March 6, 1956 D. M. ROBINSON 2,737,593

METHOD OF IRRADIATING STREAMS OF LIQUIDS, GASES, FINELY DIVIDED SOLIDS, ETC., BY CONTINUOUS BEAMS OF HIGH INSTANTANEOUS IONIZATION DENSITY

Filed July 3, 1952 3 Sheets-Sheet 1

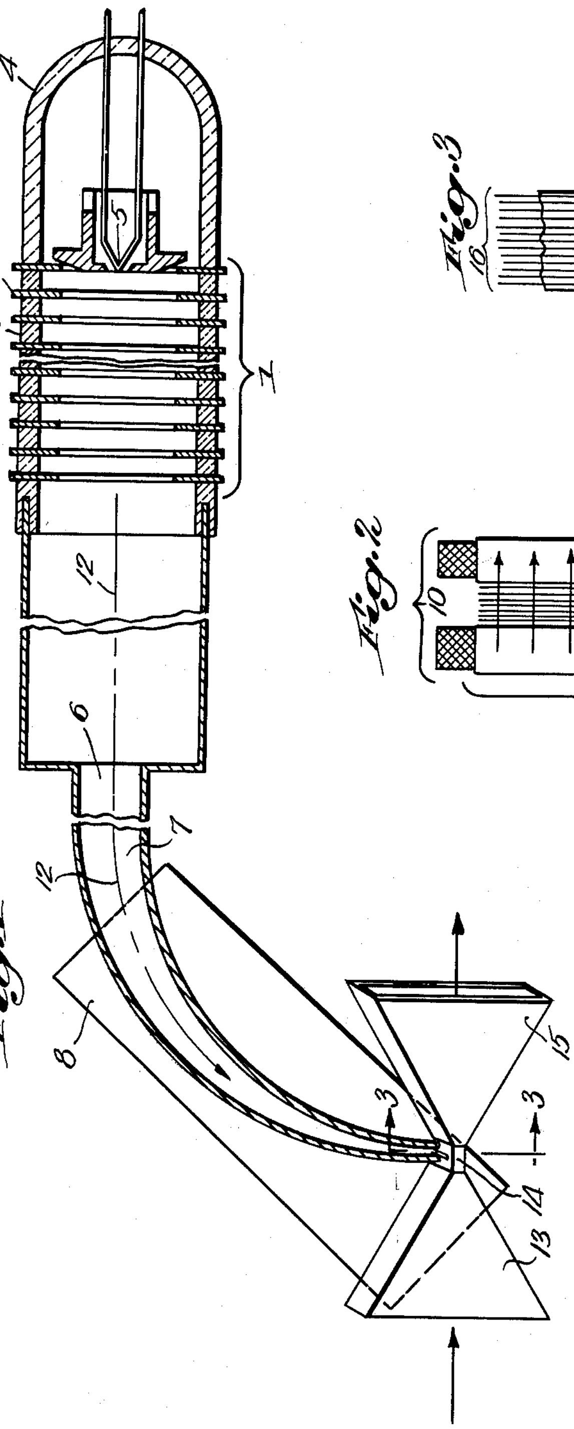

Fig. 1

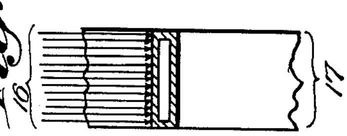

Fig. 3

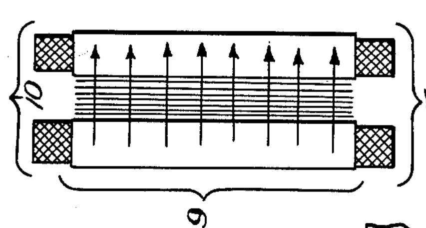

Fig. 2

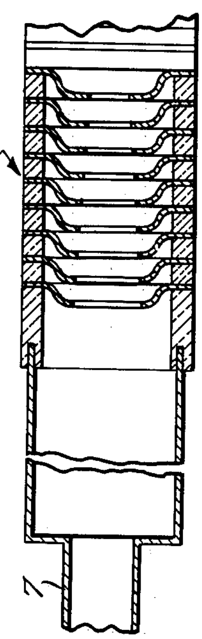

Fig. 1A

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Fig. 4

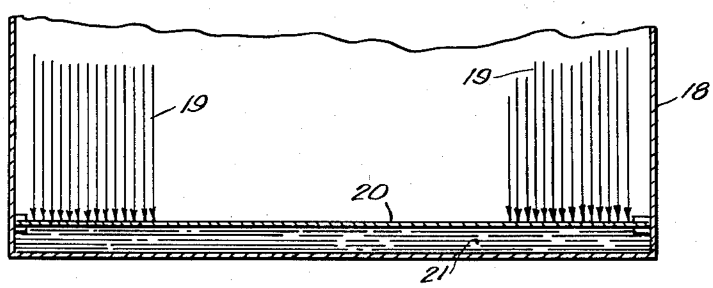


Fig. 5

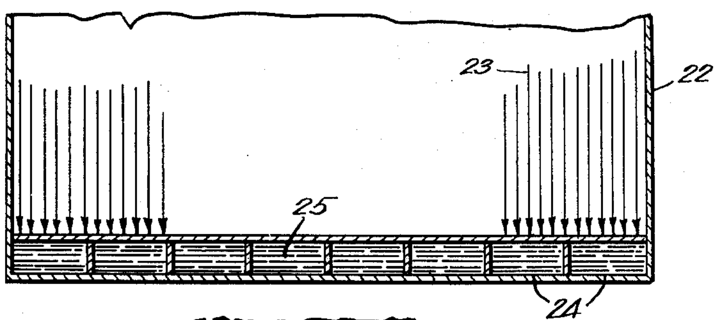
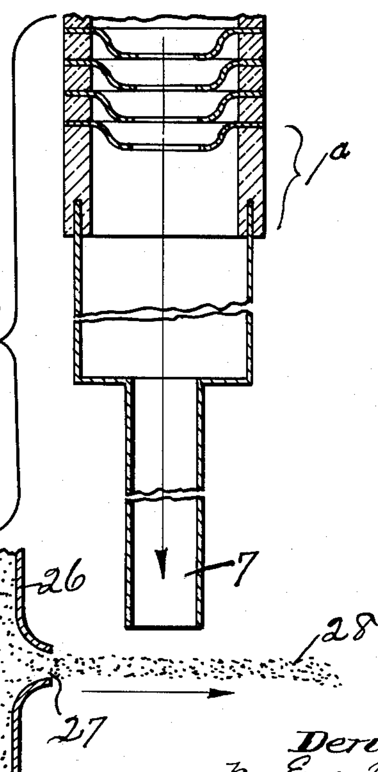


Fig. 6



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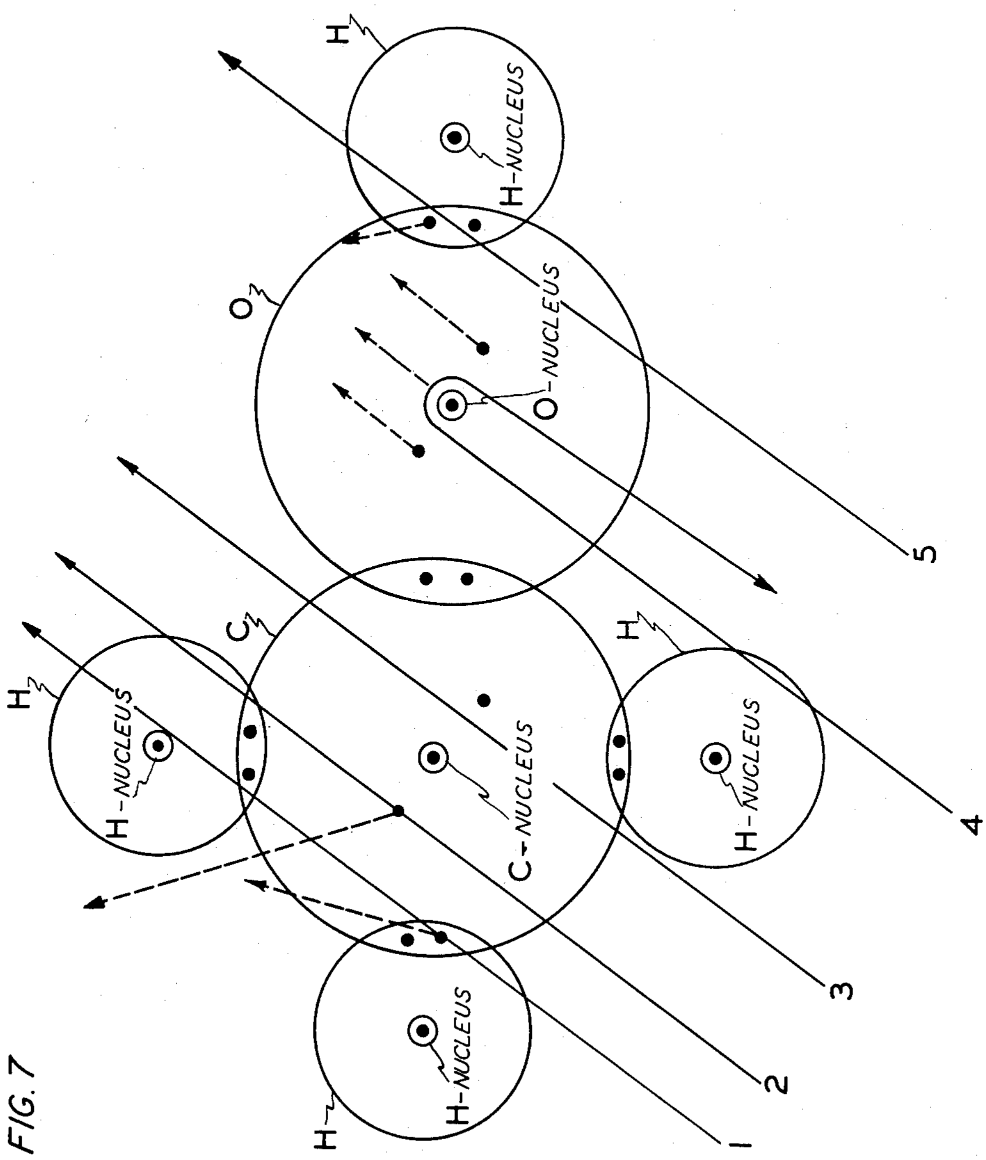

FIG. 7

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METHOD OF IRRADIATING STREAMS OF LIQUIDS, GASES, FINELY DIVIDED SOLIDS, ETC., BY CONTINUOUS BEAMS OF HIGH INSTANTANEOUS IONIZATION DENSITY

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Application July 3, 1952, Serial No. 297,065

3 Claims. (Cl. 250—49)

This application is a continuation in part of my co-pending application, Ser. No. 184,882, filed September 14, 1950, now U. S. Patent No. 2,680,814, for Method of and Apparatus for Sterilizing Streams of Liquids, Gases, Finely Divided Solids, etc., by Continuous Beams of High Instantaneous Ionization Density.

This present invention particularly relates to the method of delivering the ionizing energy of a concentrated beam of high-energy electrons to matter to be irradiated with a minimum of chemical effect due to low energy ionized particles, by focusing the electron beam into the shape of a thin sheet and causing the matter to be irradiated to travel through said sheet transversely thereto.

When a substance is subjected to ionizing radiation, many low-energy ions are produced. These ions would eventually recombine with one another, but in the meantime they may cause undesirable side effects. Such undesirable side effects will be minimized if the rate of recombination is maximized. If the ionization density is d, the rate of recombination is proportional to d^2. Therefore, by increasing the ionization density, the rate of recombination is increased even more. By focusing the concentrated electron beam into the shape of a thin sheet and moving the matter to be irradiated through said sheet transversely thereto, the ionization density is increased so as to minimize the chemical effect due to low-energy ionized particles.

While maximum ionization density is achieved by not only focusing the beam of electrons into the shape of a thin sheet but also discharging the matter in fluid form at very high velocity, increased ionization density results from either so focusing the beam or so discharging the matter. In said application, Ser. No. 184,882, now U. S. Patent No. 2,680,814, of which the present application is a continuation-in-part, I broadly claim discharging the matter in fluid form at very high velocity, whether or not the electron beam is focused into the shape of a thin sheet. In the present application, I broadly claim focusing the electron beam into a thin sheet, whether or not the matter to be irradiated is discharged in fluid form at very high velocity.

The present invention utilizes and is applicable to any concentrated high-energy stream of electrons. Therefore, while I have in the drawings illustrated (though more or less diagrammatically) certain forms of parts of the Van de Graaff high-voltage electrostatic generator, and have briefly described the same, my invention is in no wise limited to the use thereof in practicing my invention.

The invention herein disclosed is most appropriately practiced with technique involving high-voltage direct current from steady high-voltage direct-current sources and not with impulses or surges.

Having thus set forth the objects of my invention and the general nature thereof, I will now disclose certain embodiments of means or apparatus by which I may carry out or practice the method thereof.

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In said drawings:

Fig. 1 is a view, partly in longitudinal section and partly in side elevation, of an acceleration tube of a high-voltage electrostatic generator, as, for example, of the Van de Graaff type, wherein is created, and axially along which is directed, a beam of high-energy electrons, said beam being of substantially circular cross-section and of small diameter which, by suitable focusing means, is shaped into a very thin sheet that is in this figure shown as narrow and impinging directly downward onto a very thin stream of any desired nature but of the full width of the electron beam sheet, and forced under high pressure through a substantially horizontally positioned conduit;

Fig. 1A is a longitudinal sectional view on a small scale of an acceleration tube of late Van de Graaff type that may be employed in the practice of my invention;

Fig. 2 is a side view of the magnetic field and representing diagrammatically focus means for changing the form of the electron beam of very small circular diameter into a thin sheet;

Fig. 3 is a vertical section upon the line 3—3 of Fig. 1, indicating the electron beam, now in sheet form, impinging upon the stream through the very thin top wall of the conduit in a vertical direction and along a line whose thickness is that of the electron beam sheet;

Fig. 4 is a vertical section representing another embodiment of apparatus for practicing the method of my invention, and wherein the electron beam is created as a wide, thin, electron sheet by the employment of a cathode that is of corresponding width and thickness, and which sheet is projected downward through a correspondingly shaped acceleration tube of a high-voltage electrostatic generator onto a thin stream in a single conduit of the full width of the electron sheet and having a very thin top wall constituting a window at the elongated, narrow area where the electron sheet impinges vertically upon the top wall of the conduit and penetrates therethrough to sterilize the stream of whatever nature;

Fig. 5 is a view similar to Fig. 4, but representing the thin stream as forced under high pressure through a conduit that is composed of a series of thin, narrow tubes that together may equal the width of the single conduit represented in Fig. 4;

Fig. 6 is a view, partly diagrammatic to indicate the projection of the material or substance, of whatever nature, and as hereinafter described, in a free state and at a very high velocity, directly into the path of the high energy electron beam as the latter issues from the acceleration tube directly into free air, and very close to the discharge end or window of the acceleration tube; and

Fig. 7 is a representation, highly diagrammatic, of a molecule of methyl alcohol, the larger circles representing the atoms of which the molecule is composed, the diagram also representing, by certain very small circles respectively, a hydrogen nucleus, a carbon nucleus and an oxygen nucleus, and the dots representing atomic electrons, the full line arrows representing paths of bombarding electrons and the dotted-line arrows representing the resulting paths of the struck particles.

Referring more specifically to the nature and purpose of my invention and to several embodiments of means for practicing the process or method constituting the invention, I create according to one embodiment, a high-energy electron beam which, either by a cathode shaped to provide a sheet-like beam or by suitable means, is either created as, or is shaped into, a sheet of substantial width from edge to edge, but preferably very thin from front face to back face, such sheet-like beam impinging preferably at right angles downwardly onto a horizontally flowing stream, of the broad or generic character hereinbefore stated, but herein shown as passing through a conduit, under high pressure, the width of which stream is preferably equal to the width of such electron beam in sheet form, so as to act only along a thin transverse line on the constantly traveling liquid or other stream to irradiate it as the stream passes under such transverse line, which is the thin sheet of high-energy electrons.

When the product to be irradiated is a liquid of viscosity not too much greater than that of water, such liquid may be forced under pressure through a thin-walled tube or conduit at high velocity, and if such tube or conduit is in the path of the electron beam, the required dosage is delivered at a very high instantaneous ionization density. If the velocity of the liquid or other stream is high, and if the depth of the liquid and the dimension of its confining tube or conduit in the direction of motion of the high-energy electrons is small, and if the dimension of the focused electron beam which impinges upon the said tube or conduit is small in the direction of the flow of the liquid or other stream (that is, if the electron beam be delivered as a thin sheet of width substantially the same as the width of the liquid or other stream), the result is that there is achieved an instantaneous ionization of great density.

Referring more particularly to the drawings, and first to the construction shown in Figs. 1, 1A, 2 and 3, I have at **1** in Figs. 1 and 1A represented in central, longitudinal section an acceleration tube of a high-voltage electrostatic generator of Van de Graaff type, but I may use any source of high-voltage electrons, capable of producing a continuous intense beam. The wall of said acceleration tube is herein shown as composed of a multiplicity of alternating metallic electrode rings **2** and insulation rings **3** bonded together as disclosed in the U. S. patent to Trump and Cloud, No. 2,460,201, or, as in the U. S. patent to Van de Graaff and Buechner, No. 2,517,260. At one end the said acceleration tube is provided with the cathode assembly **4**, having therein the cathode **5**, and at its opposite end, instead of being provided with an anode, it is open so that the high-vacuum interior of the acceleration tube is in open communication at **6** with the continuation **7** of the acceleration tube. While in Fig. 1 the acceleration tube is shown as horizontally positioned for use, it may be and in some cases is desirably vertically positioned for use.

Certain of the metallic electrode rings **2**, as, for example, every third ring, or every ring, are (as usual in the Van de Graaff type of acceleration tube) connected to corresponding electrodes of the electrostatic generator, with the result that a substantially uniform electrostatic field is formed of substantially the entire cross-sectional area of the acceleration tube, extending along the wall of the tube in a manner not herein necessary to describe more fully.

While I have described in some detail an accelerator of the Van de Graaff type, it is to be understood that my method or process may be practiced, as stated, by the use of any source capable of producing a continuous intense beam of high-voltage electrons. The method herein disclosed and claimed may, so far as the step of creating an electron beam of high intensity is concerned, be carried out by the acceleration tube shown in Fig. 1 and Fig. 1A hereof, or/and by any of the numerous structures of apparatus shown in the co-pending application of Van de Graaff and Buechner, Ser. No. 297,036, now Patent No. 2,714,679, filed July 3, 1952, among which are the structures of apparatus identified as Exhibits A, B, D, and E and referred to as such by the Board of Appeals of the Patent Office in its decision dated March 31, 1952, in the co-pending application of Van de Graaff and Buechner, Ser. No. 128,084, filed November 18, 1949, now Patent No. 2,608,664, August 26, 1952. The step of establishing the sheet-like form of the beam can be, and is herein described, as carried out by focusing the beam into a sheet-like form, or by originally creating said beam in sheet-like form. The step of presenting a thin stream of material under pressure may be carried out by the means shown in Fig. 1 or by the means shown in Fig. 5, or the material may be discharged into free space as shown in Fig. 6 hereof or in any other desired manner.

Referring further to the type of acceleration tube here shown, and particularly to Fig. 1, the high-energy electron beam emanating from the cathode **5** and directed lengthwise the said aceleration tube **1** is of small diameter and is substantially circular in cross section. It may, for example, have a diameter on the order of one centimeter. That beam, entering the narrower portion of the tube at **6** and passing along the small diameter tube **7** constituting a part or continuation of the acceleration tube **1**, within which is preserved the high-vacuum condition that exists in the portion of the acceleration tube of greater diameter, enters the region of action of the focusing means (merely diagrammatically indicated at **8**) which extends to and includes the conduit or tube through which the liquid, gas, vapor or other stream to be irradiated is forced under high pressure. I have diagrammatically indicated in Fig. 2 at **9** the magnetic field, and at **10**, **11** the coils producing the electric field, which are in suitable direct current circuit that need not be more fully referred to.

The means diagrammatically indicated at **8** in Fig. 1 and at **10**, **11** in Fig. 2, focuses into a well defined rectangle or preferably a sheet of any desired thickness, the electron beam indicated by a line **12** in Fig. 1 extending axially of the acceleration tube **1** and its continuation **7** from the cathode **5**. The longer dimension of the electron beam thus focused into a preferably thin sheet, has one dimension preferably equal to the width of the liquid, gaseous or other stream of the character hereinbefore indicated; that is, the width of the electron-sheet beam has been kept equal to the width of the liquid, gaseous or other stream, and the other dimension of the electron-sheet beam, measured in the direction of motion of the liquid, gaseous or other stream that is being irradiated thereby has, by the focusing means, been made as small as it is practicable to make it.

Such a system, producing focusing in one plane considerably greater than in a plane at right angles to it, is known as a system of cylindrical optics, and is diagrammatically indicated at **8**, **9**, **10** and **11** in Figs. 1 and 2. Such a result (namely, that of changing the shape of the high-voltage electron beam, originally circular in cross-section, into a sheet) is obtained by the means diagrammatically represented in Figs. 1 and 2. Therein, the high-voltage electron beam **12**, directed at great speed from the cathode **5** along the axis of the acceleration tube **1** has a circular cross section and a diameter, for example, of one centimeter. On passing in a uniform magnetic field, it is bent at right angles and focused in one plane, but not in the other. That is, on arriving at the focus point, the high-voltage electron beam comes to an extremely sharp focus in one direction, but remains in its original size in a direction at right angles to the plane first referred to just above. That is, the high-voltage electron beam, now in sheet form, remains in its original dimension in the direction that is the width of the electron sheet, but its dimension has greatly decreased in the direction which is the thickness of the now shaped or focused electron sheet.

Referring further to Fig. 1, as illustrating merely one apparatus for practicing the method of my invention, I have diagrammatically indicated the liquid, gaseous or other stream and its containing conduit or tube as not very wide, but the illustration thereof in this figure is more for the purpose of indicating that the high-voltage electron sheet is delivered vertically downward onto the top wall of the conduit or tube that conducts a very thin stream of a liquid, gaseous or other nature, to be irradiated. Actually, but not necessarily, that stream has a width which is the same as the high-voltage electron sheet into which form the electron beam **12** has been shaped. My invention is not limited with respect to the width of the high-voltage electron sheet.

Referring again to Fig. 1, I have at **13** indicated a funnel-shaped inlet for delivering thhe stream of the broad or generic character defined, to be irradiated under high pressure to a conduit, tube or pipe **14** which has a very small interior dimension from top to bottom—that is, in the direction in which the high-voltage electron sheet impinges upon it, and also its wall is very thin. Extending from the conduit, tube or pipe **14** is an outwardly flaring member **15** for delivering the now irradiated liquid, gaseous or other stream for further processing. Actually and in practice the wall of the conduit, tube or pipe **14** is equal to the width of the high-voltage electron sheet, and it is to be understood that the high-voltage electron sheet impinges in a substantially vertical direction in a transverse line onto the top of the conduit, tube or pipe **14**, and that all along such transverse line the top wall of the said conduit, tube or pipe **14** is very thin, that is, as thin as possible while retaining strength enough to resist the high pressure of the liquid, gas, vapor, finely divided solid material or the like that is being irradiated. As already stated, the electron beam and the sheet into which it is shaped are within the vacuum system at all times, until they pass through the electron window into the conduit.

As already indicated, the stream, when a liquid, has a scouring action upon the inner surface of the walls of the tube **14** and acts as a very efficient coolant.

In Fig. 3 I have indicated, but merely diagrammatically, at **16**, the width of the high-voltage electron sheet, and at **17** the width of the conduit or tube for the stream of liquid, gas, or of other character, as hereinbefore set forth, and it will be seen that the two are of equal width. The width is merely diagrammatically there indicated.

In Fig. 4, I have represented in vertical section and merely diagrammatically, the lower end only of an acceleration tube which at its upper end has an emitting cathode much longer than it is broad, or otherwise stated, it is wider than it is thick, at its emissive area, to create a high-voltage electron beam that initially has the form of a sheet that may be of great width or of any suitable width, and may be very thin from back to front, but which may be of any suitable or desired thickness.

In said Fig. 4 the lower end of the acceleration tube is indicated at **18**, and the high-voltage electron beam in sheet form is indicated by the downwardly directed arrows **19** which, it is to be understood, are not shown entirely across the acceleration tube, though the high-voltage electron sheet does so extend. I here employ the normal focusing means in the acceleration tube to produce an image of the same type on the top wall of the conduit or tube **20** through which is forced, under high pressure, the stream **21** of liquid, gas, or other character as hereinbefore stated, and which is here shown as very thin and which is indicated as of the full width of the high-voltage electron sheet. In Fig. 4 the conduit or tube **20** is of full width of the high voltage electron sheet **19**, and in its upper wall there is provided a very thin window-like area that may be of aluminum or other material that will withstand the pressure of the stream **21** of liquid, gas or other character.

In Fig. 5 the construction is or may be the same as in Fig. 4, the lower end of the accelerator tube being indicated at **22**, and the high-voltage electron stream by the arrows **23**, but instead of employing a single conduit or tube for the stream of liquid, gas, or other substance, as in Fig. 4, I provide a series of conduits or tubes **24** placed side-by-side and together equalling the total width of the high-voltage electron sheet **23**. The top wall of each conduit or tube **24** has formed thereon a thin window-like area, as in Fig. 4. The series of streams, each under high pressure, are indicated at **25**.

It is to be understood that when I employ a series of conduits or tubes for a series of streams of liquid, gas or other substance to be irradiated, I may provide a single wide electron sheet of the full width of all the conduits or tubes, or I may provide a series of high-voltage electron beams or relatively narrow sheets, each of the width of a single conduit or tube, and together equalling the width of all of said conduits or tubes. What I have herein described are merely examples of apparatus which I may employ in carrying out the method or process herein disclosed, and which I herein claim.

In all of the embodiments of means thus far herein disclosed for practicing the method or process constituting my invention herein claimed, I have represented the described stream-carrying tube or tubes, conduit or conduits, as passing through the vacuum system connected to the lower end of the acceleration tube, and I have so indicated in Fig. 1, so that the high-voltage electron beam in sheet form impinges upon the tube or tubes, conduit or conduits, without suffering any scattering by passing through intervening air or other gas. The wall thickness of each tube or tubes, and particularly the upper horizontal face thereof, is preferably the very minimum necessary to support the pressure of the gas or vapor stream. Because of the narrowness of the high-voltage electron beam in the direction of flow of the liquid, gas, vapor or stream of other character (that is, the thinness of the high-voltage electron sheet from the front face to the back face thereof) in this embodiment of means for practicing my method or process, the region of the tube wall (or tube walls) that is required to be extremely thin, is also very narrow (that is, in the direction of flow of the stream that is being irradiated), and preferably the "window" through which the high-voltage electron beam in sheet form passes to and impinges upon the stream of liquid, gas, vapor or stream of other character, is only slightly bigger than the cross-sectional size of the high-voltage electron sheet itself. This small window is supported on both sides (that is, transversely of the direction of flow of the said stream) by suitable members to give the necessary reinforcement, thereby effectually supporting the pressure of the liquid.

The high-voltage electron sheet is not, in the disclosed embodiments of means for practicing my method or process, actually increased from its dimension in the acceleration tube. It is possible to have a high ratio between the width and the thickness of the high-voltage electron sheet, but this is done by making the high-voltage electron sheet extremely thin, not by widening the said sheet itself.

Although in the practice of my method or process, the initial pressure is very high at the entrance of the orifice of the tube or tubes, conduit or conduits into which, as indicated in Figs. 1 to 5, the stream of liquid, gas, vapor or other material, such as herein set forth, is introduced to be therein irradiated as described, the pressure at the constriction (shown, for example, in Fig. 1) may be very low, in accordance with Bernouilli's principle, and therefore the herein described high-voltage electron window itself does not have to withstand a high fluid pressure. The window may, therefore, be made very thin in order to have minimum electron scattering.

In order to obtain quantity flow of the liquid, fluid or other material to be irradiated, I provide a wide but thin stream thereof. Under certain circumstances, a stream thickness of one-half or one millimeter may be sufficient.

The method or process constituting my invention, as already stated, is applicable not only to liquids, but also to the suspension of solids in liquid mediums, such solids, for example, as finely divided flours, small grains such as wheat, chemicals in powder or grain form, also to streams composed wholly of finely divided solids, and to gases or vapors at high velocities, either alone or as carriers for small solid or liquid particles (that is, to dusts and sprays).

When gas rather than liquid is the carrier, the velocity may be exceedingly high, much higher than those obtainable with liquids. The method or process constituting my invention is applicable to and includes chemical processes involving liquids where high, instantaneous density is required, or is desirable, to produce effects of direct ionization without side effects.

In the case of the ionization of gas or vapors, the dimension of thickness of the stream thereof in the direction of electron flow may be greater than the indicated thickness of a liquid stream or streams. Therefore, the proportions of the tubes or conduits through which the gas and/or vapor is forced under any suitable pressure, will be varied accordingly.

A high dosage, sufficient to irradiate, can be given by the method or process herein disclosed, in a flowing liquid in an exceedingly short time, for example, in 10^{-5} seconds as shown by the calculation given in said application, Ser. No. 184,882, of which this application is a continuation in part.

If, for example, a liquid is forced to flow through an opening 1 mm. x 1 mm. square, under a pressure of 150 pounds per square inch, then, assuming that the density of the liquid is equal to that of water, that the liquid is non-viscous (no internal friction), and that there is uniform velocity across the cross-section of the stream:

Let
v=velocity of stream in ft./sec.
p=initial pressure in lbs./ft.^{2}
P=density in slugs/ft.^{3}

Then:

$$v=\sqrt{\frac{2p}{P}}=\sqrt{\frac{2\times150\times144}{62.5/32.2}}=149 \text{ ft./sec.}$$

$$v_{mm}=30\times10\times149=44{,}700 \text{ mm./sec.}$$

Assuming that the cathode-ray beam is .5 mm. thick in the direction of flow of the liquid stream, and letting t=the dosage time.

$$t=\frac{15}{44{,}700}=1.12\times10^{-5} \text{ sec.}$$

Now, assume that $\frac{1}{15}$ of the total energy of a 2-mv., 250 microampere cathode-ray beam is absorbed by the liquid stream.

$$\text{Energy absorbed}=2\times10^6\times250\times10^{-6}\times\frac{1}{15}=$$

$$W=33.3 \text{ watts}$$

Letting volume of liquid flow/sec.=V.

$$V=\frac{44{,}700\times1\times1}{1000}=44.7 \text{ cc.}$$

If a dose of 1 roentgen requires a dose of 8.5×10^{-6} joule/cc., then the dosage given to the flowing liquid is

$$D=\frac{W}{8.5\times10^{-6}V}=\frac{33.3}{8.5\times10^{-6}V}=87{,}500 \text{ roentgens}$$

The dose thus delivered in about 10^{-5} seconds may be increased to any desired or required level; for example, it may be made two million roentgens, by suitably increasing the current in the electron beam apparatus, giving a beam sufficient to produce two million roentgens in 10^{-5} seconds under the conditions above described, such apparatus being under construction by High Voltage Engineering Corporation of Cambridge, Massachusetts, to which this application is assigned.

The present invention comprehends and includes also a method or process of irradiating a liquid or liquids with solids in suspension or a stream composed wholly of very finely divided solids, in which stream, whether it be liquid or partly liquid, or composed wholly of finely divided solids, it is required to produce a chemical change by a direct ionization process, and wherein it is at the same time desired to keep to a minimum undesirable secondary or side chemical processes or actions produced by indirect action or ionization. Such a method or process consists, therefore, in irradiating the said streams of liquids, or liquids with solids in suspension or finely divided solids, including chemicals in powder or grain form or a stream composed wholly of finely divided solids, with an electron beam of desirably small cross-sectional area, and always of high-charge density, and causing the material to be irradiated to flow rapidly through such thin electron beam, thereby delivering the required total dosage with maximum instantaneous ionization density.

In Fig. 6 I have represented diagrammatically the projection of the material or substance, of whatever nature, in a free state and at high velocity immediately into the path of the high energy electron beam. Therein I have represented at **1a** the lower part of an acceleration tube of the type shown in Figs. 1 and 1A, and the small diameter continuation thereof at **7**, preferably terminating in a window of any suitable character.

Desirably, in very close proximity to the outlet end or window of the acceleration tube **1a** is positioned a chamber or receptacle **26**, a small portion only of the wall of which is represented, and having an outlet **27**, through which the material **28** of whatever nature, is discharged under very high pressure and at great velocity directly into the path of the high-voltage electron beam that issues into free space through the lower end or window of the said acceleration tube **1a**.

Thus the electron beam delivers its irradiation charge in a single passage of the material or substance **28** through the high energy beam, so that there is achieved in each succeeding portion of such material or substance an instantaneous ionization of great density, and with a minimum of chemical effect due to low energy ionized particles.

In Fig. 7 of the drawings is a highly diagrammatic representation of a molecule of methyl alcohol. The six large circles represent the six atoms of which the molecule is composed, namely, four hydrogen atoms, each marked H, one carbon atom marked C, and one oxygen atom marked O. Centrally within each of the four hydrogen atoms in a small circle marked H-nucleus, each indicating a hydrogen nucleus of a hydrogen atom. Centrally within the carbon atom is the nucleus marked C-nucleus, and centrally within the oxygen atom is the nucleus marked O-nucleus. At a number of places upon each of the atoms is a dot. Each of these represents an atomic electron or particle.

There are represented five full line arrows respectively marked 1, 2, 3, 4 and 5. Each of these represents the path of a bombarding electron of the high-voltage beam created at the cathode of the herein described acceleration tube and accelerated through the length of the tube and issuing through the window at the end thereof and immediately impacting upon the substance or material, a single molecule whereof is diagrammatically indicated in said Fig. 7. The dotted-line arrows represent the resultant paths of the affected atomic electrons or particles.

Arrow No. 3 shows a bombarding electron passing entirely through the molecule without encountering any particle. Arrow No. 5 shows the path of a swift electron through part of the molecule where a valence electron is encountered in a close collision but not sufficiently close to impart to the valence electron enough energy to escape from the molecule. However, enough energy is imparted to the struck electron to cause a shift in its position and to give it energy of excitation, thus producing an alteration in the molecular structure. Arrow No. 1 shows a valence electron being struck and ejected from its atom. Arrow No. 2 shows an inner orbital electron being struck and ejected from its atom. In some cases electrons may be ejected from atoms with considerable energy. In such cases the ejected electron may be capable of ionizing many other atoms in its path, and is then called a delta-ray.

Arrow No. 4 shows the nucleus of the oxygen atom being "struck," and the shape of the arrow No. 4 indicates the bombarding electron (negative charge) which passes around the "struck" nucleus (positive charge). Such nucleus may be thereby "ejected" from its molecule and will usually carry with it most of its circumnuclear electrons. This illustrates the fact that a bombarding electron may in some cases travel around a nucleus in a comet-like path, and pull the nucleus out of its molecule.

Having thus set forth the method or process constituting my invention and examples of apparatus by which such method or process may be effectively carried out or practiced, I desire it to be understood that although specific terms are used in setting forth such method or process, they are employed in a generic sense and not for purposes of limitation, the scope of the invention being set forth in the following claims.

I claim:

1. The method of delivering the ionizing energy of a concentrated beam of high-energy electrons to matter to be irradiated with a minimum of chemical effect due to low-energy ionized particles, which method comprises: producing and directing a concentrated beam of high-energy electrons; focusing said electron beam into the form of a thin sheet; and moving the matter to be irradiated through said thin sheet transversely thereto.

2. The method of delivering the ionizing energy of a concentrated beam of high-energy electrons to matter to be irradiated with a minimum of chemical effect due to low-energy ionized particles, which method comprises: producing and directing a concentrated beam of high-energy electrons; focusing said electron beam, by a system of cylindrical optics, into the form of a thin sheet; and moving the matter to be irradiated through said thin sheet transversely thereto.

3. The method of delivering the ionizing energy of a concentrated beam of high-energy electrons to matter to be irradiated with a minimum of chemical effect due to low-energy ionized particles, which method comprises: producing and directing a concentrated beam of high-energy electrons; subjecting said electron beam to the deflecting action of a uniform magnetic field, whereby said electron beam is focused into the form of a thin sheet; and moving the matter to be irradiated through said thin sheet transversely thereto.

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