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MASS SPECTROMETER

2,908,816

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2 Sheets-Sheet 1

FIG.1

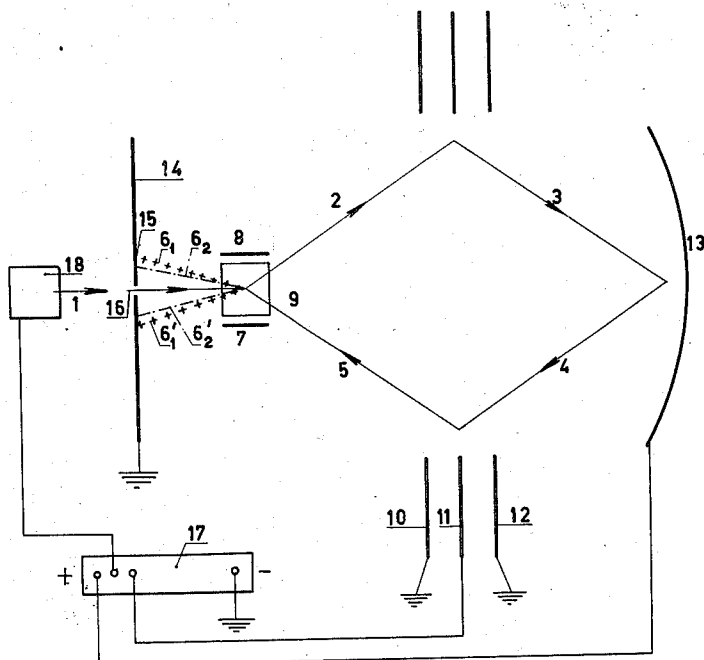
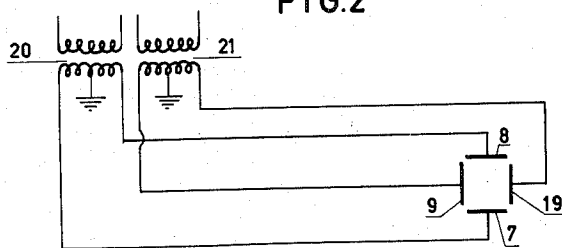


FIG.2



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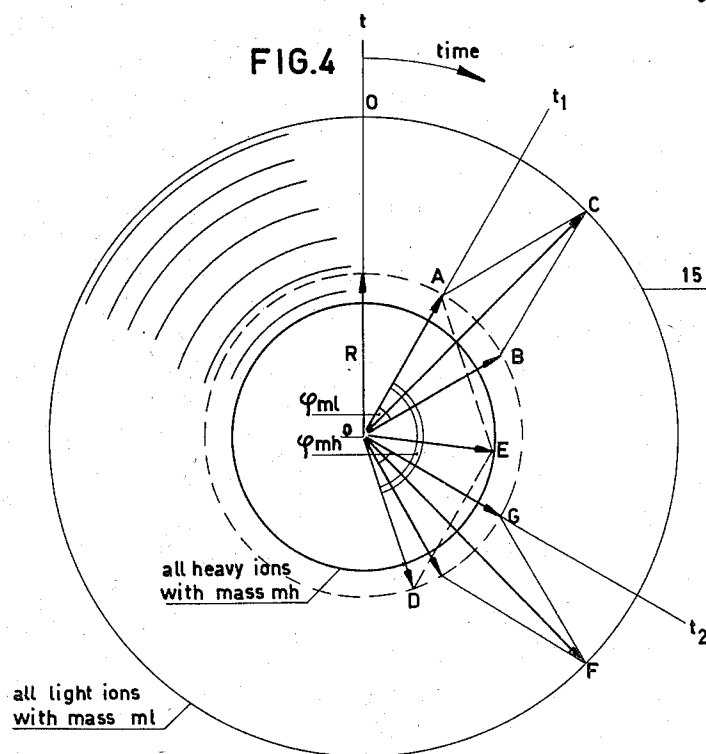
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FIG. 3

The diagram illustrates an optical system. Light from a source (1) passes through a lens (18) and a plate (14) with a central aperture (15). The light then passes through a series of lenses (2, 2', 3, 3', 4, 4') and a final lens (13). The system is labeled with various components and their positions.



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MASS SPECTROMETER

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1 Claim. (Cl. 250—41.9)

The invention relates to a mass spectrometer.

It is known to separate atoms varying in mass by using the deflection in a magnetic field, the curvature radius of the path of a charged particle being proportional to the square root of the mass. The drawback of this method is that very strong magnets must be used in order to obtain a proper separation, requiring obviously much excitation energy. If, for instance, an acceleration voltage of 25 kv. is chosen, the deflection radius for hydrogen nuclei at a field intensity of 5000 oersted is about 4 cm. Then the deflection radius for heavy particles with a molecular weight of 200 amounts to 60 cm., which of course is not sufficiently small. Even at a field intensity of 15000 oersted the deflection radius has a value of 20 cm. Another drawback of the usual method is that it is practically impossible to vary the acceleration voltage by a factor of 200, which is necessary for covering the whole scale.

The object of the present invention is to overcome these disadvantages and the invention relates to a mass spectrometer in which the particles are deflected by means of electric fields.

Since the action of electric fields on the particles passing through them is independent of the mass, an artifice must be applied to allow their use for mass separation. This artifice is based upon the fact that particles varying in mass have a different transit time. This method has been used by Perry and Chaffee for determining the mass of electrons. According to this method the electrons emitted by an electron source are accelerated and then pass through the space between the plates of a condenser fed with an alternating voltage. Another condenser, connected in parallel with the first one, is positioned at a certain distance therefrom in such a way that the electrons which have not been deflected in the first condenser pass between the plates of the second one and strike a screen. To this end it is necessary that the distance between the condensers divided by the velocity of the electrons is equal to half the period of oscillation of the alternating voltage multiplied by an integer. By adjusting the frequency or the acceleration voltage it is possible to reach this condition and to determine the mass of the electrons, since the velocity of the electrons is dependent thereon. This method has been used by Smythe and Mattauach for the separation of ions (Physical Review, 28, 1275, 1926, and Physikalische Zeitschrift, 33, 899, 1932). The method has, however, some drawbacks, since on the one hand the beam is periodically interrupted and on the other hand the separating power is not sufficiently high. An increase in the separating power is at the cost of the intensity.

In the mass spectrometer according to this invention a beam of ions generated in a known way is sent through an electric deflection system in which a rotary electric field deflecting said ion beam is generated, after which this beam is reflected by an electro-static reflection system which is arranged at a certain distance from the deflection system and is again focussed in the electric deflection

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system, thereby giving the beam of ions a second deflection, which beam subsequently strikes a screen.

An embodiment of a mass spectrometer according to the invention is hereinafter described, by way of example, with reference to the accompanying drawings with Figures 1, 2, 3 and 4.

In the drawings:

Figure 1 shows a diagram of the arrangement as described above.

Figure 2 shows a diagram of the condenser plates 7, 8 and 9, 19 which are connected with the transformers 20 and 21, respectively.

Figure 3 shows a diagram of a part of Figure 1 in perspective.

Figure 4 is a diagram with the aid of which the segregation will be explained.

In Figures 1, 2, 3 and 4 the same reference numerals are used to indicate like parts of the spectrometer.

Reference numeral 18 designates a source of positive ions of any conventional type such as is well known to the mass spectrometer art, wherein a suitable charge is vaporized by heating, and the vapors therefrom are fed to an ionizing chamber provided with an exit orifice. In this chamber they are subjected to electron bombardment and are ionized by a stream of electrons emitted from a cathode and directed across the chamber. The ion source is maintained at a suitable potential from a direct current source, indicated at 17. The ion beam 1 passes through a narrow opening 16 in a grounded screen 14 and subsequently through the deflection system 7, 8, 9, 19 in which a rotary electric field is generated. This system consists of two pairs of deflection electrodes, one pair being schematically indicated by condenser plates 7 and 8, the other by condenser plates 9, 19. Although for the sake of clearness the deflection system is represented as a system of flat plates, in reality it is desirable to give the electrodes such a shape that the field in the area used is homogeneous or substantially homogeneous. The plates 7, 8 and 9, 19 are connected to the transformers 20 and 21 respectively. These transformers are fed by alternating current sources of any suitable type so that they deliver voltages to plates 7, 8 and 9, 19 which are 90° out of phase with each other. The plates 9, 19 lie in spaced vertical planes while plates 7, 8 lie in spaced horizontal planes. A rotary electric field is formed in the space circumscribed by this deflection system, as a result of which ion beam 1 is deflected along line 2. Due to the rotation of the field, the deflected beam is not stationary but carries out in the space such a movement, that it describes a conical surface. The frequency of this movement is obviously the frequency of the rotary field. The deflected beam 2 subsequently enters the electric field of an electrostatic reflecting system which comprises an electrostatic lens 10, 11, 12, of which the electrodes 10, 12 are grounded and the electrode 11 is given a positive potential and a rotationally symmetric mirror 13 positioned behind this lens, said mirror also having a positive potential. Ion beam 2 is deflected in the electro-static lens according to line 3, enters the field of mirror 13 and is reflected by said mirror as shown by line 4. On passing the lens for the second time the reflected beam 4 is deflected along line 5 and focussed in the deflection system 7, 8, 9 where it is deflected along the line 6. The ion beam subsequently strikes the screen 14 at 15.

As said before the ion beam 1 emerges from a narrow opening 16 in the screen 14 and passes through a rotating electric field of constant amplitude. In this rotating field all ions are deflected, in a direction which is perpendicular to the axis of the system.

If we locate a fixed rectangular system of coordinates in a plane perpendicular to the axis of the deflecting field on which plane the particles impinge, the deflection of

any of the particles irrespective of their mass can be represented by:

$$x = A \cos \omega t$$

$$y = A \sin \omega t$$

where A is a constant, ω is the frequency of the rotating field, t the time. These expressions are exact when the transit time of the particles through the deflecting field is very short as compared with the period of rotation. If this is not the case the only difference is that the deflections are slightly dependent on the mass of the particles. After leaving the deflector system the particles are focussed by the lens, reflected by the mirror and then by the lens focussed in the deflection system. As the deflection is perpendicular to the axis of the field the velocity in the direction of the axis is not modified and the time interval between leaving the deflection system and reentering this system depends on the axial velocity of the ions. As all of the ions have the same energy, due to the applied accelerating field, so that the heavy ions have a lower velocity than the light ones, this time interval is different for ions of different mass. Therefore a heavy ion will reenter the deflection system later than a light ion which left the deflection system at the same time. The direction of the rotating field will therefore not be the same for both reentering ions and as a consequence thereof their second deflection will be different. If we assume that the above-mentioned time interval corresponds with a phase variation of ψ_m (the index referring to the mass of the ion) the coordinates of the particle when impinging on a screen perpendicular to the axis of the electric field may be represented as follows:

$$x = A[\cos \omega t + \cos(\omega t + \psi_m)]$$

$$y = A[\sin \omega t + \sin(\omega t + \psi_m)]$$

so that the locus of the particles with mass m on the screen is given by

$$x^2 + y^2 = 2A^2(1 + \cos \psi_m)$$

where each mass has its own locus.

This locus is a circle with radius

$$A\sqrt{2(1 + \cos \psi_m)} = 2A \cos \frac{\psi_m}{2}$$

So the radii of the loci are different for different masses of the ions and any particles having the same mass will impinge on a circle having a radius which is specific for its mass.

In this way the segregation of the particles with the same mass is obtained.

This will be further illustrated with the aid of the Figures 3 and 4.

The rotary field of the deflection system 7, 8, 9, 19 gives the same magnitude of deflection to any of the particles with the same energy irrespective of their mass when they pass through this system for the first time. So if a continuous stream of particles with the same energy coming from the ion source passes through the field this beam of particles will be deflected, and since the deflection system has a rotary field, the beam will describe a conical surface.

The beam describes one conical surface during one period of rotation of the rotary field.

The time of entering of the beam (originating from the ion source) into the deflection system determines the place of the beam on this conical surface.

In Fig. 3 it is shown that the ion beam 1 arriving at the rotary field 7, 8, 9, 19 at the time t_1 will be deflected along the line 2.

This beam deflected along line 2 enters an electrostatic lens 10, 11, 12. The electro-static lens breaks this deflected beam from along line 2 to along line 3. This beam broken along line 3 is reflected by the field of a mirror 13 to a beam along line 4. On passing the lens 10, 11, 12 for the second time this beam reflected along

line 4 is broken along line 5 and focussed in the electric rotary field of the deflection system 7, 8, 9, 19 where this beam is deflected for the second time. On the other hand the ion beam 1 arriving at the rotary field 7, 8, 9, 19 at the time t_2 will be deflected along line 2' and for the first time broken by the lens 10, 11, 12 along line 3' reflected by the mirror 13 along line 4' and for the second time broken by the lens 10, 11, 12 along line 5' and focussed in the electric rotary field of the deflection system 7, 8, 9, 19 and deflected for the second time in this deflection system.

It is obvious that ions of any mass will be present in these beams.

On the other hand the particles, the heavy ones and the light ones having the same energy have different velocities.

This follows from the formula:

$$E = \frac{1}{2} m V^2 = \text{constant}$$

So the light ions in a beam need less time for covering the distance from the rotary field through the lens to the mirror and back through the lens to the rotary field than the heavy ones.

By passing the rotary field for the second time the field vector has turned over an angle. The value of this angle is dependent on the time for covering said distance, so this angle is small for light particles and large for heavy particles. This is shown in Figure 4.

We assume that the field vector, which is perpendicular to the axis of the deflection field, has the magnitude R .

The particles, the heavy and the light ones, coming from the ion source and arriving at the deflection field at the moment t_1 will be deflected by this field vector in the direction OA.

After covering the distance to the mirror and back to the deflection system the field vector in this system has turned more for heavy particles than for light particles.

So, for a light particle with e.g. the mass (m_l) the field vector has turned over the angle ϕm_l in the direction OB and for a heavy particle with e.g. the mass (m_h) the field vector has turned over the angle ϕm_h in the direction OD.

So the particle with the mass m_l arriving at the deflection system for the first time at the time t_1 will be deflected first in the direction OA and next when passing through the deflection system for the second time in the direction OC because of the composition OC of the two vectors OA and OB.

When a light particle with the same mass m_l arrives at the deflection system at the moment t_2 it will be deflected first in the direction OG and next when passing through the deflection system for the second time in the direction OF.

When on the other hand a particle with e.g. a mass m_h arrives at the deflection system at the time t_1 , coming from the ion source it will also be deflected in the direction OA; next, when passing through the deflection system for the second time it will be deflected in the direction OE, because of the composition OE of the two vectors OA and OD.

For a quick survey of the various ion masses in the beam it is sufficient to use a fluorescent screen which then shows as many illuminated rings as there are different ions in the beams. It is a question of commonly known technique to provide means to measure—if desired—the current transported by the ions of a predetermined mass. For instance, it is possible to use as a screen a surface which the electric charges applied to it by the ions (screen of the same character as the well known iconoscope) and scanning the area representing the locus of the ions of said predetermined mass with an electron beam.

Further the screen can be designed as a series of concentric mutually isolated or separately earthed metal rings

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each coinciding with the locus of the ions with a predetermined mass.

It is of course possible to contrive other embodiments according to the invention. Thus it is possible to use for example a flat mirror. Then the lens should be such that the ion beam, after having passed through it, is directed perpendicularly to the mirror. It is also possible to use two deflection systems instead of one, the ion beam deflected in the first deflection system being focussed in the second deflection system by the electrostatic reflection system and subsequently striking a screen positioned behind the second deflection system.

I claim:

A mass spectrometer comprising an ion source for producing an ion beam, means to generate a transverse rotating electro-static field, an ion collecting screen, positioned perpendicularly to the ion beam emitted from the ion source and provided with an orifice, so as to allow

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the passage of said beam through said orifice into said field, an electro-static lens positioned beyond said field generating means, an electro-static mirror positioned beyond said lens, the screen, the field generating means, the lens and the mirror being aligned so as to constitute a system symmetric with respect to an axis defined by the ion beam emerging from the ion generating means, the position of the mirror being such that the ions are reflected thereby to be deflected for a second time by the lens and by the electro-static field, so as to fall on said screen at a distance from the axis variable with the ion mass.

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