DECEMBER 1, 1931 PHYSICAL REVIEW VOLUME 38

THE PRODUCTION OF HEAVY HIGH SPEED IONS WITHOUT THE USE OF HIGH VOLTAGES

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(Received October 19, 1931)

Abstract

A method has been developed for the multiple acceleration of ions to high speeds without the use of high voltages. The ions travel through a series of metal tubes in synchronism with an oscillating electric potential applied alternately to the tubes such that the electric field between tubes is always in a direction to accelerate the ions as they pass from the interior of one tube to the interior of the next. The ions are thereby successively accelerated to speeds corresponding to voltages as many times greater than the high frequency voltage applied to the tubes as there are tubes. In the present experiments a high frequency voltage of 42,000 volts at a wave-length of 30 meters applied to 30 such accelerator tubes in line resulted in the production of a current of 10^{-7} amp. of 1,260,000 volt singly charged Hg ions. The surprising effectiveness of this experimental method for the generation of intense beams of high speed ions is due to the development of simple, convenient and effective methods for focusing and synchronizing the ions as they pass through the accelerating system. The present experiments show that ions having kinetic energies in excess of 1,000,000 volt-electrons can be produced in this way with quite modest laboratory equipment and with a convenience surpassing the direct utilization of high voltages, that the limit to the attainable ion speeds is determined mainly by the length of accelerating system and the size of the high frequency oscillator system, and consequently that the production of 10,000,000 volt ions is an entirely practicable matter.

Introduction

Recent advances in our knowledge of the structure of matter and its interaction with radiation have in a large measure resulted from experimental studies of collision processes. Apart from experiments in the realm of radioactivity, practically all of these investigations have been concerned with energy interchanges in amounts less than 100,000 volt-electrons. A survey of this situation impresses one that the unexplored domain of higher energy processes awaits the experimenter with promise of much new and important knowledge of the properties of atoms.

There is of course a general recognition of the importance of this field of investigation and several laboratories are developing the technique of the production of high voltages and their direct application to vacuum tubes for the generation of high speed electrons and ions. Highly significant progress in this direction has been made by Coolidge,[1] Lauritsen,[2] Tuve,[3] Brasch and Lange,[4] Cockroft and Walton,[5] Van de Graaff[6] and their collaborators who

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[1] W. D. Coolidge, Am. Inst. E. Eng. **47,** 212 (1928).

[2] C. C. Lauritsen and R. D. Bennett, Phys. Rev. **32,** 850 (1928).

[3] M. A. Tuve, G. Breit and L. R. Hafstad, Phys. Rev. **35,** 66 (1930).

[4] A. Brasch and J. Lange, Zeits. f. Physik **70,** 10 (1931).

[5] J. J. Cockroft and E. T. S. Walton, Proc. Roy. Soc. **A129,** 477 (1930).

[6] R. J. Van de Graaff, Schenectady meeting American Physical Society, 1931.

have each developed distinct techniques for voltages of the order of magnitude of one million.

These methods, involving as they do the direct application of high voltage, are subject to certain important limitations. In the first place, it appears that experimental difficulties go up so rapidly with voltage that though the region of one million volts is within the realm of practicability, the region of ten million volts is beyond the present experimental domain. In the second place, these high voltage methods involve apparatus quite beyond the equipment of most physical laboratories and are somewhat cumbersome for detailed experimental investigations of the types that have been carried out in the range of low velocities.

It is for these reasons that we are concerning ourselves with the development of methods for the production of high speed particles which do not require the use of high voltages. Our objective thus is two-fold; first, to make practicable the production of particles having kinetic energies considerably greater than those producible by direct high voltage methods and second, to make the production of particles having kinetic energies in the region of one million volt-electrons a matter than can be carried through with quite modest laboratory equipment and with an experimental convenience which, it is hoped, will lead to a wide-spread attack on this highly important domain of physical phenomena.

Three distinct methods are being developed in our laboratory. One of the methods is for the production of high speed electrons and at the present time is in its early stages of development.[7] Another method designed for the acceleration of relatively light ions has reached a rather advanced stage of development and has already been briefly described;[8,9] a detailed account is expected to be published soon. The third method applicable to heavier ions is the subject of the present paper.

The fundamental principle of this method was experimentally demonstrated several years ago by Wideroe[10] who succeeded in producing 50,000 volt potassium ions in a tube to which the maximum applied voltage was about 25,000 volts. In our initial experiments[11] the method was developed to the production of 210,000 volt mercury ions with an applied voltage of 10,000; i.e., a voltage amplification of 21 was obtained. In the present work new developments have lead to a voltage amplification of 30 and the production of 1,260,000 volt singly charged ions. It is shown also that the method can be readily extended to the production of ions having kinetic energies of the order of magnitude of 10,000,000 volt-electrons.

The Experimental Method

An outline of the experimental arrangement will make clear the important features of the method. A series of metal tubes arranged in line (labeled ac-

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[7] This method was discussed briefly at the symposium on high voltages at the Pasadena meeting of the American Physical Society (June 1931).

[8] E. O. Lawrence and N. E. Edlefsen, Science **72**, 376 (1930).

[9] E. O. Lawrence and M. S. Livingston, Phys. Rev. **38**, 834 (1931).

[10] R. Wideroe, Arch. f. Elektrotech. **21**, 387 (1929).

[11] E. O. Lawrence and D. H. Sloan, Proc. Nat. Acad. Sci. **17**, 64 (1931).

celerators in Fig. 1) are attached alternately to the inductance of a high frequency oscillatory circuit. A high frequency voltage applied in this manner produces at any instant electric fields between successive accelerator tubes of opposite direction and equal magnitude. If at one instant an ion finds itself between the first and second tubes with the field in the right direction it will be accelerated into the second tube, and if the time consumed in passing through this tube is equal to the half period of the oscillating field, it will arrive between the second and third tubes with the field reversed in direction in such a manner that it will receive an additional acceleration on passing into the third tube. If the tubes are made successively longer in the proper way (approximately the square roots of integers times the length of the first tube), for any frequency of the applied oscillations there will be a corresponding voltage such as will cause the ion to move up through the series of accelerators in synchronism with the oscillating field, gaining between each pair of accelerators an increase in kinetic energy corresponding to the applied potential difference. Thus, for example, in the present experimental tube 42,000 volts applied to the 30 accelerators resulted in the production of ions having kinetic energies corresponding approximately to 30 times 42,000 volts, i.e., 1,260,000 volts.

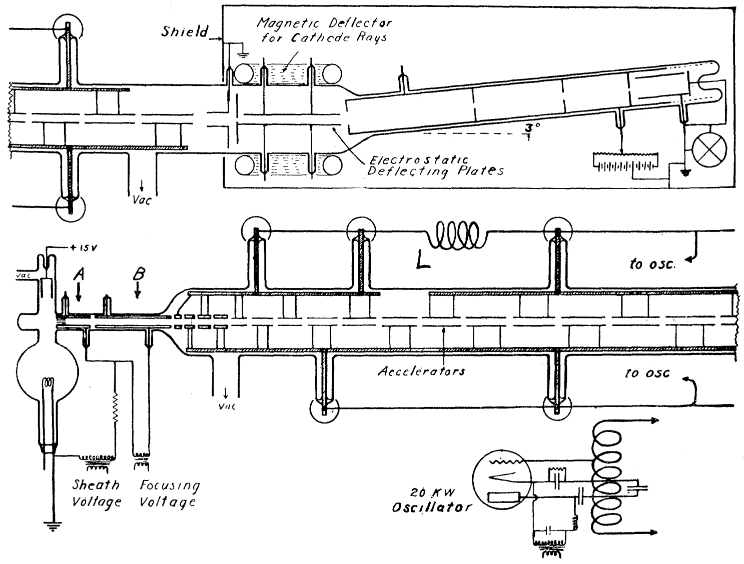

Fig. 1. Diagram of apparatus.

THE EXPERIMENTAL ARRANGEMENT

The essential components of the experimental arrangement are the line of accelerator tubes in a suitable vacuum, an intense source of ions with focusing devices to draw them properly into the first of the accelerators, electrostatic deflecting plates in conjunction with a collector and galvanometer to select out and measure the speeds of the ions, a high frequency oscillator, and a satisfactory vacuum system. It is perhaps well to describe these parts of the experimental arrangement in some detail.

The ion source

Because the ion beam must travel a long path of restricted cross section the initial focus of the beam is of an importance comparable with its intensity. The ions must start out approximately in the right direction if they are to succeed in passing all the way through the accelerator tubes.

The hot cathode arc discharge was chosen as the source, not only because it gives a copious supply of ions at low vapor pressures, but also because of the circularly symmetric fields so readily obtained about circular electrodes in the positive ion sheath which are an important help in focusing. Without the arc plasma slight irregularities in the construction and position of all the electrodes in the source would have unpredictable effects upon the focus of the emergent ion beam. The arc has the added advantage that ions so formed have random velocities very small compared to that acquired in falling through the positive ion sheath of the electrode drawing the ions out.

The ions are formed in a hot cathode mercury vapor discharge at 10^{-3} mm of mercury pressure. The accelerating system receives positively charged mercury ions from this arc by means of a negative electrode A (Fig. 1) inserted into the positive column. Between this electrode and the arc is a positive ion sheath or space charge region from which the electrons are repelled by the 10,000 volts negative potential of the electrode. Some of the ions from the arc plasma which acquire 10,000 volts velocity by falling through this space charge enter a hole drilled through the electrode along the principal axis of the accelerator system.

The canal rays thus projected through the hole in the first electrode form a divergent beam, the amount of the divergence depending on the arc current density, the vapor pressure, and the negative potential of the electrode (sheath voltage) as well as the shape of the opening in the face of the electrode at the boundary of the sheath. The second electrode B, 15,000 to 20,000 volts more negative than the first, has its end tapered to provide a suitably curved axially symmetric field between the electrodes which sharply focuses the beam into the region of the high frequency accelerators.

These first two electrodes are each about 8 cm long with a 5 mm hole which, with the small opening 1 mm in diameter and 10 mm long into the arc region, provide a pressure drop between the latter at 10^{-3} mm of mercury pressure and the high frequency accelerator region which is evacuated by two high speed condensing and pumping systems to less than 10^{-5} mm Hg pressure.

The accelerating system

The accelerator cylinders consist of short lengths of copper tubing 5 mm in diameter, all in line with the beam from the ion source, and supported alternately from copper bus bars above and below the group of hollow cylinders. These bars are the opposite terminals of the inductance of the oscillating circuit. The lengths of the tubes increase as the square roots of integers since the ions gain equal increments of energy between successive accelerators, i.e., the velocities of the ions increase with the square root of the number of times they are accelerated. The lengths of the cylinders are adjusted on the basis of the first one having an effective length of 1 cm, the overall length of the 30 cylinders being about 114 cm. The actual length of the cylinders is decreased by the length of the insulating gap between them.

Since the applied potential is sinusoidal the ions travel part of the distance across the gap in fields perceptibly different from peak values. The shorter the gap between successive cylinders the greater is the effective potential fall for the ions on crossing a gap. On the other hand the gap must be fairly long to permit the use of high voltages, to reduce the inter-electrode capacity, and to give greater equality between the fields at points on and off the axis.

A gap of 20 percent of the distance between centers of cylinders yields effectively 96 percent of the applied potential; this makes the first ten gaps too short to give sufficiently uniform fields, the first three even being too short to prevent sparking between electrodes; the necessary separations of the first three electrodes reduces them to mere rings. To enhance the field uniformity large disks with a hole in the center of each are therefore used for the first few accelerators (the disk arrangement is not shown in Fig. 1). Though disks of this type provide greater homogeneity of the fields, an ion passing from one to the next in a half cycle receives only 63 percent of the maximum of the applied voltage. Rather than increase the voltage applied to these first few enough to compensate for this loss, two extra stages of these disk accelerators are added. The first ten accelerators are of this hybrid design and are attached to a variable loading inductance (L, Fig. 1) which makes possible easy adjustment of the high frequency voltage applied to them relative to the voltage applied to the rest of the accelerators.

Electrostatic resolution and measurement of the ion beam

The beam of high velocity ions emerging from the final accelerator passes through a slit 3 mm wide and between a pair of electrostatic deflecting plates 20 cm long and 1 cm apart, across which are applied suitable potential differences to deflect the beam through an angle of 3 degrees into a line of slits leading to a Faraday collector as shown in Fig. 1.

The purpose of deflecting the ion beams is two-fold; in the first place, electrostatic deflection of the beam in this way serves as a velocity analyzer, and secondly, the collector being off the line of the accelerators, the slit system provides essential shielding of the collector from x-rays generated in the accelerators and in the ion source as well as on the deflecting plates. A magnetic field perpendicular to the axis of the tube deflects to the walls cathode rays generated along the tube, thereby preventing them from striking the deflector plates and generating x-rays which would pass freely through the line of slits to the Faraday collector. Protected thus from all stray radiations and charged particles, the collector is available to locate ion beams of 10^{-12} ampere using a high resistance leak across the electrometer. Without this relatively high current sensitivity the correct initial adjustment of focusing voltages, the discharge current, the synchronizing voltage, and phase correction voltage for each new frequency of the oscillator would be a difficult matter of chance.

The high frequency oscillator

A 20 K. W. Federal Telegraph water-cooled power oscillator tube is used in a self excited Hartley oscillator circuit. Working into a very low resistance load, the tube impedance is readily matched by connecting it across only a small portion of the total inductance, thus giving a greatly increased voltage at the terminals of the entire inductance. Applying a 60 cycle peak voltage of 15,000 volts to the oscillator, the high frequency voltage obtained across some preliminary accelerator tubes was as high as 90,000 volts at 42 meters wavelength. Because of close spacing and dirty electrodes, the present accelerator tube sparks between electrodes at 45,000 volts. The high frequency voltage is adjusted by varying the 60 cycle voltage on the plate of the oscillator tube. The importance of being able to vary this voltage at will is suggested by the fact that changing the applied voltage 1 percent below the optimum value reduces the number of ions getting through the accelerating system to a few percent of the optimum current.

The vacuum system

Little difficulty is experienced in maintaining a satisfactory vacuum in the region of the accelerators. Two condensation pumps with large liquid air traps attached to the tube as indicated in Fig. 1 suffice to maintain a vacuum of about 10^{-5} mm of Hg (ionization gauge measurement) in all parts of the tube excepting the ion source. This pressure is low enough to give the high speed ions requisite free paths and to allow the application of high frequency voltages to the accelerators. It is found that the maximum voltage that can be applied is determined essentially by the condition of the surfaces of the electrodes and not by the degree of vacuum obtained.

PRODUCTION OF AN INTENSE HIGH SPEED ION BEAM

Proper synchronization and focus of the ion beam all along its path naturally are essential to the production of an intense beam of high speed ions.

Synchronization

The first requirement for synchronization of the ions with the oscillating field is obviously that voltages are applied to the ion source electrodes AB such as will cause the ions to arrive at the first accelerator tube with proper speeds.

The problem of applying the correct high frequency voltages to the several accelerators is not a simple one. The first ten of hybrid design require a voltage different from that applied to the remaining stages. Moreover, though the remaining accelerators are attached to the same bus bars the potential distribution along them is not uniform, due to the distributed capacity and inductance; this effect depends on the frequency and cannot readily be calculated. Even if for a given frequency and tube design the voltages on the accelerators were calculated, it would be difficult to estimate accurately the percentage of the applied sinusoidal potential effectively contributing to the kinetic energy of an ion crossing various shapes of gaps between accelerator electrodes. Indeed, this percentage is very much dependent on the distance from the axis of the ion path, which must remain somewhat uncertain because of mechanical inaccuracies of alignment. Add to this the change in potential distribution with operating frequencies and it becomes apparent that some sort of flexible adjustment must be available for empirical synchronization of the ions all along their paths.

Many synchronizing devices have been considered. The simplest in principle is to alter the gap separations of the accelerators individually until the ions do experience accelerations which cause them to travel through the tube in synchronism. The same end would be achieved by a system for changing the length of each accelerator itself to correspond to the velocity of the ions passing through it. Such empirical mechanical adjustments would undoubtedly be cumbersome; a much more feasible method is the adjustment of the high frequency voltage applied to the several accelerators by the introduction of variable loading inductances along the busses supporting the line of accelerators.

A single loading coil (L, Fig. 1) for the first ten accelerators has been found to be sufficient; a longer tube which might require several is impractical in a single oscillatory circuit at these high frequencies. In the present experiments, the loading coil determines the voltage on the first ten accelerators relative to that on the remaining stages such as to give the ions velocities upon entering the eleventh tube which enable them to proceed in approximate synchronism with the oscillations. The introduction of the loading coil in the first few stages has proved to be very effective for purposes of synchronization and, therefore, is of cardinal importance in the scheme.

The possible variations in phase between the alternating potential and the velocity of the ions through the column of accelerator electrodes indicate the latitude of adjustment of the applied potentials. Exact synchronism occurs when the ions cross the center of each gap at the same phase angle of the applied sinusoidal potential. While this is the ideal case and not difficult to realize in practice, large deviations from this behavior will still permit acceleration of the ions which as a result emerge with final velocities varying as widely as 5 percent above or below the synchronizing value.

With the loading inductance and the applied high frequency voltage adjusted to the optimum values giving continuous synchronism of the ion beam, the reduction of the high frequency voltage by 2 percent practically eliminates the current of ions which have final velocities corresponding to those of synchronism—though several percent of the ions still get through the system out of synchronism and with reduced final emergent velocities.

If now instead of decreasing the applied voltage it is increased beyond the value for synchronism a complex array of possible phase relations of velocity and frequency occur. An ion crossing the center of an accelerator gap before or after the instant of maximum applied potential may still receive sufficient energy to pass on in synchronism; indeed, it may receive more than this required amount and thereby its velocity becomes greater than that for synchronism. If this were the situation when it leaves the accelerator system, the ion would emerge with more energy than that acquired when traveling in precise synchronism. If, however, when only partly through the system, it gets so far ahead in phase that it crosses between accelerators before the potential has built up to the synchronizing value, the accelerations will be insufficient for the ion to gain further excessive velocity and the main portion of the beam traveling in synchronism would soon overtake it. Thus, while its average velocity through the system equals that of a synchronized ion, due to its early excess velocity, its final velocity will be below that of the main group. So it is that an excessive oscillator voltage transmits ions over a greater phase angle and with a wider emergent velocity distribution, only slightly reducing the number acquiring the normal velocity. This spread in velocities is always observed experimentally.

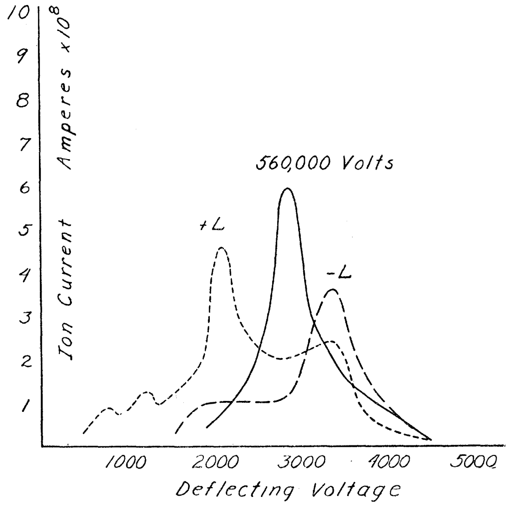

Fig. 2. Variation of current as ions of various velocities are deflected into the collector.

When the synchronism is not uniform, due to a distortion of the optimum potential distribution along the system, even more striking phase variations occur. Fig. 2 shows the variation of current as ions of various velocities are deflected into the collector; the ordinates are the currents to the collector corresponding to various deflecting voltages on the deflecting plates given by the abscissas. The velocity distributions for three distinct cases are shown. The heavy central curve is obtained with a potential distribution along the accelerators similar to that described in the preceding paragraph; i.e., when the optimum voltage is applied resulting in continuous acceleration of the ions. Less voltage eliminates the peak and reduces the whole curve nearly to zero. More voltage on the oscillator broadens the peak and reduces it slightly due to the phase displacements mentioned. With the inductance loading the first ten accelerators increased, raising thereby the voltage applied to them, and with the voltage applied to the remaining accelerators lowered to an optimum value giving a sharp peak in the current versus deflecting potential curve, it is seen that the peak (labeled $+L$) represents velocities below those for synchronism. These ions started out too fast and required less acceleration later on to be kept in approximate phase with the oscillations. Similarly, if the inductance is decreased lowering the voltage on the first set of accelerators and the voltage on the remaining accelerators correspondingly increased to bring the ions through with a sharp peak of intensity (curve labeled $-L$), the beam is found now to consist of higher velocity ions than those of synchronism. These ions fall behind in phase in the first accelerations and the higher voltages bring their velocities up until they are crossing the gaps at or even before the instant of maximum of this excessive potential, resulting in the excessive final velocities.

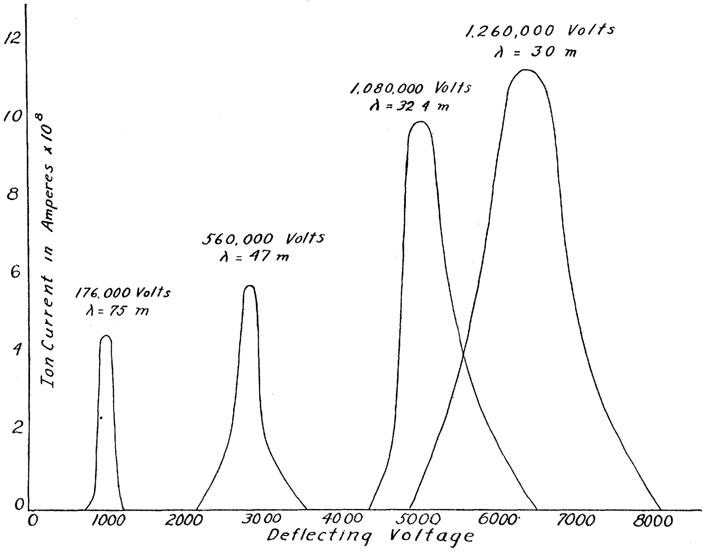

Fig. 3. Ion current plotted against deflector potential; curves for four different oscillator frequencies.

These remarks account in a qualitative way for the larger portion of the ion beams. However, it is seen that the velocity distributions of the ions in all cases extend over a wide range and indeed for curves $-L$ and $+L$ there are subsidiary peaks. The presence of two peaks in each of these cases is probably to be ascribed to ions traveling through the accelerators in phases approximately 90 degrees apart. This remark becomes clear when it is realized that there are two portions of each cycle during which the ions are synchronously accelerated. A more detailed discussion of this matter can profitably be reserved for a later time.

In Fig. 3 are plotted ion current versus deflector potential curves for four different oscillator frequencies. In each case the curves represent data obtained with the loading inductance on the first ten accelerators adjusted to give continuous acceleration of the ions with the applied high frequency voltage on the remaining accelerators slightly above the optimum value, thereby resulting in some broadening of the peaks of the curves. Calculations from the deflecting voltages and geometry of the arrangements show that the peaks in each case correspond approximately to ion velocities corresponding to synchronous acceleration. Thus, the curve corresponding to the wavelength of 30 meters represents the production of singly charged mercury ions having energies in excess of 1,260,000 volts. It will be noticed that as the frequency is increased and the voltage and velocities are higher, the maximum ion currents are also greater. This may be attributed to the decreasing relative magnitude of random velocities and the ever present space charge repulsion forces and other stray fields compared to the focusing action of the applied electric fields. This matter of focusing is discussed more fully below.

The above considerations make it evident that if the applied sinusoidal voltage has a peak value somewhat in excess of that corresponding to synchronization of the ions with the frequency used, a quite appreciable portion of the cycle is effective. It is partly for this reason that this method is capable of producing relatively large high speed ion currents.

Focusing the ion beam

In considering the experimental arrangement one is inclined to the belief that it is not capable of yielding relatively intense beams of high speed ions; at first sight it would appear that the number of ions traversing the whole group of accelerators would be a very small portion of the number entering the first accelerator. It would seem that stray fields and space charge effects together with imperfect alignment of the tubes would be the cause of deflection of most of the ions from the very restricted solid angle defined by the final accelerator.

In the early stages of the experiments we were very much concerned with this matter of beam intensities and devoted much thought to ways and means of focusing the ions all along their paths through the system. The methods developed are quite successful, since about 10 percent of the ions starting through the accelerators which have the possibility of traveling through the system actually emerge from the final accelerator.

The first requirement in the production of an intense beam of high speed ions is of course the projection into the first accelerator of a copious supply of ions traveling with proper velocities axially with the cylinders. This initial focusing adjustment is accomplished by trial and error methods, the procedure being to raise the high frequency voltage on the accelerators slightly above the theoretical value for synchronism, and then to adjust the voltages on the ion source electrodes AB until a maximum ion current is obtained at the collector.

The most important focusing occurs along the accelerators and is accomplished quite automatically by the curved electric fields between adjacent cylindrical accelerators. An ion crossing the gap between the tubes in synchronism receives an acceleration in towards the axis during the first half of the distance from the inside of one cylinder to the inside of the other, and an approximately equal outward acceleration during the remaining half of the gap length. In first approximation, the net result is a displacement of the ion towards the axis of the cylinders. Because the ion traverses the second half of the gap in a slightly shorter time than it does the first half, the inward velocity component gained in the first half is not quite overcome in the second half, and therefore, the ion retains a slight inward component of velocity as a result of crossing the gap. An ion slightly out of phase with the oscillations may gain a much greater component of velocity at right angles to the line of accelerators. For example, if the ion arrives at the center of the gap after the peak of the oscillations, then during the second half of its course across the gap the average outward component of the electric field is smaller than the corresponding inward component during the first half of the path across the gap, and hence the inward velocity gained in the first half is not neutralized in the second half. This effect is a rather important one and makes it desirable to use applied high frequency voltages with peak values not too greatly in excess of that corresponding to resonance.

This focusing action of the curved fields between accelerators has proved to be highly efficacious; it appears that the decrease of intensity of the beam due to imperfect focus through the accelerators is really insignificant in the case of the 30 accelerators of the present experiments, suggesting that many more accelerators may be incorporated without appreciable loss in beam intensity.

DISCUSSION

This method is most conveniently used in the production of high speed heavy ions because the heavier ions travel slower and, consequently, require shorter accelerating systems. For a given kinetic energy, the speeds of ions vary inversely as the square roots of their masses. For a given oscillating frequency, the required length of the accelerating system is proportional to the ion speeds. It follows that for ions of atomic weight 22 an accelerating system must be three times as long as that required for mercury ions to produce the same kinetic energies. This increase in length is not excessive, and therefore it may be concluded that the method is applicable to the majority of ions.

The present experimental development has achieved one of the objectives outlined in the introduction, namely, the production of ions having energies of the order of magnitude of one million volt-electrons without the use of cumbersome high voltage equipment and with considerable experimental convenience. It is interesting to inquire to what extent the present work has progressed along the road to the other goal, i.e., the production of 10,000,000 volt ions.

To reach higher energies in this way, it is clearly necessary either to increase correspondingly the high frequency voltages at shorter wave-lengths applied to the accelerators or increase the number of accelerators. From experience with the present tube it seems that the voltage on the accelerators cannot conveniently be increased by more than a factor of two and, consequently, the region of 10,000,000 volts can be attained only by increasing the number of accelerators.

With but one oscillatory circuit the limit to the number of accelerators that can be used is established by the capacity of the system. The arrangement of accelerator tubes, bus bars, leads and inductances can be improved considerably over that of the present arrangement; a quite considerable reduction of capacity and increase in general circuit efficiency can be achieved by putting the inductances in the vacuum along with the accelerators. However, these improvements can hardly decrease the capacity per accelerator by much more than a half.

It is evident, therefore, that recourse must be taken to the use of several oscillators in parallel, each exciting a separate group of accelerators. Experiments are now under way to develop this idea. A new tube under construction has a longer accelerating system divided into two sections, the first 36 accelerators being driven by one radio frequency power amplifier, the next set of 20 accelerators being energized by another amplifier, both being excited by a master oscillator which thereby keeps the voltage on all accelerators in phase. The electrode construction is of much lower resistance and capacity and should withstand an applied potential of 80,000 volts at a wave-length of 27 meters. An average current of more than 10^{-7} amperes of singly charged Hg ions should thus be produced with energies of about 4,500,000 volt-electrons. The use of multiply charged ions, as in the earlier work, should greatly increase the ion speeds obtainable. Triply charged Hg ions traversing the accelerating system of the tube now being built would possibly gain 8,000,000 volt-electrons of energy.

If these next experiments are successful, they will be regarded as strong evidence that the experimental limit to the obtainable ion speeds is determined simply by the length of the tube and the number of oscillators. For example, it is estimated that 10,000,000 volts singly charged Hg ions would be produced by an accelerating system 40 feet long with 8 power amplifiers in parallel.

We are much indebted to the Federal Telegraph Company through the courtesy of Dr. Leonard F. Fuller, Vice-President, for the loan of essential equipment. One of us (D. H. S.) also is grateful to the Coffin Foundation for the award of a fellowship.