Finally the lowest curve gives the limiting energy for Störmer's limit $\gamma_1=1$ for which all directions are forbidden.

It is a pleasure to renew the expression of our gratitude to the various persons, mentioned in our preceding paper, who have helped us to carry out the research of which this paper is another fruit. One of us is indebted to the Massachusetts Institute of Technology for continued support while this investigation was being completed at Louvain, and to the University of Louvain for providing numerous facilities during the period of his residence there.

[16] For trajectories of the second kind a somewhat higher energy limit can be readily found from the relation $e^x \leq 2\cos\lambda$ above which the acceleration $d^2x/d\sigma^2$ is necessarily positive. For the same reason negative values of γ_1 are of no interest.

SEPTEMBER 15, 1936 PHYSICAL REVIEW VOLUME 50

Excitation-Curves for Fluorine and Lithium

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(Received July 6, 1936)

Observations on the alpha-particles emitted by lithium and the gamma-rays emitted by lithium and fluorine when bombarded with protons of energies up to 1000 kv have been improved by the use of a corona-free, 10,000-megohm voltmeter-resistor for voltage-measurements. By this means the accuracy of our measurements has been brought to two percent on an absolute scale and about one percent on a relative scale. Oscillograph-studies of voltage-fluctuations have shown that up to 1000 kv the voltage is constant to ±1.4 percent "peak-ripple." For the distribution-curve for voltage *versus* time the "half-maximum" width is about one percent at 1000 kv. Results thus far obtained for the gamma-ray resonances are as follows:

Voltage	Element	Half-width
328 kv	F	< 4 kv
440 kv	Li	11 kv
892 kv	F	<12 kv
942 kv	F	<15 kv

There is an indication of a weak multiplet structure in fluorine in the region between 500 and 700 kv with a broad but fairly prominent "resonance" at 650 to 700 kv. The existence of a resonance in lithium at 850 kv was not confirmed.

Introduction

Our work on proton-disintegrations last year[1] demonstrated the existence of sharp resonance-effects in nuclear disintegrations which called for voltage-control considerably more refined than that given by any apparatus then in existence. Such work depends essentially on the accurate reproducibility of specified voltages, and this requirement is not sufficiently well satisfied even by rectifier and condenser installations, unless means for voltage-measurements more accurate than spark-gap or particle-range determinations are provided. Unless very special precautions are taken, sphere-gap measurements are rarely reproducible to better than five percent. Even the official calibration-curves for sphere-gaps have been changed by more than ten percent during the past two years. The absence of reliable information on the range-energy relation for protons would prevent the

[1] Hafstad and Tuve, Phys. Rev. **48**, 306 (1935); also Tuve, Hafstad and Dahl, Phys. Rev. **48**, 315 (1935).

use of this method even though apparatus which would permit both rapid and accurate determinations of ranges were devised.

In addition to the problem of specifying the mean voltage used, is that of determining quantitatively the deviations from the mean during any given interval of time. This information is essential in specifying such things as widths of resonance-levels, which have a theoretical meaning and value only when it is demonstrated that the observed widths are not produced by inhomogeneities in the incident ion-beam.

Technique

Tube

Our apparatus is essentially as previously described. A new glass tube has been installed in which provision was made for permitting accurate axial alignment of the electrodes. In this tube the baffle-plates at each electrode have been eliminated so that the pumping speed through the tube is essentially that given by the 12-inch diameter of the glass tube rather than that of the inside diameter of the electrodes. This arrangement will permit the use of much larger total ion-currents as soon as correspondingly fast pumps can be provided. At present the pumping speed at the base of the tube is approximately 30 liters per second, which is small compared to that used in most high-voltage installations.

As was expected, the new tube, with its properly aligned electrodes, practically eliminated the annoying fluctuations in position of the spot which constituted the principal difficulty encountered in the work reported last year. The effectiveness of the focusing of such a tube is attested by the fact that with the same tube a concentrated ion-beam can be obtained at any voltage from 200 to 1200 kv.

Corona-free, 10,000-megohm voltmeter-resistor

For the highest possible accuracy in voltage-measurements, a wire-wound voltmeter-resistance would be desirable. Such units are available commercially for x-ray voltages, but the cost of such units arranged for 1000 kv would be prohibitive, and a corona-free design could hardly be attained by reason of the dimensions of the unit resistors, especially if a full-scale current of 100 microamperes were required (10,000 ohms per volt). However, a close approximation can be achieved by using modern metallized "grid-leak" resistors which give voltage-current curves that are nearly ohmic in character. Any deviation from linearity can be corrected for by a calibration of such resistors against "purely ohmic" wire-wound units.

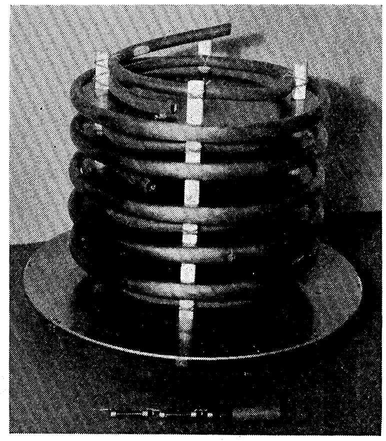


FIG. 1. Construction of corona-free voltmeter-resistor.

In the assembly of such resistors in series to be used with very high voltages, the greatest technical problem is the elimination of corona. Of several possible solutions the simplest appeared to be that indicated by Fig. 1, which has now been proved to be entirely satisfactory. The individual resistors of 10 megohms each, rated at one watt or 1000 volts maximum, are connected in series in groups of 20, slipped into a thick-walled rubber tube to insure proper spacing, and then connected between brass disks 12 inches in diameter, which are protected against edge-corona by $\frac{3}{4}$-inch copper tubing soldered to the circumference of each disk. The disks are separated by 2-inch Isolantite rods as spacers. Fifty such units make up the 10,000-megohm resistor. This construction limits the voltage-gradient to 20 kv per 2-inch section which is safely below corona-values, provided no dust or lint is permitted to collect on the surfaces. To guard against the latter the entire assembly was mounted in the "Textolite" cylinder shown in Fig. 2. This cylinder was on hand from previous work. As may be seen from Fig. 2, it is somewhat short for its purpose and

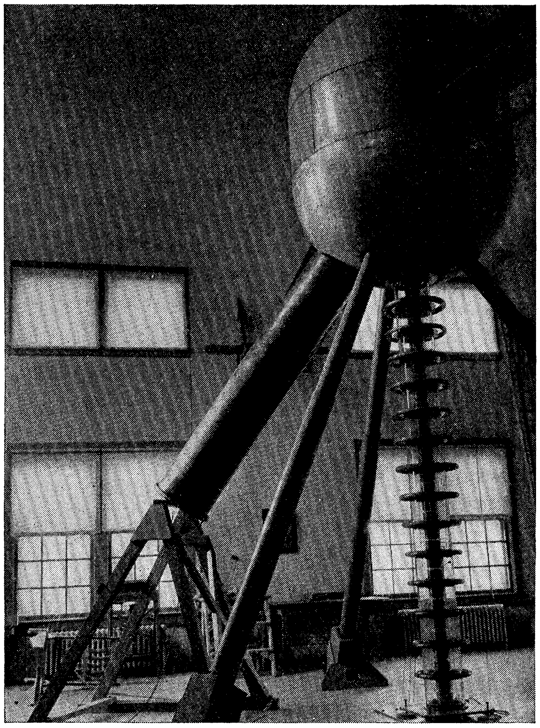


FIG. 2. 1200-kilovolt electrostatic generator showing tube and voltmeter-resistor.

at present sparks to earth over the outside of this cylinder determine the maximum voltage, 1150 kv, attained by this generator. Some difficulty was experienced when this resistance-unit was first mounted due to corona at the junction between the resistor and the sphere. This was largely eliminated when care was taken to design in such a way that the equipotential through the first corona-disk agreed roughly with the corresponding equipotential for the sphere itself.

The resistance-unit shown in Fig. 2 measures only the voltage between the outside sphere and ground. With our somewhat inconvenient arrangement of concentric spheres the voltage between the one-meter and the two-meter spheres must be measured separately. A similar resistance-unit of six 20-kv sections was accordingly installed between the two spheres, the current being indicated by a meter installed at the surface of the outside sphere and read by a telescope.

Voltmeter-calibration

Through the courtesy of Dr. L. S. Taylor of the National Bureau of Standards we were able to calibrate our resistance against his wire-wound standards in 5-section, 100-kv units. Results on separate determinations agreed to within two percent. The voltage corresponding to any given current through the entire resistor is then obtained by adding the voltages of the separate, independently calibrated units, and the total voltage is obtained by adding the separately determined inside voltage (between spheres) and outside voltage (to ground).

The possibility that part of the measured current at high voltages may be due to corona between sections of the voltmeter has been eliminated by three independent tests. First, during calibration, the units were carried to 40 percent over-voltage before corona occurred, thus allowing a safe margin above usual operation-conditions. Second, after installation the voltage-scale was tested for linearity by setting the mass-1 spot to a given deflection at the highest voltage and then reducing the voltage until the mass-2 spot was deflected to the same position. By this test the voltmeter read two percent low at the highest voltages attained. This error is therefore not only small but opposite in sign to that expected from corona. Finally, making use of an effect first reported to us by Herb but since frequently tested here, an effort was made to detect the change in current-reading which should be produced when any incipient corona was stopped by the introduction of CCl_4 vapor into the voltmeter-resistor casing. No effect was observed even at the highest voltages.

Charging current

In all work done so far our maximum target-currents have been limited by our pumping speed so that maximum charging currents have not been necessary and accordingly we have operated our belts at reduced speeds to reduce mechanical vibration. The added current-drain due to the voltmeter could be readily compensated by increased belt-speed, if desired. However, during some tests on a disk-type electrostatic generator[2] it was noted that charging currents could be greatly increased by introducing a thin dielectric between the current-

[2] O. Dahl, Rev. Sci. Inst. 7, 254 (1936); E. H. Bramhall, Rev. Sci. Inst. 5, 18 (1934).

carrier and the earthed inductor, and making a simultaneous increase in spray-voltage. Adoption of this technique on our belt-machine doubled our previous charging currents so that we now operate at reduced speed and with only the "ingoing" belts charged, thus reducing the unsteadiness arising from incipient sparking at the belt-openings when operating at the higher voltages.

Voltage-fluctuations

As before, variation of voltage was accomplished by moving a set of corona-points toward or away from the sphere. At all except the highest voltages, where sparking occurred, it was immediately obvious from the steadiness of the voltmeter-needle that no erratic voltage-fluctuations were occurring. It is important to note that this steadiness is a property which is apparently inherent in a corona-limited, constant-current machine, and is attained without recourse to smoothing condensers or compensating devices of any kind.

Since the period of a portable microammeter is usually of the order of one second, there was of course a possibility of relatively fast fluctuations which were smoothed out by the period of the meter. To eliminate this possibility observations were made with a cathode-ray oscillograph connected across a one-megohm resistance in series with the voltmeter-multiplier resistance. When due allowance was made for the low impedance of the resistor-unit to high frequency pulses (capacitative impedance equals resistive impedance at 100 cycles), it was immediately clear that no deviations from the mean of greater than one or two percent were occurring. To obtain a quantitative measure of the fluctuations, however, a photographic record was necessary. For this purpose the 10,000-megohm resistor was connected to a single-stage, vacuum-tube amplifier operating a high-sensitivity Dudell oscillograph (700 cycles) which recorded on a moving film. The results for the voltage on the outside sphere are shown in Fig. 3. From these records the distribution-curves for 250 equally spaced ordinates measured from each of these curves were obtained. Similar records were taken for the voltage-fluctuations on the inside sphere. The voltage between the spheres showed a noticeable 60-cycle ripple which was absent on the outside sphere; from this and other evidence the voltage-fluctuations may be considered inde-

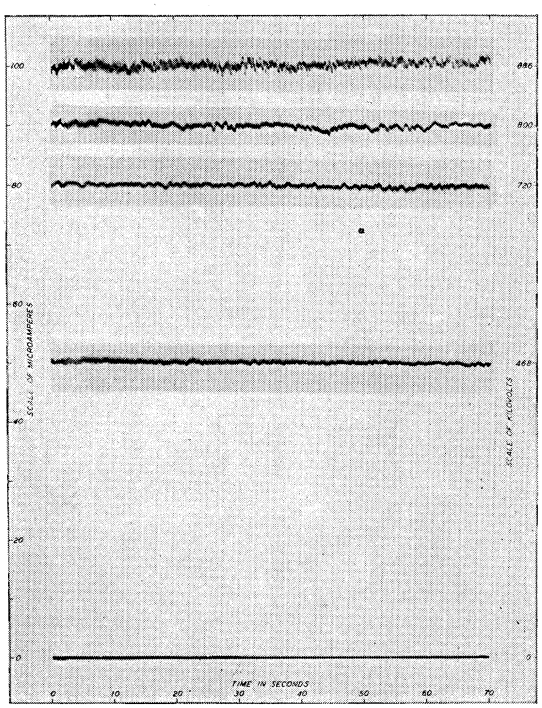
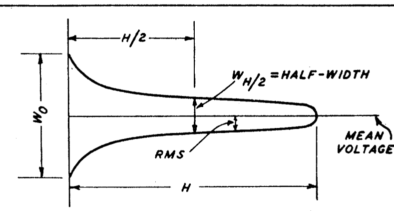


FIG. 3. Voltage-fluctuations, 2-meter electrostatic generator.



VOLTAGE IN KV	FLUCTUATION IN KV OR PER CENT		
	RMS	$W_{H/2}$	W_0
468 (OUTSIDE)	1.20	3.70	5.60
105 (INSIDE)	1.20	1.20	1.90
573 (TOTAL)	1.70	3.90	5.90
FLUCTUATION %	0.29	0.68	1.03
720 (OUTSIDE)	1.9	5.5	11.1
105 (INSIDE)	1.2	1.2	1.9
825 (TOTAL)	2.24	5.7	11.2
FLUCTUATION %	0.26	0.69	1.35
800 (OUTSIDE)	3.3	8.0	16.0
105 (INSIDE)	1.2	1.2	1.9
905 (TOTAL)	3.5	9.2	16.2
FLUCTUATION %	0.39	0.89	1.8
886 (OUTSIDE)	4.6	9.7	27.7
105 (INSIDE)	1.2	1.2	1.9
991 (TOTAL)	4.7	9.8	27.8
FLUCTUATION %	0.48	0.98	2.8

ORDINATES: INSTANTANEOUS VOLTAGE FROM OSCILLOGRAPH-TRACE
ABSCISSAE: TOTAL TIME SPENT AT CORRESPONDING VOLTAGE

FIG. 4. Analysis of voltage-fluctuations on 2-meter electrostatic generator.

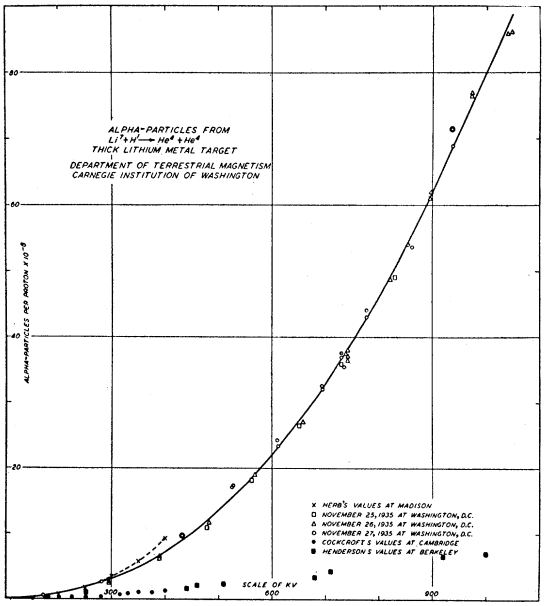


FIG. 5.

pendent. In this case the widths of the two distribution-curves for the fluctuations should be added in the same way as the probable errors for independent error-curves, namely, $W_{1+2} = (W_1^2+W_2^2)^{\frac{1}{2}}$. The data for the separate distribution-curves as well as for the total voltage are given in Fig. 4. This study shows that even at 990 kv the maximum "spread" of the fluctuations is only 28 kv or ±1.4 percent "peak-ripple."

YIELD-CURVES

Accurate yield-curves for either particles or gamma rays can give much information of value in the development of a theory of the nucleus, as has been demonstrated especially by the work of Breit.[3] While yield-curves are desirable for all possible elements, we have thus far concentrated on lithium, on which much work has already been done,[4] and on fluorine[5] in order to establish an absolute voltage-scale by means of its many resonances. Observations will be extended to other elements as time permits.

[3] Breit and Yost, Phys. Rev. **48**, 203 (1935).
[4] Cockcroft and Walton, Proc. Roy. Soc. **A137**, 229 (1932); Henderson, Phys. Rev. **43**, 98 (1933); and Oliphant and Rutherford, Proc. Roy. Soc. **A141**, 259 (1933).
[5] McMillan, Phys. Rev. **46**, 868 (1934).

ALPHA-PARTICLES FROM Li^7+H^1

This problem has long been studied under gradually improving experimental conditions. The recent precision work[6] on this problem and consequent calculations of theoretical expectations[7] emphasized the need for more observations at the higher voltages.

Our most recent results for a thick target are given in Fig. 5, with results of other observers included for comparison. In order to obtain reproducible results it was necessary to adopt a target-technique in which a freshly prepared target of lithium metal, evaporated onto a copper plate in vacuum, could be moved across the ion-beam so as to present a fresh surface as often as desired. This technique has not yet been extended to thin targets because of the obvious difficulty of insuring uniformity. Un-

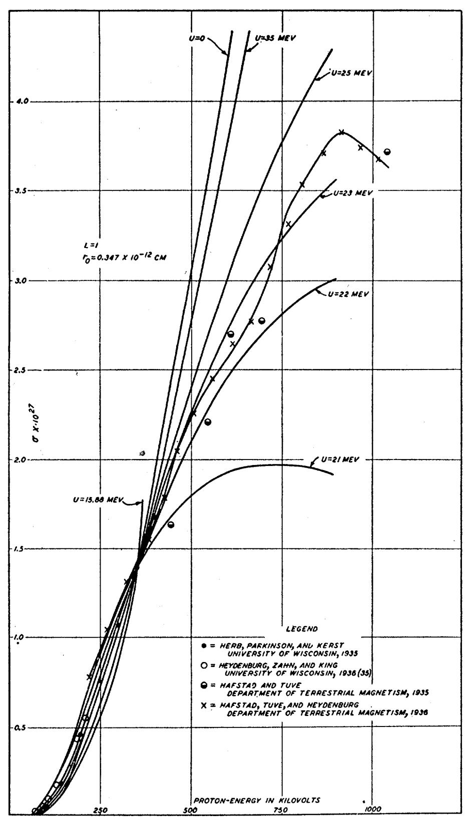


FIG. 6. Comparison theoretical and observed excitation-functions for lithium.

[6] Herb, Parkinson, and Kerst, Phys. Rev. **48**, 118 (1935); Heydenburg, Zahn, and King, Phys. Rev. **49**, 100 (1936).
[7] Ostrofsky, Breit, and Johnson, Phys. Rev. **49**, 22 (1936).

fortunately thick target data can be compared with theory only by assuming a law for the range-energy relation for the protons in lithium. This has been done following Herb[6] and the results compared with theoretical values[7] in Fig. 6. It may be seen that our recent results deduced from thick-target data agree well with preliminary values obtained from thin-target observations last year. Plotted in this way the data exhibit irregularities not present in the original data and lead one to suspect that the range-energy relation for protons in lithium may be something other than the $V^{\frac{3}{2}}$ law assumed. However, it is clear from these data that the cross section is not constant above 400 kv as reported by Henderson.

Still more detailed observations on lithium will be needed before the thin-target yield-curve or, more explicitly, the true "excitation-function" for this process can be definitely established.

Gamma-Rays from Li^7+H^1

Our work on the gamma-rays from lithium reported last year has been repeated (1) in order to establish the resonances on an absolute voltage-scale and (2) in order to determine, if possible, the widths of the resonance-levels. Observations were made, as before, using the Lauritsen type of electroscope. Representative results, the last of a series of curves, are given in Fig. 7. By comparison with our previous work it will be noted that the lower resonance occurs at practically the same position on this voltage-scale (440 kv) as on the rather arbitrary scale used last year (450 kv), again disagreeing markedly with the resonance-position of 650 kv reported by the Pasadena observers.[8] In Fig. 7 it may also be noted that there is no confirming evidence for the resonance at 850 kv reported in our paper last year. It is probable that the gamma-rays observed were due to a contamination by fluorine which has an extremely strong resonance-line at approximately this voltage. This possibility is favored by the fact that in order to obtain a sufficiently thin lithium target (less than 20 kv stopping power) the amount of Li present was reduced dangerously close to the contamination-levels of any materials giving large yields. In the present instance fluorine is especially to be suspected since CaF_2 had been used as a target in experiments just preceding the observations on lithium.

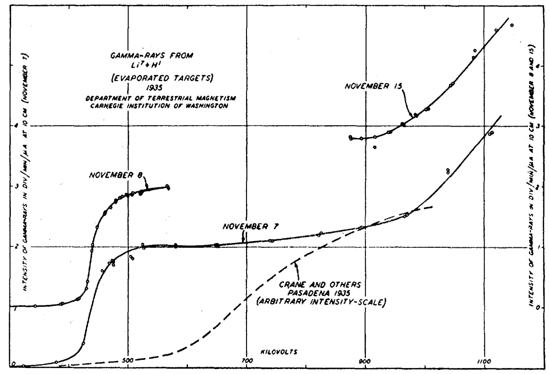


Fig. 7.

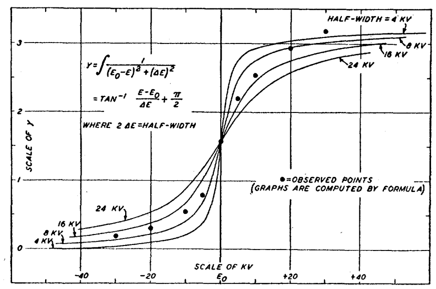


Fig. 8. Determination of half-width of 440-kv lithium gamma-ray resonance.

The importance of obtaining estimates of absolute yields for curves such as the above is recognized, but the problem is too difficult to permit dependable values to be given at the present time. Comparisons with radium are misleading, for the gamma-rays involved in the present reaction are of extremely high energy as has been shown by the work of Lauritsen and his collaborators.[8] It appears at present that both energies and intensities of gamma-rays will have to be determined by the laborious cloud-chamber methods.

In addition to the location of a level, the question of the width of the resonance-level is of theoretical importance. A special effort was made to set limits on the 440-kv resonance in lithium. In Fig. 8 are shown integrated curves for resonances of various "half-widths"[9] with the ob-

[8] Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **48**, 125 (1935).

[9] It is customary to use the width at half-maximum or "half-width" as a measure of the sharpness of a resonance-

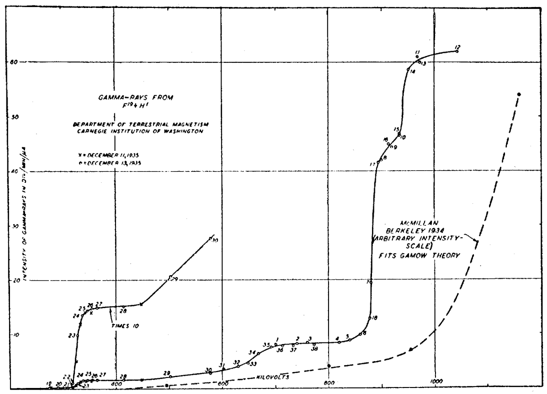


Fig. 9.

served points for the lithium-curve superimposed. From this comparison one can conclude that the "half-width" of the observed lithium-resonance curve is about 12 kv. However, part of this width must be ascribed to voltage-fluctuations, which produce a spread in the energies of the ions in the incident beam. Referring to Fig. 4 one estimates this width to be about 4 kv, leaving a width of about 11 kv $=(12^2-4^2)^{\frac{1}{2}}$ for the true resonance-width for this 440-kv process in lithium. This conclusion is open to the possible objection that the measurements of the voltage-fluctuations were not made at the same time as the gamma-ray measurements. However, the consistent behavior of the generator as indicated by the resistance-voltmeter and in our oscillographic tests seems to preclude the possibility that the voltage-fluctuation was abnormal by a factor of three during the taking of the observations on lithium. Further evidence that the above width is not due to the apparatus is given by the fact that a much smaller width was observed in fluorine as will be discussed below.

Gamma-Rays from $F+H^1$

Our results for this process are given in Fig. 9. The observations were primarily made to establish the several fluorine resonances on an absolute voltage-scale and to test the "resolving power" of our apparatus in the higher voltage-regions. The points shown in Fig. 9 are numbered in the order in which they were taken, each point requiring from three to ten minutes for a complete observation. The agreement between points 1, 2, 3 and points 36, 37, 38 taken several hours later is particularly satisfying. The existence of the close doublet with components at 894 and 942 kv has been checked by several indedently observed curves and appears to be real. The fact that these two lines are close probably accounts for the broad resonance-peak observed in this region in the observations made last year, when with less precise voltage-measurements our apparatus effectively had less "resolving power."

In the region from 400 to 700 kv the rapid rise in the curve suggests the possibility of several minor resonances. An effort was made to test this possibility, but no conclusive results were obtained due to difficulties in devising a suitable target. Crystals of CaF_2 were shattered by the localized heat of bombardment, and CaF_2 powder was blown about by electrostatic forces; hence, to obtain more precise data, experimentation with other compounds of fluorine will probably be required.

Estimates of the "half-widths" of the 328-kv, 892-kv, and 942-kv resonances made in the same way as for lithium give "observed" values of about 4 kv, 10 kv, and 15 kv, respectively. Since from the table in Fig. 4 these values appear to be practically equal to the "half-widths" of the voltage-distribution curves, the only permissible conclusion is that the "true" widths are probably smaller than these "observed" values.

Discussion

Process of gamma-ray emission[10]

Any explanation of the observed resonance for the emission of gamma-rays when Li^7 is bombarded with protons has to make use of a temporary semistable state (virtual level) of Be^8. The mean life of this level is determined by the half-value breadth of the level and is thus $(1/4\pi)(510/11)(h/mc^2)=3.7h/mc^2=3\times10^{-20}$ sec. The width of the level must be due to its damping by all possible modes of decay.[11]

curve; see, for example, Slater and Frank, *Introduction to Theoretical Physics*, p. 37.

[10] We are indebted to Dr. Placzek and Professor Teller for valuable discussions of the problem of gamma-ray emission. We understand that these ideas will be published in a paper in the Physical Review which will appear shortly. The theoretical treatment given here in connection with the Li gamma-ray problem is due to Professor Breit.

[11] See, for example, Breit and Wigner, Phys. Rev. **49**, 519 (1936).

The virtual level of Be^8 may either radiate directly into a lower level of Be^8 or it may decay by disintegration into two alpha-particles at least one of which will then have to be excited. It is hard to account for a number of gamma-ray wave-lengths using only quantum jumps between different levels of Be^8 because such levels are more likely to disintegrate into two normal alpha-particles than to radiate gamma-rays. For this reason Crane and Lauritsen have assumed that the Be^8 nucleus first of all disintegrates into a normal and an excited alpha-particle; later the excited alpha-particle is supposed to radiate the complex gamma-ray spectrum. According to a recent report[12] the spectrum consists of a single line having an energy of 17 MEV and the main support for this picture of the process appears to be withdrawn.

Some preliminary observations made in Washington indicate that there may be also present a gamma-ray of 8-MEV energy. These observations were made on the magnetic curvature of Compton electrons expelled from a thin sheet of glass (about 500 kv thick) in a Wilson cloud-chamber by the $Li+H^1$ gamma-radiation. It was found that of 31 tracks with energies above 2 MEV which definitely originated in the thin glass sheet 22 fell in the region between 7.5 to 9.5 MEV. The only higher-energy Compton electrons were in the vicinity of 11 MEV, where three tracks were found.

According to the above it is still somewhat uncertain whether the gamma-ray spectrum consists of a single line or not. If it does, the simplest explanation is to suppose that the virtual state radiates directly into the normal level of Be^8. Afterwards the Be^8 nucleus may or may not dissociate depending on its still somewhat uncertain mass. We failed to observe any irregularity in the excitation function for the ordinary 8-cm alpha-particles in the vicinity of 440 kv either with thick or with thin targets. In the thick-target observations alpha-particles having a range greater than 7.6 cm would have been counted. The thin-target experiments were concerned with particles having greater penetrating power than 1.2-cm alpha-particles. This indicates that the resonance to gamma-rays has to do with states of excitation of the Be^8 nucleus which do not dissociate into normal alpha-particles. Quantitative measurements of gamma-ray intensities are at present still too uncertain to be sure of their number. Since, however, the probability of mechanical disruption is, under ordinary circumstances, many times greater than the probability of radiation it is probable that the virtual level of Be^8 is *barred* from disintegration into alpha-particles through the operation of some rather rigid selection-rule. This conclusion appears to be very probable for any mechanism involving radiative transitions within the Be^8 nucleus. It does not follow on the hypothesis of disintegration into a normal and an excited alpha-particle because such a disintegration could conceivably be so much more probable than disintegration into normal alpha-particles that no change in the yield of the 8-cm alpha-particles would be expected.

According to our present admittedly crude measurements of the yield of gamma-rays the collision cross section at resonance is roughly 10^{-27} cm^2. Substituting this into formula (14) given by Breit and Wigner and using $h\Gamma=5$ kv one finds that either $h\Gamma_r\sim 1$ volt and $h\Gamma_s\sim 5$ kv or else $h\Gamma_s\sim 1$ volt and $h\Gamma_r\sim 5$ kv. This means that there are essentially two possibilities for accounting for the order of magnitude of the yield: (1) The damping of the virtual level is due practically entirely to the possibility of break-up by dissociation into Li^7+H^1, the order of magnitude of $h\Gamma_r$ is then so small that it is most reasonable to explain the process as being due to the emission of gamma-rays to a lower level of Be^8. (2) The damping due to disintegration into Li^7+H^1 could be supposed to be small ($h\Gamma_s\sim 1$ volt) and all of the width of the level would be attributed so some other mode of disintegration. The high value of $h\Gamma_r$ would not fit in with the expected probability of gamma-radiation within the nucleus. This mode would then involve some such process as the disintegration into excited and normal alpha-particles. The very small value of $h\Gamma_s\sim 1$ is however somewhat improbable because it indicates that transitions from Li^7+H^1 to the virtual level are much less likely than ordinary calculations indicate. [It would be possible similarly to interpret $h\Gamma_s$ as due to protons and $h\Gamma_r$ as due

[12] Delsasso, Fowler, and Lauritsen, Seattle Meeting, Am. Phys. Soc. (1936).

to alpha-particle disintegrations using a large Γ_s and a small Γ_r arising from some selection rule.] A process with a small Γ_s and a large Γ_r cannot, however, be completely excluded, particularly since the gamma-ray spectrum is not yet certain. It would mean that the virtual level happens to be practically decoupled from Li^7+H^1 and at the same time it would have to dissociate more readily into a normal and an excited alpha-particle than into two normal alpha-particles. Thus even though a small Γ_s and a large Γ_r are not logically excluded the number of conditions to be satisfied is greater and the radiative capture of Be^8 hypothesis fits in more naturally with present evidence. Experiments on the anomalous scattering of protons by lithium at the resonance voltage should differentiate between the two alternatives. On the hypothesis of the radiative transitions within Be^8 a scattering cross section of the order of 5×10^{-24} cm^2 would be expected while alpha-particle disintegration would be associated with a much smaller scattering cross section.

According to quantum mechanics energy-levels can be classified into even and odd and for closed systems there are no transitions between levels of these two classes; on the other hand electric dipole radiation jumps occur only between levels of one class and those of another[13] (Laporte's rule). It has been mentioned that if radiation takes place between levels of Be^8 a selection rule is needed to prevent the disintegration of the resonance level into two normal alpha-particles. Since two normal alpha-particles obey Einstein-Bose statistics and have no spin, the resonance level could be assumed to be odd and disintegrations into normal alpha-particles would be then prohibited. At the same time it would be necessary to arrange for stability against decay into a normal and an excited alpha-particle. Such stability can be automatically provided by supposing that the first odd excited level of the alpha-particle lies more than 17 MEV above the normal level. This is not in contradiction with Feenberg's calculations on the position of the lowest ^1P level in the alpha-particle and the ^3P level is probably above the ^1P level on account of the presence of exchange forces in the nucleus. On the above picture an

[13] E. Wigner, *Gruppentheorie.*

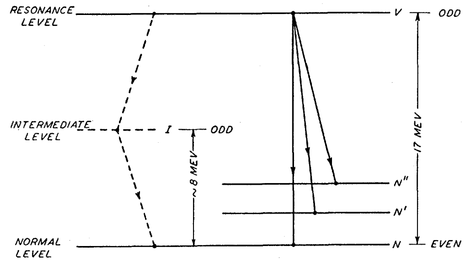


FIG. 10. Level system for Be^8.

electric dipole radiation can take place from the virtual to the normal level of Be^8. If the gamma-ray is actually quite monochromatic then one has to suppose that there is no other level between the resonance level and the normal state to which a transition with radiation can take place. It is very difficult, however, to be sure that even the 17-MEV component of the gamma-ray is monochromatic and so far as we are able to tell at present there is just as much evidence for a gamma-ray multiplet having components between 13 MEV and 17 MEV as for an entirely monochromatic gamma-ray. Confining ourselves for the present to the possibility of the first radiative transition occuring in Be^8 the following type of energy-level diagram of Fig. 10 can be considered as possible. The resonance level V is is responsible for the capture of the protons. It is supposed to be "odd" so as not to disintegrate into normal alpha-particles. No irregularity in the excitation-curve for the 8-cm particles will be then expected because odd and even levels do not interact. The normal level of Be^8 is designated by N and is supposed to be even. The 17-MEV ray may arise through electric-dipole radiation in the jump VN. In addition there may be either odd or even levels N', N'' within say 3 MEV of N. If these levels are even, there may be electric dipole-transitions VN', VN'' accompanied by subsequent disintegration into short range alpha-particles. If the levels N', N'' are odd no disintegration into alpha-particles would be likely to occur from them and instead soft gamma-rays would be emitted, in such jumps as $N'N$. It is more probable that the levels N', N'' are even and a search for short range alpha-particles appears to be worthwhile. In addition to the group of levels N', N'' there appears to be no reason against admitting an odd level I approximately between V and N. Magnetic dipole or quadripole radiation would then account for 8-MEV gamma-rays, an indication of which has been obtained. Since, it was supposed that the first odd level of the alpha-particle is more than 17 MEV above normal in order to account for the stability of V, the level I would also be stable towards mechanical disruption and the absence of 4-MEV alpha-particles would follow. It is as yet not completely certain experimentally that such particles are not present in small amounts and the "odd" character of the level I is, therefore, not an absolute necessity. It should be noted that in thick targets with protons well above the resonance voltage the 4-MEV alpha-particles would be produced somewhat inside the target and would consequently be harder to detect.

In the above discussion and diagram levels are designated as odd and even in accordance with what appears to be likely from present conjectures about the normal state of Be^8. Clearly the only essential part of the argument is concerned with using selection rules. Thus the level V could be supposed to be even with odd spin and would still be stable towards disintegration into normal alpha-particles. It appears to be premature to list all possible arrangements of levels which might be consistent with present experimental facts. A certain degree of probability can be attached however to the particular assignment of levels given above making use of some recent and as yet unpublished calculations of Wigner and Feenberg. According to these one expects an even ^1D level to lie about 3 MEV above N which should be a ^1S level. The next even level (^1G) would lie about 8 MEV above N and would be thus approximately in the position of I. In order to have an electric dipole transition to N one may suppose V to be an odd P level which would then be also likely to give radiation to $N'={}^1D$. On this view there should be short-range (1.5-MEV) alpha-particles emitted from N'. Transitions to the ^1G level would not occur except through the possible influence of higher multiple radiations. If transitions to the ^1G level should occur some 4-MEV alpha-particles will be emitted because its mean life is short when estimated by means of formulas for barrier-penetration.

If the virtual level V disintegrates by gamma-ray emission all of its width must be attributed to the probability of dissociation into Li^7+H^1. A theoretical estimate of the width can be made easily by regarding the proton as subjected to a central field due to the lithium nucleus. Using the formula[14]

$$\Delta T/T=1/\int_0^{r_0}\bar{G}^2 d\rho;\quad \bar{G}(r_0)=G(r_0)=D_L\rho^{-L}\Theta_L$$

where r_0 = nuclear radius, L = angular momentum of proton with respect to Li^7, the graphs for Θ_0, Θ_1, given by Yost, Wheeler, Breit,[15] and the WKB approximation for $L=2$, we obtain for the half-width $2\Delta T=400$ kv for $L=0$, 20 kv for $L=1$ and $\frac{1}{2}$ kv for $L=2$. In this calculation the integral in the denominator was approximated by $G^2\rho$. The above estimates are likely to give too high values for the width because the disintegration of V into Li^7+H^1 depends not only on the probability of the proton escaping but also on the chance of an internal nuclear rearrangement. There is thus no difficulty in accounting for the width using head-on collisions ($L=0$) and even those for $L=1$, but it is probable that $L=2$ plays little part in the process. The normal configuration of Li^7 is very probably *odd*. Since V must also be *odd* it is probable that the capture and dissociation occurs through the partial wave $L=0$. If, contrary to present views, the normal configuration of Li^7 should be even then $L=1$ will have to be held responsible. This is less likely also since little leeway is left for the probability of internal rearrangement.

Observations recently taken in this laboratory jointly with Dr. Rumbaugh of the Bartol Foundation indicate that there is stationary level in Li^7 about 400 kv above the normal state. Presumably this level corresponds to an angular momentum of $\frac{1}{2}$ and constitutes together with the normal state of Li^7 a doublet p term. It is conceivable that the small cross section for the production of gamma-rays is partly due to the disintegration of the virtual level V into a slow proton with an excitation of Li^7 to "$p_{\frac{1}{2}}$" level. The probability of this happening at 440 kv incident proton-energy should be small, because the barrier-penetration factor for the $440-400$

[14] Breit and Yost, Phys. Rev. **48**, 203 (1935).
[15] Yost, Wheeler and Breit, Phys. Rev. **49**, 174 (1936) (the notation of this reference is used in the text above).

$=40$-kv protons decreases the probability of their interaction with the virtual level. It is possible, however, that at higher energies of incident protons evidence of inelastic collisions due to the excitation of the 400-kv level may be found.

Considerations such as the above cannot at present be effectively applied to the fluorine resonances, which have been shown to be significantly sharp, since even the reaction or reactions involved are at present uncertain.[5, 16]

Voltage-Scale for Inter-Laboratory Comparison

It has long been customary to measure voltages of ion-accelerators by giving the range in air of the ion-beam produced. However, the accurate specification of such ranges is by no means a simple matter, for such factors as straggling, ion-distribution, and current-density must be taken into account. The most readily determined specification of an ion-beam is probably a quantity which we might call the "visual range," this being merely the range of the particles in air as observed by the fluorescence produced when the beam is passed through a thin window into a darkened room. This quantity will be found to vary with current-density, room light, and different observers, and bears no definable relation to the "mean" range which is usually the quantity desired. In spite of these difficulties, however, it is repeatable to about ± 1 mm, and hence gives an accuracy of about ± 10 percent in voltage-measurements in the range in which this indicator can be conveniently used. For such purposes the relation $R=2.5V^{\frac{3}{2}}$, where V is in megavolts, describes our results for the region between 500 and 1000 kv.[17] The "visual" range will in general be longer than the "mean" range due to thin spots in windows, voltage-fluctuations (since the peaks will be measured), variations in current-density, and other such causes.

For nonhomogeneous beams the visual range will of course give only the upper limit of energies. The effective voltage for disintegrations may then be any lower value, depending on the form of the ion-energy distribution-curve. Since in such cases sharp resonance-curves such as those described in this paper will no doubt be useful in calibrating ion-beams for both energy- and ion-distribution, we have endeavored to make our determinations as accurately as was immediately practicable. The original calibration against wire-wound standards insures that the measured voltages agree with the international scale to within two percent. This includes such errors as temperature-variation, which in the present design is relatively unimportant for the resistors are operated at only one-tenth of their rated capacity. While the location of a resonance is easily determined, the accurate specification of "half-widths," on which conclusions as to ion-distribution must be based, is difficult for two reasons. First, for sharp resonances, observations must be made at intervals of about 5 kv, which at voltages over 500 kv requires that the mean energy be measured to less than one percent; second, any asymmetry in the observed resonance-curves causes an ambiguity in the specification of "half-widths" when plotted as in Fig. 8. This problem becomes even more difficult when the observed width approaches the "fluctuation-width" for in this case any slight asymmetry in the ion-energy distribution would also have to be taken into account. With these qualifications in mind the points at present available for the calibration of ion-beams of unknown energy or distribution are as follows:

Voltage	Element	Half-width
328 kv	F	< 4 kv
440 kv	Li	11 kv
892 kv	F	<12 kv
942 kv	F	<15 kv

Acknowledgment

The authors take pleasure in expressing their indebtedness to Professor G. Breit for his continued interest and advice, to O. Dahl for invaluable aid in the design and construction of apparatus, and to Dr. R. G. Herb for his enthusiastic assistance in the construction and testing of the voltmeter-resistor while a guest at our Laboratory. Our thanks are especially due to our Director, Dr. J. A. Fleming, for his constant encouragement and unfailing support.

[16] Feather, "Reports on progress in physics," Proc. Phys. Soc., Vol. II.

[17] The voltage-scale used in this laboratory last year was based on a visual range of 2.85 cm at 1000 kv, 1.00 cm at 500 kv.

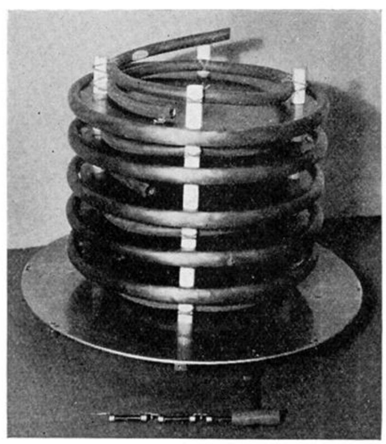


FIG. 1. Construction of corona-free voltmeter-resistor.

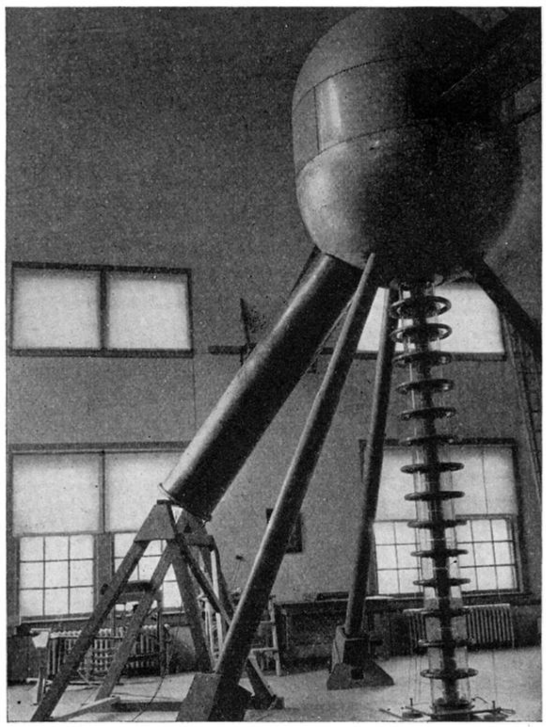


FIG. 2. 1200-kilovolt electrostatic generator showing tube and voltmeter-resistor.

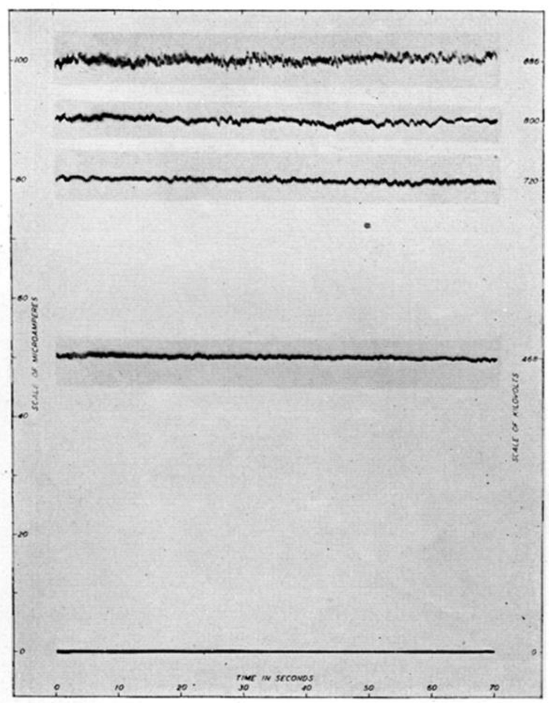


FIG. 3. Voltage-fluctuations, 2-meter electrostatic generator.