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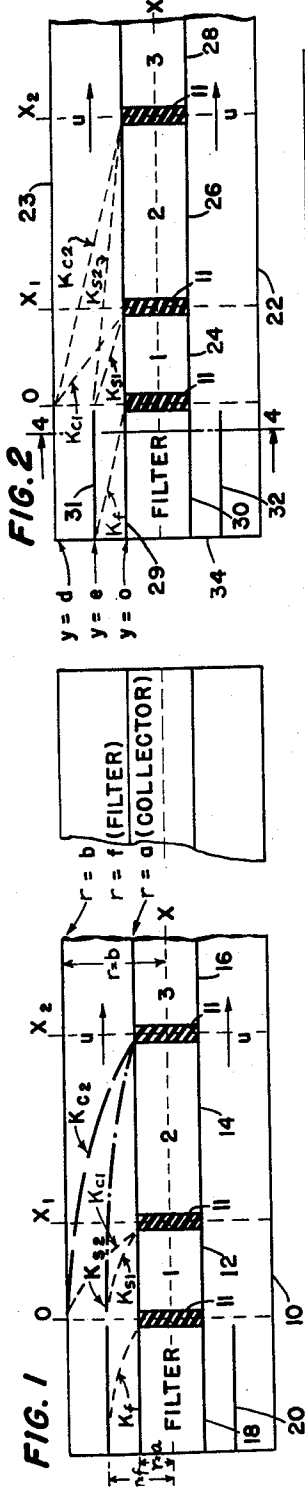
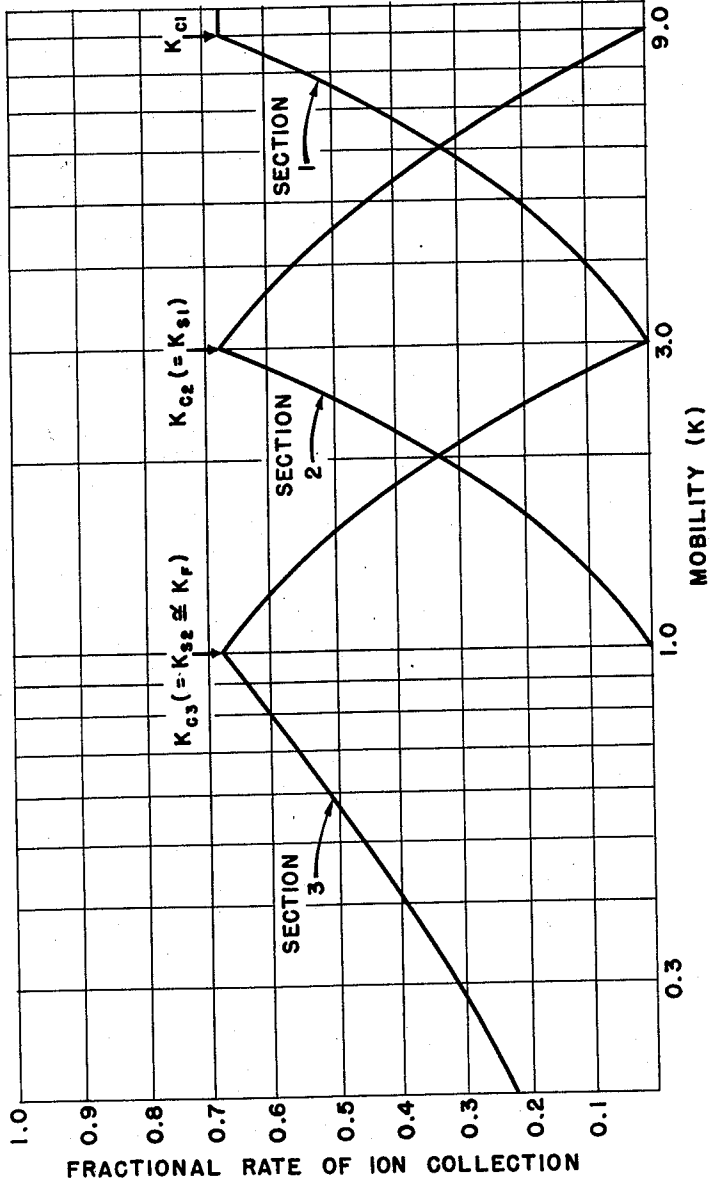
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OPTIMIZING SENSITIVITY AND RESOLUTION OF ION CHAMBER

Filed Jan. 30, 1957

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

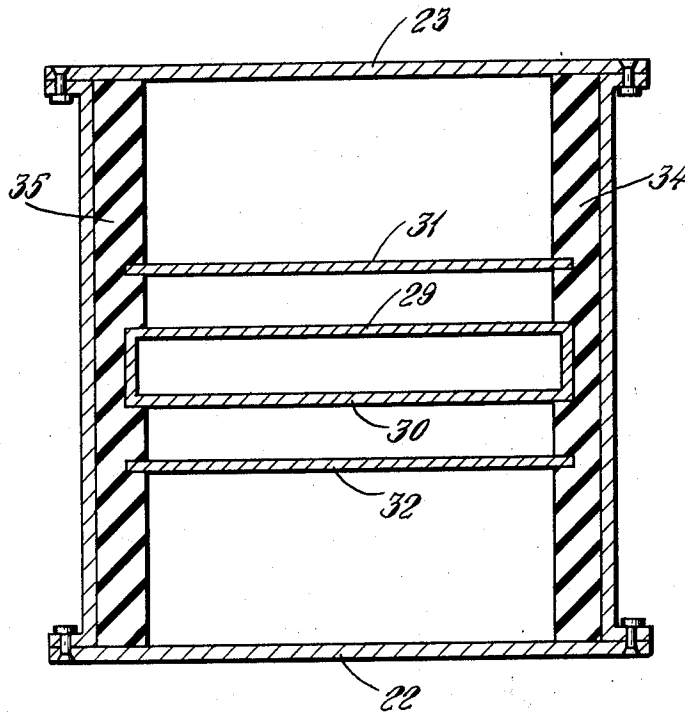


Fig. 4

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3 Sheets-Sheet 3

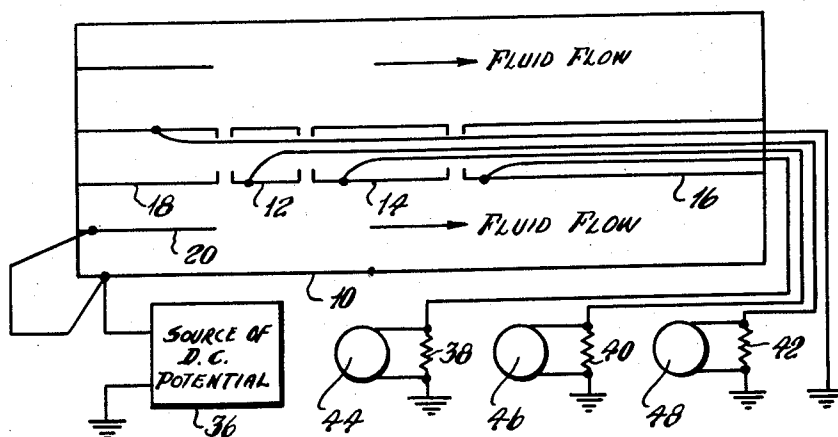


Fig. 5

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OPTIMIZING SENSITIVITY AND RESOLUTION
OF ION CHAMBER

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The present invention relates to optimizing the sensitivity and resolution of an ion chamber and more particularly to an optimizing of the sensitivity and resolution of an ion chamber accomplished by filtering a fraction of the incoming air.

Any region of the atmosphere may be described in terms of its ion content. The term "ion" as used in this specification refers to particles in the atmosphere having an electric charge. One characteristic useful in classifying ions is their distribution among various ranges of mobility. By "mobility" is meant the velocity ions in the atmosphere will attain when acted upon by electrical forces, i.e., in an electrical field of unit strength (1 volt/centimeter), a unit velocity (1 centimeter/second) will be attained by an ion of unit mobility.

If air is caused to flow smoothly between parallel plates one of which is at a given potential and the other is at ground potential, the electric field so set up will tend to sweep charged particles toward one plate or the other depending upon the sign of the charge carried by the particles. The mobility range of ions which reach the plates will depend upon the potential difference, the speed of movement of air parallel to the plates, and the length of the plates.

It is possible to collect the ions from several different mobility regions, each sampling being of a relatively narrow range of mobilities, by constructing an ion chamber having a number of plates. Since the lengths of the plates determine the mobility ranges detected by each plate, all other factors being equal, it is apparent that as the range of mobility detected by each plate is decreased, the number of ions collected per unit of time within each range becomes fewer and the current which flows as a result of these ions becomes smaller. Since ions of low mobility which enter the chamber close to the center will be attracted to the same plate as ions of greater mobility which enter farther away, the current due to these undesired ions tends to mask the current of the desired mobility range ions, thus decreasing the sensitivity of the ion chamber. To avoid this effect, it is necessary to filter the ions from the air which enters close to the plates, but such filtering also reduces the total number of ions in the desired mobility range in proportion to the area filtered.

Since it is desirable to construct an ion chamber having the maximum resolution allowed by the current sensitivity of the detectors, the filter must be constructed so as to filter a sufficient proportion of the incoming air to remove the undesired ions and allow realization of the resolution for which the ion chamber is designed, without reducing the number of ions of the desired mobility range to the point where they are no longer measurable.

An object of this invention is to optimize the sensitivity and resolution of an ion chamber which is utilized to classify the mobility of ions in the atmosphere.

Another object is to increase the resolution of an ion

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chamber by filtering ions from a predetermined portion of the sample being measured.

A further object of the invention is to increase the resolution of an ion chamber by filtering ions from a proportion of the sample equal to the reciprocal of the resolution factor.

A final object of the present invention is to achieve the optimum compromise between resolution and sensitivity of an ion chamber by filtering a predetermined fraction of the incoming air.

The exact nature of the invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification relating to the annexed drawing.

Fig. 1 shows a fragmented schematic cross-section of a coaxial ion chamber embodying the invention.

Fig. 2 shows a partial schematic cross-section of parallel-plate ion chamber embodying the invention.

Fig. 3 is a graph of single chamber mobility resolution.

Fig. 4 shows a cross-sectional side view of the ion chamber taken through Fig. 2 near the input end of the ion chamber.

Fig. 5 is a schematic diagram illustrating one method of connecting the filter and collecting section segments to the source of D.C. potential and ground.

In a multiple-sectioned ion chamber the factor of resolution, or ratio of the mobility ranges to be detected by the several sections, is determined by the relative lengths of the sections. For a chamber in which each section covers a mobility range of a factor of three, the total length of the chamber to the end of each section must have the relation $x_1 : x_2 : x_3 \dots x_n = 3^0 : 3^1 : 3^2 \dots 3^{n-1}$. Since the lengths of the previous plates must be subtracted from the total to determine the length of each collector plate, the lengths of the individual collector plates for a factor-of-three resolution is 1, 2, 6, 18, 54 etc. While a resolution factor of three is used here as an example, ion chambers embodying the present invention may be constructed having any other resolution factor.

Ion chambers are usually constructed in one of two configurations having plates in the shape of cylinders and mounted coaxially, or having flat plates mounted in parallel relation to each other. Fig. 1 shows in schematic form an elevational cross-section of a coaxial type of ion chamber, the cross-section being taken through the longitudinal axis (x). An outer cylinder 10 concentrically surrounds an inner cylinder which is composed of spaced hollow cylindrical segments 12, 14 and 16 separated by electrical insulating material 11. The space between the inner and outer cylinders permits air to pass completely through the ion chamber.

A suitable D.C. potential difference establishes an electric field in this collection space (between inner and outer cylinders) which is constant along the direction of flow of air and which permits the collection of the desired ions on the separate inner segments and the monitoring of the corresponding separate electric currents from these collecting segments. Application of such a potential difference can, for example, be accomplished (see Fig. 5) by connecting the outer electrode 10 to a source of D.C. potential 36 of the desired value, connecting the other terminal of this source to ground potential, and connecting each collecting segment (12, 14, and 16) separately through an appropriate electrical resistance (38, 40, 42) to ground potential, a separate voltmeter (44, 46, 48) being employed to determine the voltage resulting from ion flow through each resistance. The segments 12, 14, 16 and 18 are also known as electrodes, collecting electrodes, or collecting plates and the outer cylinder 10 can be called the reference electrode.

In accordance with the present invention, an additional

segment 18 is added to the inner cylinder at the input side of the ion chamber and is concentrically surrounded by a cylindrical reference electrode 20. This additional segment 18 and its associated concentric cylinder 20 constitute what will be herein referred to as an ion filter. The dimensions of the filter and collector electrodes are determinable from formulae hereinafter provided. Electrode 20 is connected to the source of D.C. potential 36, the inner segment 18 of the filter being grounded. As may be noted, an electric field exists in the space between electrodes 18 and 20 but not between electrodes 10 and 20 which are both at the same D.C. potentials.

Figs. 2 and 4 show elevational and side view cross-sections of the parallel-plate type of ion chamber. Top and bottom electrodes 23 and 22, as well as the inner electrodes 24, 26 and 28 and the filter components 29, 30, 31 and 32 are supported by the side pieces 35 and 34 which are composed of insulating material such as polystyrene. The inner collecting electrodes 24, 26 and 28 and the collecting electrode segment of the filter may be hollow rectangular boxes having flat upper and lower surfaces, as shown, or simply flat rectangular plates. The supply voltage wiring can be fed through the hollow space between the inner electrodes in both types of ion chamber.

The trajectory of an ion in a coaxial chamber may be visualized with the aid of Figure 1. The high mobility ions are collected near $x=0$. All the ions faster than a certain "cutoff mobility," k_c , are collected on the length 0 to x . Ions entering near the upper electrode and having the cutoff mobility for $x=x_2$ would follow the dashed lines in Figures 1 and 2 labelled k_{c2} .

The value of the cutoff mobility, k_c , for a particular length x is given in general by the expression

$$k_c = \frac{\phi}{4\pi C_m V} \quad (1)$$

where

ϕ is the volume rate of airflow (cm.³/sec.),
 C_m is the measured capacity of the total length of collector from 0 to x (cm.). The measured capacity is to include the electric fields in the airflow at the ends of a section. However, it does not include any electric fields inside dielectric material such as insulator supports.

V is the applied potential difference (volts) and k_c is in cm.²/volt sec.

Another mobility is significant when a filter is used, namely, the slowest mobility, k_s , for which any ions are collected. These trajectories are marked k_{s1} and k_{s2} in Figures 1 and 2. The specific expressions are given below for coaxial and for flat plate geometry.

In Figure 1 the trajectory of an ion of mobility k for laminar flow in a coaxial chamber is

$$r_0^2 - r^2 = xk \frac{2V}{U \ln(b/a)} \quad (2)$$

where

$r=r_0$ at $x=0$

U is air velocity along x , and

b and a are radii of outer and inner electrodes, respectively.

The $x=0$ is estimated to be the midpoint of the first insulator; it is actually determined by the effective length corresponding to the measured capacity of the chamber. The cutoff mobility, k_c , is in turn given from either Equation (1) or Equation (2) for any specified x as

$$K_c = \frac{1}{x} \frac{U(b^2 - a^2) \ln(b/a)}{2V} \quad (3)$$

The fraction of the ions of mobility k entering the chamber which is collected on the length 0 to x_2 is:

$$\left. \begin{array}{l} 1.0 \text{ if } k > k_{c2} \\ k/k_{c2} \text{ if } k_{c2} > k \end{array} \right\} \quad (4)$$

without filtering. For a complete filter from $r_0=0$ to $r_0=f$, the length 0 to x_2 picks up no ions slower than k_{s2} given by the expression

$$f^2 - a^2 = x_2 k_{s2} \frac{2V}{U \ln(b/a)} \quad (5)$$

For such a filter the fraction of the ions of mobility k entering the chamber (in front of the filter) which is collected and length 0 to x_2 is

$$\left. \begin{array}{l} 1 - (k_{s2}/k_{c2}) \text{ if } k > k_{c2} \\ (k - k_{s2})/k_{c2} \text{ if } k_{c2} > k > k_{s2} \\ 0 \text{ if } k_{s2} > k \end{array} \right\} \quad (6)$$

For optimum filtering the slowest mobility for which any ions are collected on section 1 should be the same as the cut-off mobility for section 2. That is, the optimum filter, as discussed above, has $k_{s1}=k_{c2}$, $k_{s2}=k_{c3}$, etc. The fractional collection on length 0 to x_2 is with this filter,

$$\left. \begin{array}{l} 0 \text{ if } k > k_{c1} \\ 1 - k/k_{c1} \text{ if } k_{c1} > k > k_{c2} \\ (k - k_{s2})/k_{c2} \text{ if } k_{c2} > k > k_{s2} \\ 0 \text{ if } k_{s2} > k \end{array} \right\} \quad (7)$$

Another important factor to be considered is the length of the filter. Since the length of the filter must be finite, it is impossible to filter all the ions from the air entering the filter portion. For an incomplete filter having a cut-off mobility k_t , ions slower than k_t will get through at a rate of k/k_t . It is found that the optimum length of the filter section is $k_t=k_{c3}=k_{s2}$, for a three section chamber. With a filter of this length the fractional collection rate in the third section is closely

$$\left. \begin{array}{l} 0 \text{ if } k > k_{c2} \\ 1 - k/k_{c2} \text{ if } k_{c2} > k > k_{c3}(k_t) \\ k/k_{c3} \text{ if } k_{c3} > k \end{array} \right\} \quad (8)$$

The fractional collection for the individual sections of collecting electrode is shown graphically in Figure 3, for a three section chamber having a resolution factor of three. The sharpening effect of the filter appears as the difference between section 2 and section 3.

In Figure 2, the trajectory of an ion for laminar flow between flat plates is a straight line since the electric field is assumed to be uniform. The cut-off mobility, k_c , for length x is given by the equation

$$k_c = \frac{1}{x} \frac{Ud^2}{V} \quad (9)$$

for the configuration in which the width of the electrodes is much larger than their separation, d . Equations 4, 6, 7 and 8 apply to the flat plate chamber as well as to the coaxial configuration.

From the above it will be seen that, to provide the maximum effective filtering with the minimum loss in sensitivity, the filter must receive that fraction of the total air entering the chamber which is the reciprocal of the factor of mobility (resolution factor). The filter should also be long enough so that its cutoff mobility is at least equal to that of the last section of the chamber, in order to realize the optimum advantages of the filter. The ion chamber used as an example has a mobility factor of three, and would require that $1/3$ of the incoming air be filtered. Thus, for a three-section coaxial ion chamber having an outer-electrode radius of b and an inner-electrode

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trode radius of a , the radius of the filter electrode (designated f in Fig. 1) should be

$$f = \sqrt{\frac{b^2 - a^2}{3}}$$

Similarly, $\frac{1}{2}$ of the air must be filtered in a chamber having a mobility factor of two, or $\frac{1}{4}$ of the air must be filtered in a chamber with a mobility factor of four. In all cases the filter is placed so as to filter the air that enters adjacent to the collector plates.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A multiple-section ion chamber formed with a passage through which ion-bearing fluid may flow comprising a filter section at the entrance to said passage and a plurality of arranged serially collecting sections, the cumulative lengths of said collecting sections bearing the relationship

$$x_1 : x_2 : x_3 \dots x_n = m^0 : m^1 : m^2 \dots m^{n-1}$$

wherein x represents distance along the length of said collecting sections from the plane of juncture of said filter section and the first collecting section, n represents the number of collecting sections and m represents the resolution factor for the desired ion mobility ranges to be detected by the collecting sections, the area of said filter section comprising a proportion substantially equal to $1/m$ of the total area of the entrance to said passage.

2. The method of classifying a gas as to the mobility of the charged particles contained therein comprising passing the gas at an even rate through a sectional ion-detection chamber, collecting in each section of said chamber only those particles having a mobility equal to the mobility of those collected in the next succeeding section divided by a preselected fixed numerical factor, and filtering the ions from a portion of the entering gas substantially equal to the reciprocal of said factor.

3. The method of classifying a gas as to the mobility of the charged particles suspended therein comprising passing the gas at an even rate through a multiple-sectioned ion chamber wherein the mobility of particles collected in each section is equal to the mobility of those collected in the next succeeding section divided by a preselected fixed numerical factor, and filtering from a portion of the gas before it enters the chamber all particles having a mobility equal to or greater than that of those to be collected, the proportion of gas filtered being substantially equal to the reciprocal of said numerical factor.

4. The method of optimizing the resolution and sensitivity of an ion chamber wherein a gas is passed at an even rate through a plurality of collecting sections having cumulative lengths bearing the relationship

$$x_1 : x_2 : x_3 \dots x_n = m^0 : m^1 : m^2 \dots m^{n-1}$$

x represents distance along the length of said collecting sections from the plane of juncture of said filter section and the first collecting section, n represents the number of collecting sections and m represents the resolution factor for the desired ion mobility ranges to be detected by the collecting sections, and wherein the cutoff mobility of the last section is K_{cn} , comprising filtering from a proportion of said gas equal to $1/m$ all ions having a mobility greater than K_{cn} .

5. An ion chamber for use in classifying a gas as to the mobility of charged particles contained therein comprising a pair of relatively displaced plates of electrically conductive material adapted to be maintained at a fixed electrostatic potential relative to each other, one of said plates being longitudinally divided into a filter segment and a plurality of collecting segments all insulated from

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each other, the lengths of said collecting segments being such that the cumulative lengths of the collecting segments from the end of the filter segment adjacent the collecting segments varies in accordance with the following series $m^0, m^1, m^2, m^3 \dots m^{n-1}$, wherein m represents the resolution factor for the desired ion mobility range to be detected by the collecting segments and n represents the number of collecting segments in the chamber, and a third plate of electrically conductive material having a length substantially equal to that of said filter segment so positioned between said pair of plates adjacent said filter segment that the area of the entrance to said chamber between said filter segment and said third plate is equal to the reciprocal of said resolution factor times the total entrance area.

6. A multiple-section ion-detection chamber formed with a passage through which ion-bearing fluid can flow comprising a filter section and a number of collecting sections electrically insulated from each other and arranged serially along the length of said passage, the cumulative lengths of said collecting sections varying in accordance with the relationship

$$x_1 : x_2 : x_3 \dots x_n = m^0 : m^1 : m^2 \dots m^{n-1}$$

wherein x represents distance along the length of said collecting sections from the plane of juncture of said filter section and the first collecting section, n represents the number of collecting sections and m represents the resolution factor for the desired mobility ranges to be detected by the collecting sections, the open area of said filter section transverse to the distance x being substantially equal to $1/m$ of the total transverse open area at the entrance to said passage, and the length of said filter section being sufficient to provide said filter section with a cutoff mobility characteristic at least equal to that of the last collecting section along said passage.

7. A multiple-section ion-detecting chamber formed with a passage through which ion-bearing fluid can flow comprising: an outer cylinder of electrically conductive material; an inner cylinder of electrically conductive material, said inner cylinder being coaxial with said outer cylinder and being divided longitudinally into a number of segments electrically insulated from each other, said inner and outer sections being adapted to maintain an electrostatic field therebetween; a middle cylinder of electrically conductive material coaxial with and substantially equal in length to the first segment at the entrance to the chamber, said first segment and said middle cylinder forming a filter section and the remainder of said inner segments and said outer cylinder forming ion-collecting sections, the cumulative lengths of said collecting-section segments varying in accordance with the relationship

$$x_1 : x_2 : x_3 \dots x_n = m^0 : m^1 : m^2 \dots m^{n-1}$$

wherein x represents distance along the length of said collecting-section segments from the plane of juncture of said filter section and the first collecting section adjacent thereto, n represents the number of collecting sections and m represents the resolution factor for the desired mobility ranges to be detected by the collecting sections, the open area of said filter section transverse to the distance x being substantially equal to $1/m$ of the total transverse open area at the entrance to said passage, and the length of said filter section being sufficient to provide said filter with a cutoff mobility characteristic at least equal to that of the last collecting section along said passage.

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