

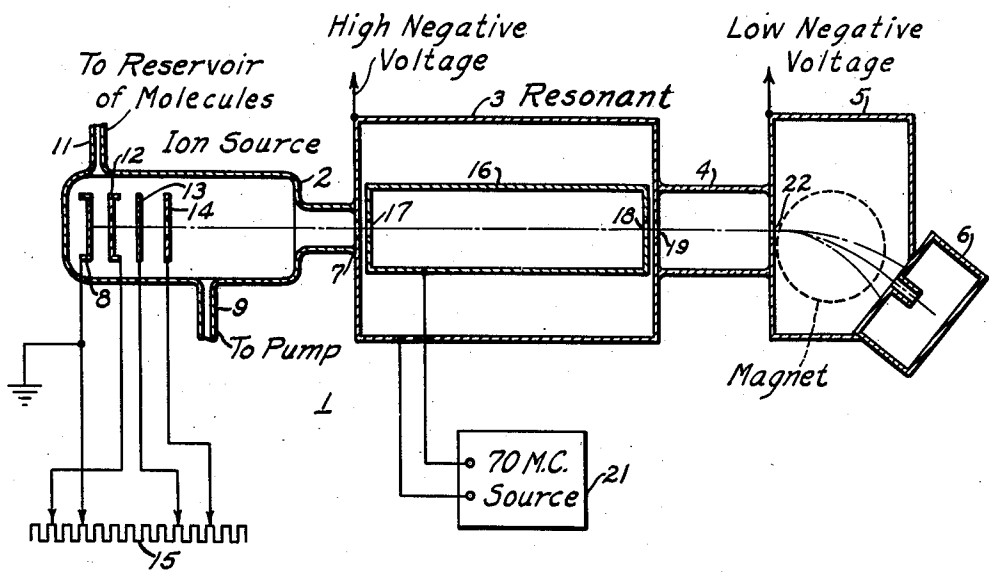
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DEVICE FOR SEPARATING PARTICLES OF DIFFERENT MASSES

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DEVICE FOR SEPARATING PARTICLES OF
DIFFERENT MASSES

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My invention relates to arrangements for separating particles of different mass from mixtures thereof and, in particular, relates to an arrangement for separating isotopes of the chemical elements. Its operation depends upon a particularly effective method of imparting widely different velocities to particles of even very slightly different mass, and then utilizing the difference in velocity for effecting physical separation of the particles.

One object of my invention is, accordingly, to provide a novel arrangement and method for separating, from mixtures thereof, particles which differ from each other in mass.

Another object of my invention is to provide a novel and improved arrangement and method for causing electrified particles having different masses to be physically separated from each other.

Still another object of my invention is to provide a novel and improved method of producing widely different accelerations between particles having masses which differ from each other.

Another object of my invention is to provide a novel arrangement and method for producing widely different velocities as between ions having only slightly different masses.

A further object of my invention is to provide a novel arrangement and method for segregating from mixtures thereof different isotopes of the same chemical element.

Other objects of my invention will become apparent upon reading the following description, taken in connection with the drawings, in which the single figure is a diagrammatic showing of one form of apparatus in which the principles of my invention may be embodied.

Referring in detail to the drawings, a vacuum-tight chamber 1 may be considered to be subdivided into five different chambers 2, 3, 4, 5 and 6, which act, respectively, as a source of accelerated ions 2, and electrical differentiating chamber 3, a decelerating chamber 4, a magnetic deflection chamber 5, and an ion-collecting chamber 6. The chamber 2 may be provided with walls of glass or other insulating material and be sealed at 7 to the differentiating chamber 3 which may have conducting walls. The walls of the decelerating chamber 4 may be of insulating material, while the walls of the deflection chamber 5 and the ion-collecting chamber 6 may conveniently be of conducting material.

The chamber 2 is provided at one end with an electronically-emissive cathode 8 of any type

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known in the art to be suitable as a source of a concentrated electron beam. The chamber 2 is likewise provided with an offtake 9 to a vacuum pump of sufficient capacity to maintain the desired vacuum in the above-mentioned system of chambers, even when a desired quantity of gaseous ions is allowed to flow into the chamber in the immediate vicinity of the cathode 8 through a duct 11 leading from a reservoir of molecules of the substances which it is desired to separate from each other. In front of the cathode 8 there is provided a series of diaphragms 12, 13 and 14 of a type known in the art to be suitable for producing a concentrated beam of ions or other charged electrical particles. The diaphragms 12, 13 and 14 are connected to a suitable source 15 of direct-current potential which has one terminal connected to the cathode 8 and also, preferably, to ground. The wall of the chamber 2 opposite to the end containing the cathode 8 is pierced with an aperture which is aligned with similar apertures in the plates 12, 13 and 14. It will readily be evident that if the diaphragm 12 is positive relative to the cathode 8, electrons will be accelerated in the space in front of the latter, and that these will ionize any molecules which have been allowed to flow into the chamber 2 through the duct 11. If the diaphragms 13 and 14 are negative in potential relative to the cathode 8, they will accelerate positive ions thus produced by the electron stream along a path passing through their apertures and through the aperture in the end wall of the chamber 2 which is adjacent the chamber 3.

A high negative potential is imparted to the chamber 3 relative to the cathode 8, and the end wall of the chamber 3, which is adjacent the chamber 2, is provided with an aperture which is aligned with the apertures in the diaphragms 13 and 14. Such a system of electrical potentials will produce a narrow beam of positive ions accelerated to a high velocity which will pass into the interior of the chamber 3. Where it is desired to produce a stream of negatively charged ions or negatively charged electrified particles, it will be obvious to those skilled in the art that the potentials of the diaphragms 13 and 14 and chamber 3 relative to the cathode 8 should be the reverse of those above-described.

In the interior of the chamber 3, there is provided a field-free enclosure 16 which may take the form of a conducting cylinder supported on insulators (not shown) from the walls of the chamber 3 and provided with a pair of apertures 17 and 18 in its end walls which are aligned with

the apertures in the diaphragms 13 and 14 and in the end walls of the chambers 2 and 3, as above-described. A narrow space intervenes between the respective end of the cylinder 16 and the adjacent end walls of the chamber 3, and a source of alternating potential 21 which may, for example, have an amplitude of 1000 volts and a frequency of 70 mc. per second, is connected between the cylinder 16 and the chamber substantially at one end thereof 3. It will be evident from the foregoing description that an alternating voltage will be set up in the spaces between the end walls of the cylinder 16 and those of the cylinder 3, but that the space in the interior of the cylinder 16 will be virtually an electric-field-free space in which any electrified particles entering through the apertures in one end of the cylinder 16 will move without acceleration or deceleration until they pass through the aperture in the opposite end of the cylinder 16.

The end wall of the chamber 3, which is remote from the chamber 2, is provided with an aperture aligned with the apertures 17 and 18, and the above-described arrangement will be seen to be such that a beam of electrified particles emanating in front of the cathode 2 will be passed through the apertures in the diaphragms 13 and 14, the apertures 17 and 18 and into the interior of the decelerating chamber 4. The end wall of the chamber 4, which is adjacent the chamber 5, is of metal and is provided with an aperture 22 which is aligned with the apertures 17 and 18. This end wall is impressed by a suitable voltage source (not shown) with a negative voltage which is much lower than that impressed on the chamber 3. It will be seen to result from this arrangement that the electrified particles in the above-mentioned beam will pass through the aperture 22 with a much lower velocity than that which they possessed while passing through the cylinder 16.

The electrified particles, when about to pass through the aperture in the end wall of the chamber 3 which is adjacent the chamber 2, will have a kinetic energy corresponding to the product of their electrical charge by the voltage of the cylinder 3 relative to the cathode 2. Since the electrical charge produced on ions in front of the cathode 2 will, in general, be the same even though the ions differ from each other in mass, the velocities of the ions when they enter the chamber 3 will be inversely proportional to the square roots of their respective masses. However, one of the principal problems to be solved by my above-described arrangement is the separation of ions, such as isotopes of the same element, which differ from each other only slightly in mass. In such cases, the velocity of ions of each particular isotope will be the same, and the velocity of different isotopes will differ from each other only slightly, the velocities of different isotopes being inversely proportional to the square root of their respective masses.

In the space between the end wall of the chamber 3 and the adjacent aperture 17, the ions will be subjected to an alternating electric field having the frequency of the source 21 which will further accelerate or decelerate them in an amount depending upon the instantaneous value and sign of this electric field. The ions will then pass through the field-free space along the axis of the cylinder 16 and will arrive at the aperture 18 with the same velocity that they had on leaving the aperture 17. However, the time at which they

arrive at the aperture 18 will obviously depend upon the respective velocities with which they pass through aperture 17, and as has just been stated above, this velocity will differ for isotopes of different mass, and will also differ even as between isotopes of the same mass which pass through the aperture 17 at different times in the cycle of the voltage impressed by the source 21.

The source 21 impresses an electric field on the space between the aperture 18 and the aperture 19 which is exactly equal and in the same direction as the electric field impressed on the ions just before they pass through the aperture 17. As a result, each ion will leave the aperture 19 with a velocity which depends upon the relative phase of the electric field between the apertures 18 and 19 and the electric field in front of the aperture 17 at the instant of passing; and this relative phase will depend in turn on the time consumed by the ion traversing the distance from the aperture 17 to the aperture 18. In accordance with the foregoing considerations the length of the chamber 3 is selected to be substantially equal to the length of a half-integral number of cycles of the frequency of the source 21 so that it is possible to cause ions having the mass of one isotope to traverse the distance between the apertures 17 and 18 in some half-integral number of cycles of the source 21; but, on the other hand, electrified particles, such as other isotopes having masses which differ from that of the first-mentioned isotope, will have different velocities in passing through the chamber 3 and will correspondingly enter the electric field between apertures 18 and 19 when the latter has a different phase from that of the electric field in front of the aperture 17 when they pass through it. Thus, the ions of the selected isotope first mentioned will enter the decelerating chamber 4 with the same velocity that they had in entering the chamber 3; but all other isotopes will have different velocities from those that they had in entering the chamber 3. The effect of the passage through the chamber 3 is thus to differentiate from each other the velocities of different isotopes, or other electrical particles having identical charges but different masses.

Within the decelerating chamber 4, the electrified particles are subjected to an electric field which tends to greatly slow them down, nearly but not quite to zero velocity. It can be shown that the residual velocities with which the particles pass through the aperture 22 will differ very greatly as between isotopes or other particles of even slightly different mass.

After passing through the aperture 22, the particles pass through a magnetic field of constant magnitude which is perpendicular to the direction in which they are moved. Such a magnetic field will cause moving particles to be deflected into curved paths, the curvature of the path depending upon the velocity with which they are moving as well as their masses. Thus, two isotopes passing through the aperture 22, even if of nearly the same mass, will have, in accordance with the foregoing description, widely different velocities and will correspondingly follow paths of widely different curvature in the chamber 5. The collecting chamber 6 is provided with an aperture corresponding in position to the path followed by the isotope which it is desired to collect. All such isotopes will, therefore, pass into the collecting chamber 6, while all other isotopes or charged electrical particles will be scattered about on the walls of

the chamber 5 or on the exterior walls of the chamber 6.

Since the velocity with which two different isotopes pass through cylinder 16 is, as above stated, inversely proportional to the square root of their respective masses, the time they consume in passing from the aperture 17 to the aperture 18 will be proportional to the square root of their respective masses. It is obviously possible to so select the frequency of the source 21 that the time thus consumed by the desired isotope is an odd number of half periods of the source 21, but the time consumed by an undesired isotope is an even number of half periods of the source 21. Under such circumstances, the velocity with which the first isotope passes through the aperture 19 is the same as that with which it entered the chamber 3, but the velocity with which the undesired isotope enters the aperture 19 is less than that with which it entered the chamber 3 by an amount corresponding to twice the alternating voltage of the source 21. This affords an effective means of widely differentiating the velocities of egress of two isotopes, or other electrically charged particles, entering the chamber 3 with substantially identical velocities.

While I have described an arrangement in which the number of ions passing through the apertures in the diaphragms 13 and 14 is substantially constant with time, it is also within the scope of my invention to pulse the voltage impressed on the diaphragm 12 relative to the cathode 8 at the same periodicity as that of the source 21, or otherwise to modulate the ion beam. The phase of such pulses relative to the source 21 should be made such that an undesired isotope will never enter chamber 3 at a time when the voltage impressed by the source 21 is zero. By the expedient of pulsing the ion beam, it is possible to insure that the net velocity change suffered by an undesired isotope in passing through the alternating fields at the opposite ends of cylinder 16 has a desired value, since the phases of both the alternating electric fields through which the particle passes are fixed and predetermined quantities.

I claim as my invention:

1. In combination with a means for producing a beam of moving electrified particles, means for passing said particles consecutively through two alternating electric fields, means for decelerating by a predetermined amount said particles after passing through the second of said fields, and means for separating from each other such of said particles as have different velocities after said deceleration.

2. In combination with a source of electrically charged particles, means for establishing an electric field having a direct-current component and an alternating-current component for accelerating said particles to a relatively high velocity, means providing a field-free space traversed by said particles subsequent to said acceleration, means for decelerating said particles by an electric field having a direct-current component slightly smaller in magnitude than said direct-current component of said first electric field, and having an alternating component of substantially the same frequency and magnitude as said alternating component of said first electric field, the directions of all said electric fields being substantially parallel, and means for separating said particles in accordance with their respective ve-

locities after passing through said second electric field.

3. In combination with a source of electrically charged particles, means for establishing an electric field having a direct-current component and an alternating-current component for accelerating said particles to a relatively high velocity, means defining a field-free space traversed by said particles subsequent to said acceleration, the time spent in traversing said field-free space being some odd number of half-periods of said alternating current, means for decelerating said particles by an electric field having a direct-current component slightly smaller in magnitude than, and opposed to, said direct-current component of said first electric field, and having an alternating component of substantially the same frequency and magnitude as said alternating component of said first electric field, the directions of all said electric fields being substantially parallel, and means for separating said particles in accordance with their respective velocities after passing through said second electric field.

4. In combination with a means for producing a beam of moving electrified particles, means for passing said particles consecutively through two substantially cophasal equal alternating electric fields which are substantially parallel to the direction of motion of said particles, means for decelerating by a predetermined amount said particles after passing through the second of said fields, and means for separating from each other such of said particles as have different velocities after said deceleration.

5. In combination with a means for producing a beam of moving electrified particles, means for passing said particles consecutively through a first alternating field, a field-free space and a second alternating field, said alternating fields being substantially synchronized and having substantial components parallel to the direction of motion of said particles, the time spent in traversing said field-free space being some integral number of half-periods of said alternating fields.

6. In combination with a means for producing a beam of moving electrified particles, means for passing said particles consecutively through a first alternating field, a field-free space and a second alternating field, said alternating current fields being synchronized and having substantial components parallel to the direction of motion of said particles, the time spent in traversing said field-free space being such that said alternating current fields respectively produce changes of velocity which are substantially equal but of opposite algebraic sign in certain of said particles.

7. In combination with a means for producing a beam of moving electrified particles, means for passing said particles consecutively through two substantially cophasal equal alternating current fields which are substantially parallel to the direction of motion of said particles, and means for separating from each other such of said particles as have different velocities after passing through said two alternating electric fields.

8. In combination, means for producing a rapidly moving stream of electrified particles, a first chamber having conductive walls, a second chamber having conductive walls insulatingly supported within said first chamber, a first pair of apertures aligned with said beam in the respective walls of said first and second chambers, a second pair of apertures in the walls of the said two chambers and aligned with the path of said

beam through said second chamber, a receiver electrode for said particles outside said first chamber, and means for impressing an alternating potential difference along the axis between said first pair of apertures and for impressing a substantially cophasal and equal alternating potential difference along the axis between said second pair of apertures.

9. In combination, means for producing a rapidly moving stream of electrified particles, a first chamber having conductive walls, a second chamber having conductive walls insulatingly supported within said first chamber, a first pair of apertures aligned with said beam in the respective walls of said first and second chambers, a second pair of apertures in the walls of the said two chambers and aligned with the path of said beam through said second chamber, means for separating said particles of different velocity after they issue through said second pair of apertures, a receiver electrode for said particles outside said first chamber, and means for impressing an alternating acceleration on each particle as it traverses said first pair of apertures and for impressing an alternating acceleration of substantially equal and opposite magnitude on said particle as it traverses said second pair of apertures.

10. In combination, means for producing a rapidly moving stream of electrified particles, a first chamber having conductive walls, a second chamber having conductive walls insulatingly supported within said first chamber, a first pair of apertures aligned with said beam in the respective walls of said first and second chambers, a second pair of apertures in the walls of the said two chambers and aligned with the path of said beam through said second chamber, means for separating said particles of different velocity after they issue through said second pair of apertures, a receiver electrode for said particles outside said first chamber, means for impressing an alternating acceleration on each particle as it traverses said first pair of apertures and for impressing an alternating acceleration of substantially equal and opposite magnitude on said particle as it traverses said second pair of apertures, and means for applying a decelerating force to the particles of said beam after they issue from said second pair of apertures.

11. In combination, a first cylindrical chamber having conductive walls, and coaxial therewith a second cylindrical chamber having conductive walls positioned inside said first chamber, the end walls of said second chamber being separated from the end walls of said first chamber by relatively narrow gaps and said second chamber being insulatingly supported within said first chamber, a first pair of apertures in one pair of adjacent end walls of said chambers, a second pair of apertures in the other pair of end walls of said chambers, all said apertures being positioned on the common axis of said chambers, means for impressing an alternating voltage between said two chambers, means for projecting a stream of electrified particles along the common axis of said two chambers, and a receiver electrode for said electrified particles which have passed through said second set of apertures.

12. In combination, a first cylindrical chamber having conductive walls, and coaxial therewith a second cylindrical chamber having conductive walls positioned inside said first chamber, the end walls of said second chamber being separated from the end walls of said first chamber by rela-

tively narrow gaps and said second chamber being insulatingly supported within said first chamber, a first pair of apertures in one pair of adjacent end walls of said chambers, a second pair of apertures in the other pair of end walls of said chambers, all said apertures being positioned on the common axis of said chambers, means for impressing an alternating voltage between said two chambers, means for projecting a stream of electrified particles along the common axis of said two chambers, and means for separating particles of different velocities in said stream after they have issued from said second pair of apertures.

13. In combination, a first cylindrical chamber having conductive walls, and coaxial therewith a second cylindrical chamber having conductive walls positioned inside said first chamber, the end walls of said second chamber being separated from the end walls of said first chamber by relatively narrow gaps and said second chamber being insulatingly supported within said first chamber, a first pair of apertures in one pair of adjacent end walls of said chambers, a second pair of apertures in the other pair of end walls of said chambers, all said apertures being positioned on the common axis of said chambers, means for impressing an alternating voltage between said two chambers, means for projecting a stream of electrified particles along the common axis of said two chambers, means for applying a decelerating force to said electrified particles after they have passed through said second pair of apertures, and means for separating from each other such of said particles as have different velocities after being subjected to said decelerating force.

14. Apparatus for separating from each other electrified particles having substantially equal electric charges, but different masses which comprises means for accelerating said particles by means of a first electric field having a direct-current component and an alternating-current component, said direct-current component consisting of intermittent pulses having the same frequency as said alternating-current component, a region substantially free from accelerating or decelerating forces disposed in the path of said particles, means for subjecting said particles to a second electric field having a direct-current component slightly smaller than and opposed to said direct-current component of said first field and having an alternating component of substantially the same amplitude and frequency as said alternating component of said first electric field, the directions of all said electric fields being substantially parallel, and means for separating from each other particles having different velocities after passing through said second electric field.

15. In combination with a stream of charged particles having different velocities, means for imparting to said particles a periodic acceleration in a direction parallel to their velocities, a path traversed by said particles after said acceleration which is substantially free from forces producing acceleration in said direction and which has a length such that some of said particles traverse it in a time substantially equal to a half-period of said periodic acceleration, and means for imparting to said particles a periodic deceleration in said direction which is substantially equal and opposite to said periodic acceleration.

16. Means for separating from each other elec-

trified particles having equal electric charges and different masses which comprises accelerating the particles of desired mass to a predetermined speed, passing them consecutively through two electric fields oscillating at the same high frequency and spaced apart within a resonant cavity which resonates at said frequency; the fields being of such strength, dimensions and spacing relative to each other that particles traversing the said fields at the predetermined speed will undergo substantially equal changes of their velocities but of opposite algebraic sign, and means for separating from each other particles having different direction or speed of motion after passing through the second electric field.

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