# United States Patent

**Bell, Jr. et al.**

[15] **3,649,827**

[45] **Mar. 14, 1972**


## [54] HELICAL THREE-STAGE ISOTOPE SEPARATION


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[73] Assignee: **The United States of America as represented by the United States Atomic Energy Commission**



[22] Filed: **Aug. 13, 1970**

[21] Appl. No.: **63,456**

[52] **U.S. Cl.** ..... **250/41.9 ME,** 250/41.9 C

[51] **Int. Cl.** ..... **H01j 39/34**

[58] **Field of Search** ..... 250/41.9 ME, 41.9 TF, 41.9 C



[56] **References Cited**

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" Mass Spectromitry and its Application to Organic Chemistry," J. Beynon, Elsevier Publishing Co., New York, 1960 pp. 20, 21, 37.



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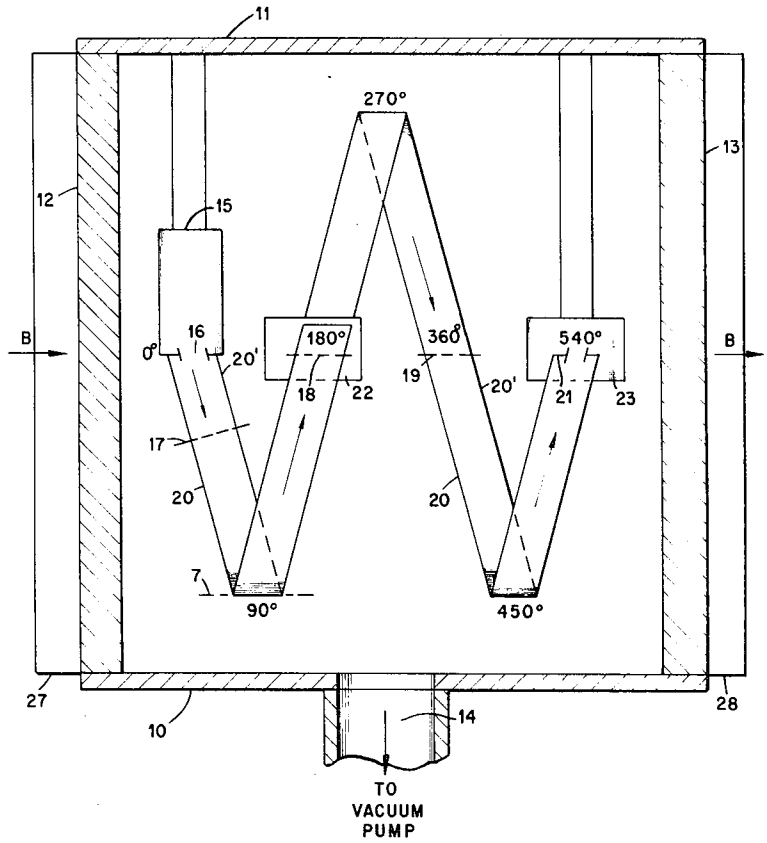
[57] **ABSTRACT**

An isotope separator of the type having an evacuated tank, a magnetic field through the tank, and an ion source and a receiver wherein the ion source is orientated at a slight angle to the magnetic field lines such that the stream of ions exiting from the ion source spiral along the magnetic field in a helical path, producing a three-stage separation after 540° of rotation, and the desired isotopic ions are collected in a receiver located at the 540° focus.


**9 Claims, 8 Drawing Figures**



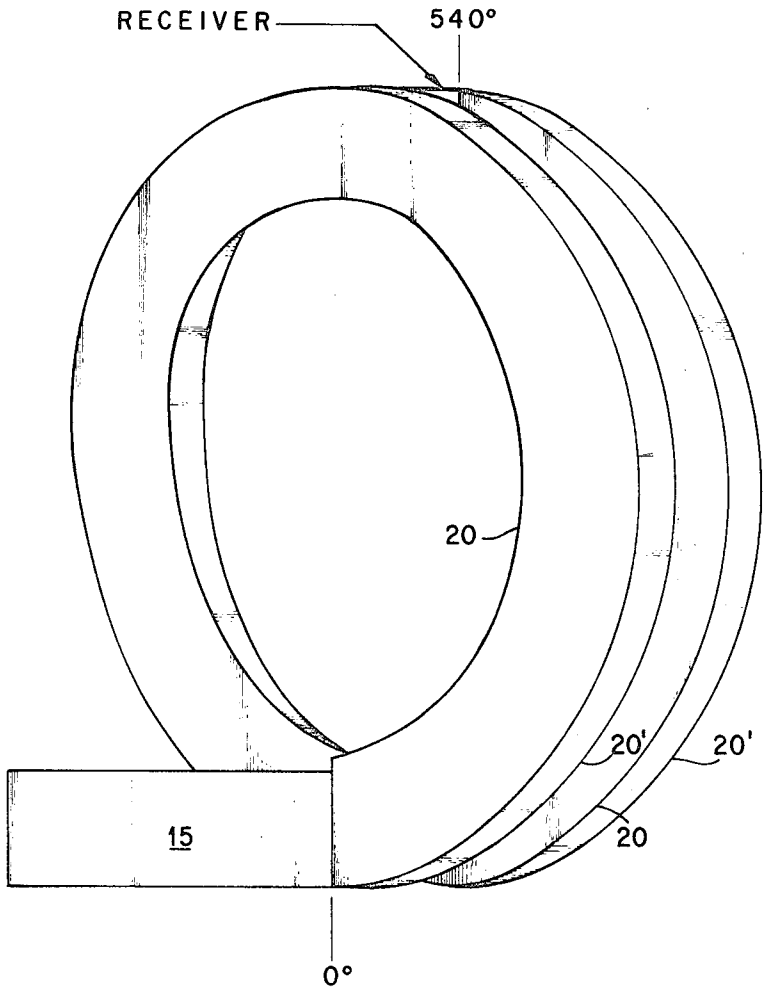



Fig. 1

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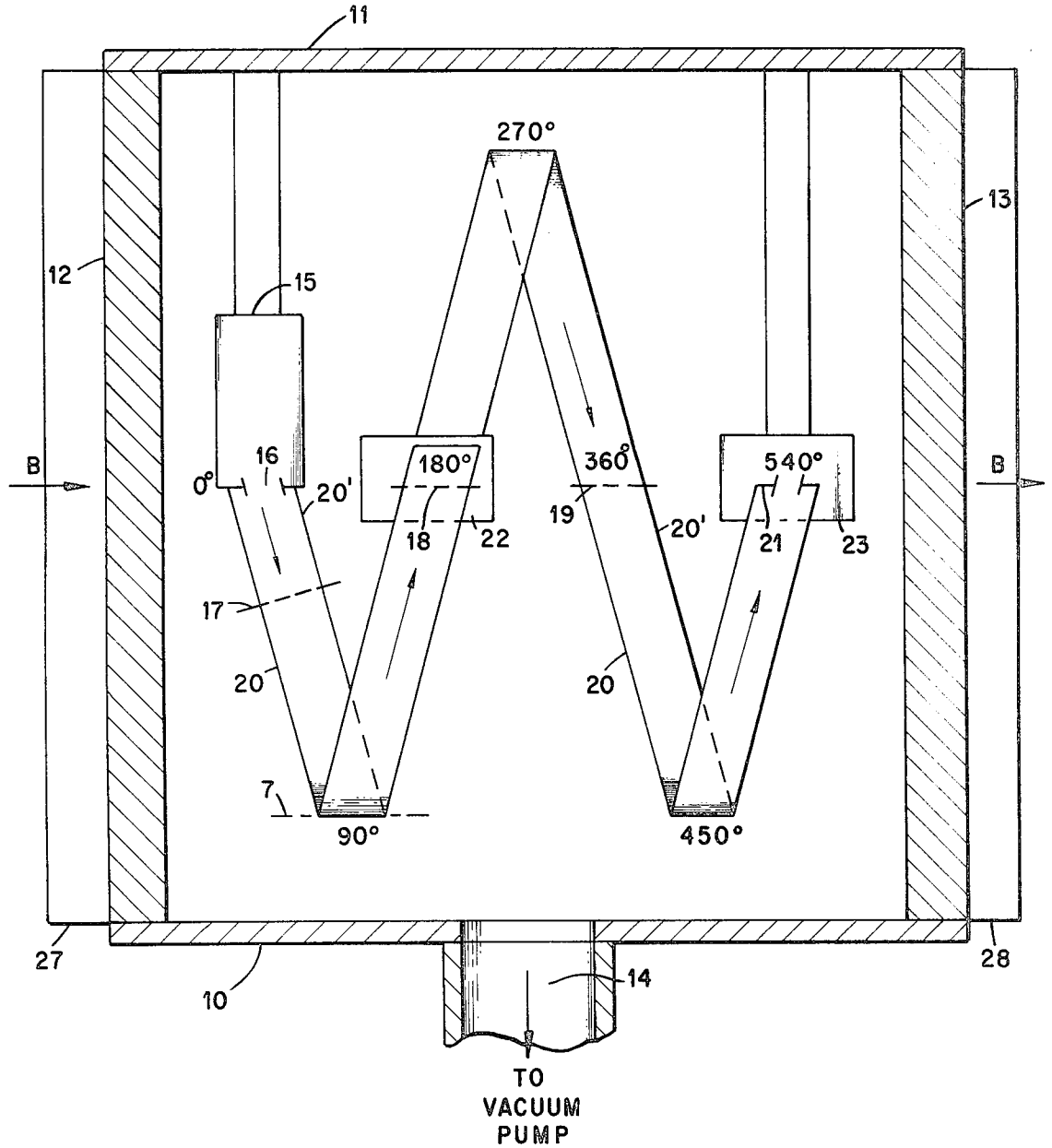


Fig. 2

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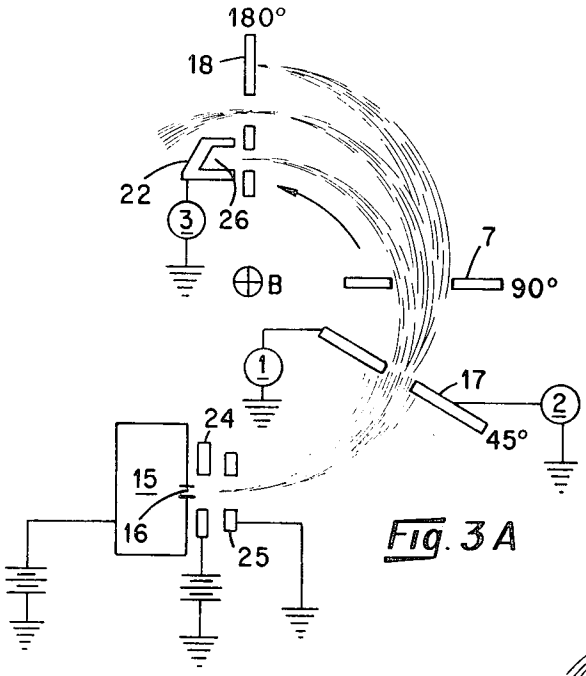


Fig. 3A

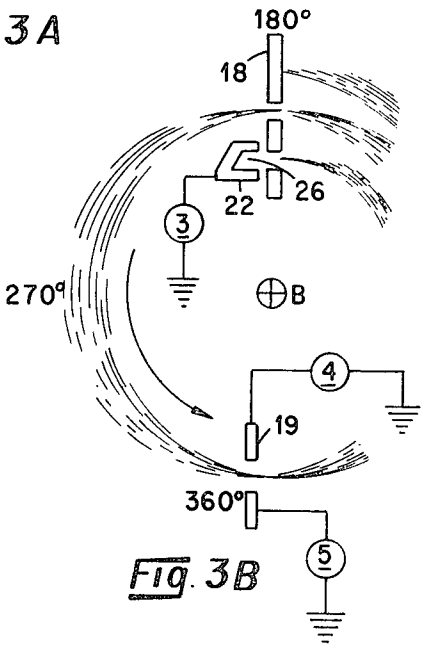


Fig. 3B

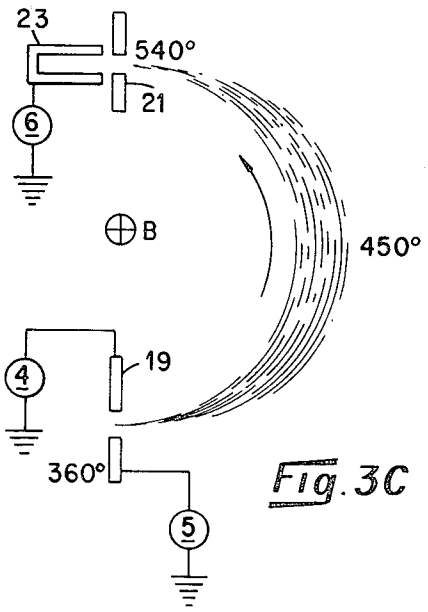


Fig. 3C

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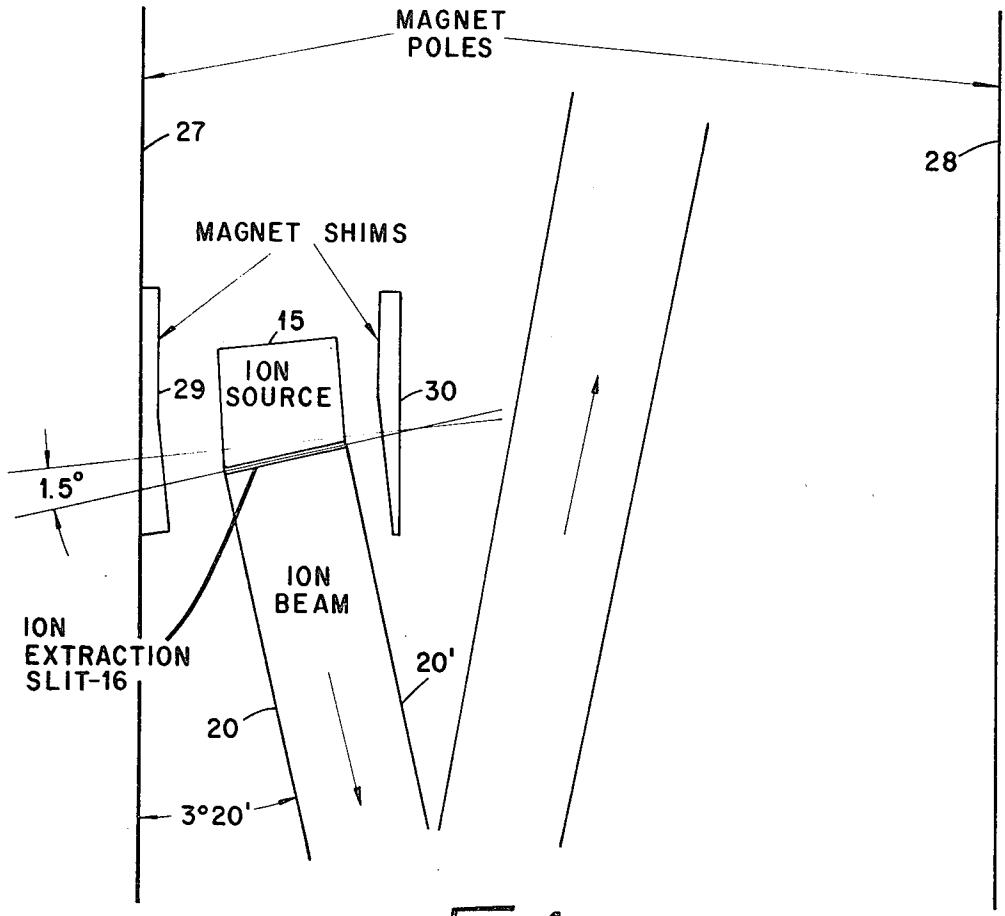


Fig. 4

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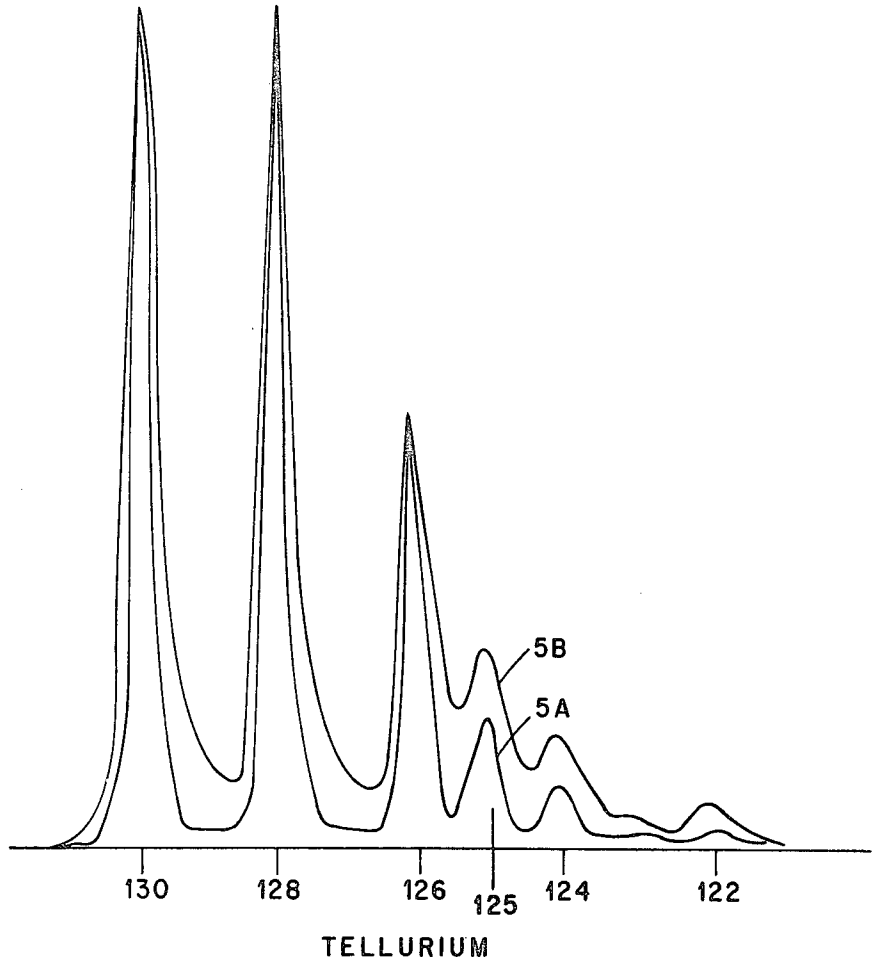


Fig. 5

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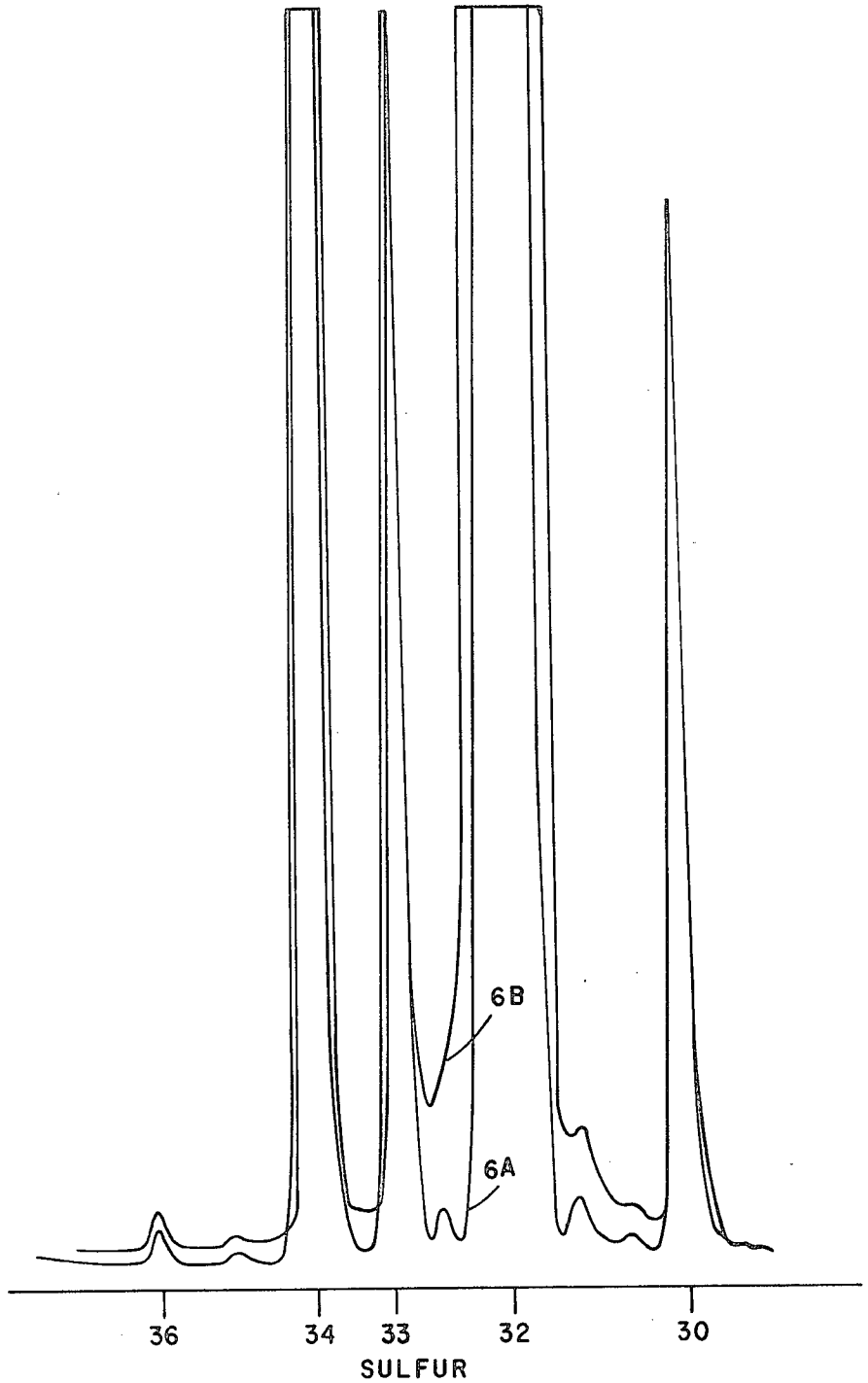


Fig. 6

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# HELICAL THREE-STAGE ISOTOPE SEPARATION

## BACKGROUND OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the United States Atomic Energy Commission.

In any isotope enrichment process, the first two concerns are complete separation of the various elemental nuclides and quantity of product separated. The calutrons now in use are routinely employed to separate isotopes in large quantities. Certain of the separated isotopes are further enriched by another separation cycle, the product of the first separation being used as the feed material for the second-pass separation. In an attempt to achieve a more perfect separation, a sector-type instrument, similar to those used at many separation sites, has recently been constructed.

Other separation sites employ multistage isotope separation instruments. Those devices may utilize a velocity selector (electrostatic separator) as one of the stages to obtain the most complete separation. Such a velocity selector limits throughout so that, in order to get useable quantities of product in addition to high purity, each of the stages is usually provided with its own individual magnet sector and individual magnet supply. Thus, there exists a need for a multistage isotope separation device that can be economically constructed by utilizing only a single magnetic field while at the same time providing a substantial improvement in the purity of the final product. The present invention was conceived to meet this need in a manner to be described hereinbelow.

## SUMMARY OF THE INVENTION

It is the object of the present invention to provide a multistage isotope separation device in which increased purity of product in addition to quantity can be achieved while using only a single magnetic field.

The above object has been accomplished in the present invention by providing a three-stage isotope separator which involves the acceleration of desired ions along a single homogeneous magnetic field as well as across it such that the ion beam from an ion source is allowed to spiral along the magnetic field in a helical path to produce a three-stage separation before arriving at the 540° position. In such an arrangement, the ion source is located off the median plane close to one tank wall and the collector is likewise off center and located close to the other tank wall. The ions pass through an angular rotation of 540° before being collected and undergo separative action each 180° in a manner to be described hereinbelow.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an isometric view of the isotope separation device of the present invention illustrating only partially some of the components thereof;

FIG. **2** is a schematic drawing of the isotope separation system using the device of FIG. **1** and illustrating the principles of the present invention;

FIGS. **3A**, **3B**, and **3C** are respective side views of the system of FIGS. **1** and **2** illustrating the separative action for each 180° thereof;

FIG. **4** is a drawing showing one arrangement of magnet shims for the separator of FIGS. **1** and **2**;

FIG. **5** shows a comparison of the tellurium isotopic spectrum at the 180° and 540° positions achieved in the operation of the system of FIGS. **1** and **2**; and

FIG. **6** shows a comparison of the sulfur isotopic spectrum at the 180° and 540° positions achieved in the operation of the system of FIGS. **1** and **2**.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

In the drawings, FIG. **1** illustrates generally the structural configuration of the three-stage isotope separator of the present invention. Only the ion source **15** and the beam boundary plates **20**, **20'** are shown in FIG. **1** for the sake of clarity. The other components of the complete system are schematically illustrated in FIGS. **2** and **3A**, **B**, **C** of the drawings. An ion beam from the source **15** is allowed to spiral along the magnetic field in a helical path limited by the boundary plates **20**, **20'** to produce a three-stage separation after 540° of rotation, and the desired isotopic ions are collected in a receiver located at the 540° focus in a manner to be described hereinbelow. Although not shown in FIG. **1**, the ion source, ion receiver, beam boundary plates, and other essential components are enclosed in a vacuum tank as described hereinafter.

In such an arrangement, the ion source **15** is located off the median plane close to one tank wall and the isotope receiver or collector **23** at the 540° location is likewise off center and located close to the other tank wall as can be seen in FIG. **2**, as, for example, viewed from the top. The vacuum tank may be formed, for example, by sidewalls **12** and **13** and back and front plates **10** and **11**, with the backplate **10** being provided with a suitable opening **14** for connection to a vacuum pump, not shown, in a conventional manner. The ion source and ion receiver are mounted from demountable front plate **11** in a conventional manner. Magnets **27** and **28** provide the desired magnetic field "B" whose direction is indicated by the arrows in FIG. **2**. It should be understood that the magnets **27** and **28** are conventional adjustable electromagnets and that these magnets do not necessarily have to be used exterior to the vacuum tank but may be mounted on inner tank liner walls, if such is desired.

The device illustrated in FIG. **2** is not drawn to scale in that the pole gap between the magnets **27** and **28** is **24** inches, and the radius of the helix formed by the boundary plates **20**, **20'** is also about 24 inches, for example. The ion source **15** is mechanically positioned in such a manner as to accelerate ions into the field at an angle of 3° 20 min. with respect to one of the magnet poles. To achieve this angle precisely, the source **15** may have its extraction slit **16** and associated components adjustable in position in relation to the magnetic field lines. The angular position of the source exit slit produces the helical path of the ion beam in the magnetic field. The beam progression along the magnetic field from ion source to ion receiver is 13½ inches.

Another manner in which the ions from the source **15** can be accelerated into the magnetic field at a desired angle is to provide magnet shims **29**, **30** of a shape such as illustrated in FIG. **4** and this would allow the beam to remain at about 3° 20 min. from a perpendicular to the magnetic field for the necessary establishment of the helix. The shims, however, would alter the magnetic field at the ion extraction slit of the ion source such that the slit may be slightly canted with respect to the field, if desired, in the vicinity of the shims at an angle of about 1.5° in the same manner as disclosed in the application of William A. Bell, Jr., et al., Ser. No. 885,790, filed Dec. 17, 1969, and having a common assignee with the present application. The canting of the ion extraction slit in this manner provides for a more efficient ion production and extraction from the ion source. The angles shown in FIG. **4** are exaggerated for the sake of clarity.

Referring now to FIGS. **2** and **3A**, a baffle **17** is positioned at the 45° rotational position of the system in the path of the ion beam and this baffle is provided with a suitable opening which restricts the beam to the desired beam width in both a radial and axial direction. A similar baffle **7** may be provided at the 90° position of the separator for the same purpose. Probes, not shown, on baffle **17** are connected to respective meters **1** and **2** as shown in FIG. **3A** and are used as an aid in beam positioning. In some operations of the separator it may be desired or preferred to eliminate the baffle **17** at the 45° position, and, in this case, the probes connected to the meters **1** and **2** would be mounted on the baffle **7** at the 90° position.

At the 180° position of the separator there is provided a conventional-type isotope receiver **22** provided with an adjustable receiver plate or baffle **18** and a plurality of isotope

collection pockets, only one such pocket **26** being shown in FIGS. 3A and 3B, for the sake of clarity. These pockets **26** are utilized for beam location, isotope collection, and mass scanning. A meter **3** is connected to the receiver **26** as an aid in beam location. These pockets are also used for monitoring the separative process with an oscilloscope, not shown, to minimize source-induced oscillations and r. f. picked up by the beam during the first 180° of rotation.

During a typical separation, all isotopic beams except the desired one are collected in these receiver pockets at the 180° position as in standard separators. The most desired isotope is allowed to pass freely through a slit (e.g., 3/16×2 inch) in an adjustable receiver plate **18** and continue to the 360° position as shown in FIG. 3B. At this point, the desired ions pass through another adjustable receiver plate **19** provided with a slit (e.g., 3/16 by 2 inch). Probes, not shown, are attached both above and below the slit in plate **19** and are connected to respective meters **4** and **5** to permit accurate location of this slit relative to the desired beam which passes freely through this slit. The position of this slit can be moved in both an axial and radial direction relative to the beam trajectory.

After the beam enters the last 180° of travel (360°–540°) it is subjected to a third mass separative action prior to being received at the 540° position in a collector pocket of an isotope receiver **23** as shown in FIG. 3C. This pocket is located behind a defining slot (e.g., 3/16×2 inch) in the receiver plate **21** of the receiver **23**. The receiver **23** is adjustable in three directions (side-tilt, in-and-out, and up-and-down) and provides essentially limitless choice of pocket position. A meter **6** is connected to the receiver **23** as an aid in positioning the slotted receiver plate **21** with respect to the incoming isotope beam.

It should be understood that the necessary charge vapor for the ion source **15** of the present invention is supplied to the ion source in a conventional manner. One means for heating the charge material for use in the ion source is disclosed in U.S. Pat. No. 3,115,575, to W. A. Bell et al., to which reference is made. The strength of the magnetic field provided by the magnets **27** and **28** of FIG. **2** is maintained at a selected value in the range from 100–3,000 gauss depending upon the atomic mass of the isotopes to be utilized in the operation thereof. It should be understood that even higher magnetic field strengths may be utilized if necessary or desired. The pressure which is maintained in the vacuum tank during the operation of the device of FIG. **2** is of the order of $10^{-5}$ to $10^{-6}$ Torr, for example. The accelerating electrode **24** and decelerating electrode **25** associated with the ion source **15** of FIG. 3A provide for the net acceleration of the ions therefrom up to about 40 kv. The exact value is also dependent upon the particular isotopic separation.

In any separator, the relationship of peak ion current to the minimum ion current appearing between adjacent peaks (peak-to-valley ratios) at any focal point (180°, 360°, 540°) is indicative of the effectiveness of the separation process. Any extraneous ion of another isotopic species, which has been scattered and/or altered in energy, may deviate in trajectory so that it will enter the pocket provided for the collection of a desired isotope and become a contaminant. Many such contaminants are stripped off by succeeding stages. This continuous energy spectrum of all isotope species (whether it is due to variation in energy from the source, variation in energy and radius from scattering, or to very low energy ions from the background gas formed by the primary beam) appears at the 180° position as background current. Graphs of ion beam intensities comprised of isotopes of tellurium and sulfur are illustrated in FIGS. **5** and **6**, respectively, to show the relative change in the spectrum and background at the normal 180° position and at the 540° position.

In FIG. **5**, curve **5**-A shows the tellurium spectrum at the 540° position and curve **5**-B shows the tellurium spectrum at the 180° position. It may be seen how the background level of extraneous energetic and thermal ions was reduced in the 540° position. The best prior $^{125}Te$ assay from a collection in a conventional 48-inch radius, 180° separator was 95 percent. The 540° separator of the present invention, which has only a 24-inch beam radius, has yielded three samples to date with assays of 98.1, 98.4, and 98.95 percent.

In FIG. **6**, curve **6**-B shows a sulfur spectrum made at the 180° position and curve **6**-A shows one made at the 540° position. The $^{33}S$ peak was allowed to go full scale in both positions so the spectral beam quality could be observed for this isotope. The spectral beam quality at the 540° position (curve **6**-A) is clearly superior to the beam quality at the 180° position (curve **6**-B).

It should be noted and understood that the curves of FIGS. **5** and **6** were obtained for both positions (180° and 540°) by varying and selectively adjusting the ion source voltage to different values such that the complete spectrum could be obtained at each position. This was done simply to demonstrate that the background level of extraneous energetic and thermal ions was reduced and the spectral beam quality was improved at the 540° position as compared to the 180° position for all isotope species. In the actual operation of the above-described 540° separator device, the ion source voltage is maintained at a substantially fixed desired voltage and the positions of the various baffles or defining slots at the 45° and/or 90°, 180°, 360°, and 540° positions are properly oriented such that only a desired isotopic species is received at the collector **23** at the 540° position while all other isotopic species are collected in the receiver **22** at the 180° position.

Some of the advantages achieved in the operation of the present invention in the electromagnetic separation of nuclides are as follows:

1. Eliminating the contaminating effects of variation in beam position normally introduced by variation in beam potential. In contrast with single-stage separation, the present system provides for three degrees of isolation (0°–180°, 180°–360°, 360°–540°).
2. Screening out in the additional stages scattered ions not having a mass-energy product equaling that of the desired ions.
3. Screening out high energy contaminating neutrals formed in charge-exchange processes occurring near the entrance to the collector.
4. Screening out the contaminants resulting from the low energy continuous spectrum background normally encountered at the receiver.
5. Screening out extraneous ions appearing at the 180° collector slot or slots prior to beam neutralization.
6. Removal of cycloiding low energy ions present in non-neutralized regions near the receiver.
7. Scattering and collision phenomena in the 180°–540° region do not introduce contamination; they only reduce total beam transmission.
8. Output capabilities of the present invention exceed those for sector-type devices because of the present calutron-like configuration and the total beam containment within a strong magnetic field which requires only one magnet and magnetic exciter-control system.
9. Electrical isolation of the beam into three segments by the various baffles and slits decouples source-induced instabilities and retards the growth of beam-induced instabilities.
10. And, finally, an entirely new technique of diagnosis of separator problems is provided by the availability of both mechanical and voltage scans at three locations.

It should be noted that a basic limitation in all prior electromagnetic separation devices not equipped with velocity filters is that ions from the source, or ions in the beams undergoing collision in the analyzing segment and acquiring a mass energy product equal to that of the desired ions, reach the isotope collector. Since the defining slots must have a finite size, there is a mass-energy band which is ultimately received. However, the three stages provided in the 540° separator of the present invention reduce the size of the finally received mass-energy spectrum to a very narrow value approaching

exact matching with the desired beam. Therefore, the isotope separator of the present invention provides an improved system wherein the purity of the desired ions collected at the 540° position thereof is substantially improved over that achievable in the prior art separators, and such a system will be most useful in producing such high purity separated material where large (calutron) quantities of such separated materials are not required. To obtain the same purity of the desired separated material in a conventional prior art calutron that is achievable in the present invention with a single separation pass (0°–540°), it would be necessary to provide for the reprocessing of separated materials for additional separation runs when the prior art devices are utilized. The present invention has been practiced in a standard calutron tank and produced of the order of 1/10 the separated quantity as a 180° calutron.

It should be understood that charge-exchange type isotope receivers, such as described in U.S. Pat No. 3,312,849, issued Apr. 4, 1967, to W. A. Bell, Jr., et al., may be used, if desired, at the 540° position in the present invention to reduce the degree of neutral-particle contamination, and thus increase the purity of the collected desired isotope material even further.

It should further be understood that the present invention as described hereinabove is not limited to the separation of the isotopes of tellurium and sulfur, but may equally be adaptable to provide for the separation of most other materials. In addition, the above-described isotope separator is not necessarily limited to the specific dimensions set forth hereinabove. For example, the magnet gap could be made larger, if desired, to allow an ion beam larger in axial length, and the ion source may be constructed so as to be mostly away from the beam path such that only the accelerating section thereof would need to be on the helix perimeter.

The present invention has been described by way of illustration rather than limitation and it should be apparent that it is equally applicable in fields other than those described. For example, the invention could be used in the field of mass spectrometry.

What is claimed is:

1. An improved electromagnetic isotope separator of the type including an evacuated tank, means for providing parallel magnetic field lines passing through said tank, an ion source within said tank and provided with an extraction slit for producing and accelerating ions across said magnetic field lines, and an ion receiver within said tank for accepting beams of separated isotopes, the improvement which comprises: first ion orienting means associated with said ion source for injecting ions from said ion source across the magnetic field lines at a slight angle from the perpendicular thereto so as to cause the ions to follow a spiral path along said magnetic field lines and form a helical ion beam, slotted baffle means positioned along and in the path of said helical ion beam to eliminate most of any undesired components of said ion beam, second ion orienting means associated with said ion receiver to permit collection of a desired isotopic ion beam after 540° rotation along said spiral path from its origin at said ion source, and a pair of spaced-apart boundary plates mounted between said ion source and said receiver and positioned in such a manner that said desired ions spiral in a helical path between said boundary plates from said ion source to said receiver, said slotted baffle means including a first adjustable baffle plate provided with an elongated slit and positioned between said boundary plates at the 45° position from said ion source for restricting the ion beam from said source to a desired beam width, a second adjustable baffle plate provided with an elongated slit and positioned between said boundary plates at the 180° position from said ion source for permitting a desired isotopic ion beam to pass freely through the slit thereof, a third adjustable baffle plate provided with an elongated slit and positioned between said boundary plates at the 360° position from said ion source such that said desired isotopic beam passes freely through said slit of said third baffle plate, and a plurality of isotope receiver pockets mounted on said second adjustable baffle plate at the 180° position, said second baffle plate being further provided with receiver slits for each of said plurality of receiver pockets and said second ion orienting means comprising an adjustable receiver plate which is provided with an elongated slit through which said desired isotopic beam is adapted to pass and be collected by said ion receiver, whereby all isotopic beams except said desired isotopic ion beam are collected in said plurality of receiver pockets at the 180° position, and said desired isotopic ion beam collected in a 540° ion receiver has substantially improved purity.

2. The separator set forth in claim 1, wherein said first ion orienting means is adapted to be mechanically positioned to provide for said slight angle.

3. The separator set forth in claim 1, wherein said first ion orienting means comprises a pair of magnet shims which are mounted on opposite sides of the extraction slit of said ion source to provide for said slight angle.

4. The separator set forth in claim 3, wherein said ion source extraction slit is canted at an angle of about 1.5° with respect to the direction of the magnetic field provided by said magnet shims.

5. The separator set forth in claim 1, wherein said magnetic field is of a selected value in the range from 100 to 3,000 gauss, and said tank is evacuated to a pressure of a selected value in the range from $10^{-5}$ to $10^{-6}$ Torr.

6. The separator set forth in claim 5, wherein said slight angle is about 3° 20 min.

7. The separator set forth in claim 6, wherein said first ion orienting means comprises a pair of magnet shims which are mounted on opposite sides of the extraction slit of said ion source to provide for said slight angle.

8. The separator set forth in claim 7, wherein said ion source extraction slit is canted at an angle of about 1.5° with respect to the direction of the magnetic field provided by said magnet shims.

9. The separator set forth in claim 8, and further including a pair of separator probes connected to separate meters in the vicinity of each of said 45° and 360° baffle plates and a separate meter connected to a receiver pocket at each of said 180° and 540° positions, said meters functioning as an aid in the proper positioning of said baffle plates and said receiver plate with respect to the path of said desired isotopic beam.

* * * * *

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,649,827 Dated March 14, 1972

Inventor(s) William A. Bell, Jr. et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 22, for "throughout" read ---throughput---

Column 6, line 53 for "separator" read ---separate---

Signed and sealed this 22nd day of August 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

ORM PO-1050 (10-69)

USCOMM-DC 60376-P69
* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334