July 28, 1959 D. R. DEWEY II, ET AL 2,897,365

IRRADIATION METHOD AND APPARATUS

Filed Oct. 8, 1956

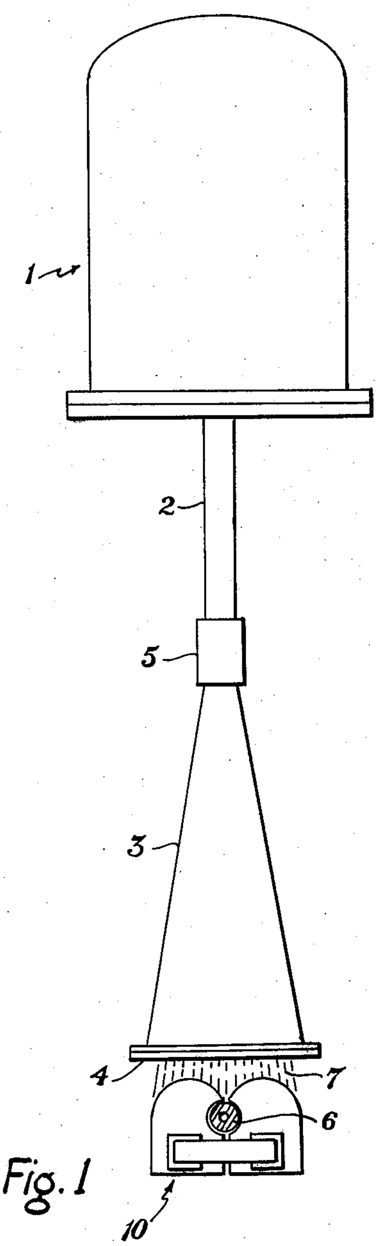

Fig. 1

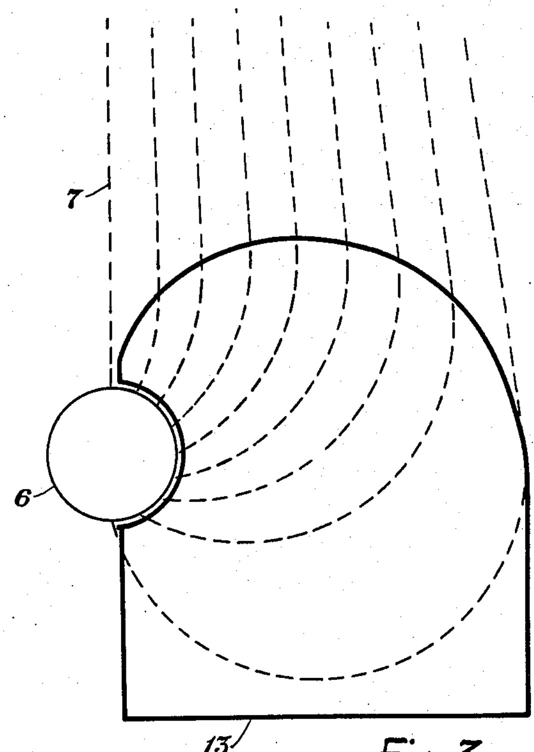

Fig. 3

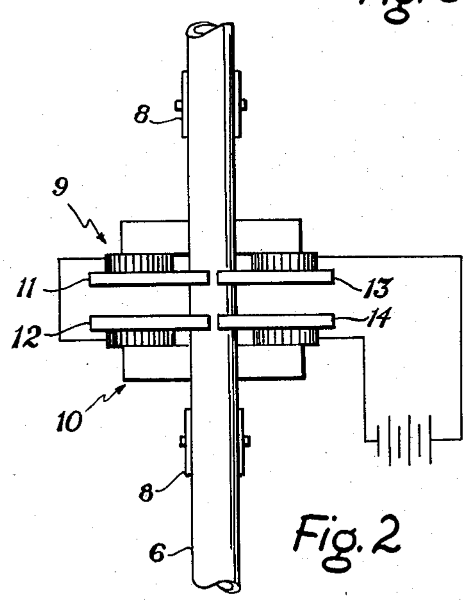

Fig. 2

United States Patent Office

2,897,365

Patented July 28, 1959

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IRRADIATION METHOD AND APPARATUS

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Application October 8, 1956, Serial No. 614,661

3 Claims. (Cl. 250—49.5)

This invention relates to irradiation with high-energy electrons and in particular to irradiation with high-energy electrons from a single electron accelerator in such a manner as to utilize the ionizing energy of the high-energy electrons in a more efficient manner. More specifically stated, the invention comprehends directing a beam of high-energy electrons whose cross-section is extended in at least one plane, from a single electron source towards an object to be irradiated and subjecting said beam to the action of a combination of magnetic fields so arranged that the electrons bombard the object to be irradiated from substantially all aspects in said plane. The object to be irradiated may be stationary, or it or a series of objects may be moved continuously or discontinuously in a direction transverse to said plane. The invention is particularly well suited to the irradiation of continuous lengths of a product or products having a generally circular cross-section, such as plastic tubing, cable, or insulated wire, or such as an axially aligned succession of bottles, ampoules, vials, collapsible containers, or similar objects. The term "generally circular cross-section" as used herein means a circular, elliptical, ovoidal, polygonal or similar cross-section. Accordingly, in the following detailed description the invention will be described with particular reference to the irradiation of a continuous length of hollow plastic tubing, but the invention is not limited to the irradiation of any particular type, shape, or composition of object to be irradiated.

The invention will also be described with particular reference to an electron accelerator in which the beam of electrons whose cross-section is extended in at least one plane, is produced by imparting a scanning movement to an electron beam; but the invention is not limited to any particular means for producing the electron beam of extended cross-section, and includes other means for accomplishing this result, such as focusing an electron beam by an electron-optical system in accordance with the teachings of U.S. Patent No. 2,737,593 to Robinson.

The invention may best be understood from the following detailed description thereof, having reference to the accompanying drawing, in which

Fig. 1 is a somewhat diagrammatic side view of apparatus embodying the invention and including an electron accelerator adapted to produce a beam of electrons of extended cross-section and means for producing a combination of magnetic fields for directing the electrons onto the object to be irradiated from substantially all aspects in the plane of the sheet;

Fig. 2 is a plan view of the means for producing a suitable combination of magnetic fields shown in Fig. 1; and

Fig. 3 is a diagram showing the electron trajectories in the apparatus of Fig. 1.

It is now becoming established that all types of living organisms are affected by gamma rays and high energy electrons and that lethal effects can be produced on un-

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wanted organisms by doses which will raise the temperature of water only a few degrees centigrade. The growing availability of streams of high energy electrons makes possible the practical application of this knowledge to the sterilization of many important products, such as pharmaceuticals, surgical instruments, animal tissues for transplant purposes, as well as for the preservation of certain foods. Only high energy electron sources, as distinct from gamma ray sources, appear to possess enough total power output to handle economically the considerable amounts of material which may require sterilization or preservation.

Moreover, the possibility of using various forms of ionizing radiation to promote chemical reactions has recently been explored, including highly endothermic chemical reactions which require large quantities of energy in concentrated form and exothermic chemical reactions which are triggered by the initial application of concentrated energy. Among available sources of ionizing radiation, high energy electrons seem to be the best medium for delivering ionizing energy in an efficient and controlled manner to a substance or substances for the purpose of promoting chemical reactions.

Measurements of the properties of high energy electrons have disclosed that their range in typical materials is small compared to that of gamma rays. A 2-million-volt electron has a maximum range in water of 1 cm. Beyond this limiting distance there is no ionizing effect, while the maximum ionizing effect occurs at one-third this angle. Although practical high-energy electron sources may be constructed for many millions of volts, such higher energy apparatus becomes progressively more expensive and also often has a lower output electron current capacity.

A common method of, in effect, doubling the range of penetration of an available stream of electrons is to irradiate the object from both sides as by reversing the object and irradiating again, or by irradiating the object simultaneously from two electron sources. However, the former is limited to the irradiation of material in rigid form, and the latter entails the additional expense and space requirements of a second electron source. Furthermore, an interruption or modulation of electron intensity would not affect both aspects simultaneously, unless the product is irradiated simultaneously, from two electron sources with special electronic coupling being introduced between the two sources; consequently, it would be difficult to re-irradiate the partially irradiated material to bring its dose up to the proper level.

The difficulties caused by the fixed range in matter of an electron beam of fixed energy is augmented in the case of objects to be irradiated which have a circular cross section, such as plastic cable which is to be irradiated in order to cross-link the molecules of which the plastic is composed in order to improve the properties of the plastic. For example, the electron energy required to penetrate a solid cable with a beam of electrons directed onto the cable from one aspect is determined by the diameter of the cable, but most of the electron beam need penetrate only a fraction of this depth. Similarly, the electron energy required to penetrate a hollow cable with a beam of electrons directed onto the cable from one aspect is considerably greater than that required to penetrate the thickness of the wall of the cable.

Referring more particularly to the drawings, one embodiment of apparatus for practising the method of the invention is shown in Figs. 1 and 2, wherein an electrostatic accelerator for the acceleration of electrons to high energy is indicated at **1**. The electron accelerator **1** may comprise an electrostatic generator of the type disclosed in U.S. Patent No. 2,252,668 to Trump in conjunction with an acceleration tube of the type disclosed in U.S. Patent No. 2,517,260 to Van de Graaff and Buechner. Alternatively, the electron accelerator **1** may comprise a microwave linear accelerator of the type described by Walkinshaw at volume 61, pages 246–254, by R. Shersby-Harvie at volume 61, pages 255–270, and by Mullett and Loach at volume 61, pages 271–283 of The Proceedings of The Physical Society (1948), or any other suitable electron accelerator, such as a resonant transformer.

Electrons are accelerated by the electron accelerator **1** in a manner not necessary to explain herein in detail and enter an evacuated tube extension **2** as a beam of high-energy electrons. Said tube extension **2** terminates in a flared portion **3** the extremity of which is closed off from the atmosphere by an electron window **4**. A beam-scanning device **5** imparts a scanning movement to the electron beam in the plane of the drawing in Fig. 1 in accordance with the teachings of U.S. Patents Nos. 2,602,751 and 2,729,748 to Robinson.

A product, material or substance which is to be irradiated, shown in Figs. 1 and 2 as a hollow plastic cable **6**, is positioned in the path of the electron beam **7**, which issues from the electron window **4** as a beam whose cross-section is extended in the plane of the drawing in Fig. 1, by suitable supports **8**. Any conventional means (not shown) may be employed to impart longitudinal traveling movement to the cable **6**. The width of the cable **6** is less than the width of the electron sheet **7**, as shown in Fig. 1, so that some of the electrons impinge directly onto the top of the cable **6**, while some of them travel to the left and some to the right of the cable **6**.

Two magnets **9**, **10** are supported so as to produce a combination of magnetic fields in the path of the electron beam **7**. The magnets **9**, **10** are so designed as to produce a magnetic field between the left-hand pole faces **11**, **12** which is directed out of the plane of the drawing in Fig. 1 and downward in Fig. 2, and also to produce a magnetic field between the right-hand pole faces **13**, **14** which is directed into the plane of the drawing in Fig. 1 and upward in Fig. 2. Therefore, electrons which travel to the left of the cable **6** are deflected in a counterclockwise direction along a substantially circular path, and the electrons which travel to the right of the cable **6** are deflected in a clockwise direction along a substantially circular path, as shown in Fig. 3. As a result, the electrons in the beam **7** are directed onto the cable **6** from substantially all aspects in the plane in which the cross-section of the beam **7** is extended, as shown in Fig. 3.

Referring more particularly to Fig. 3, the pole faces **11**, **12**, **13**, **14** must be so shaped as to give each portion of the electron beam **7** the desired deflection. Maximum deflection is imparted to the outermost extremities of the electron beam **7**, which bombard the cable **6** from the posterior aspect, while none is imparted to the central portion of the electron beam **7**, which bombards the cable **6** from the anterior aspect. Except for fringing effects, which are readily compensated for, and neglecting scatter, all electron paths will be circular and will have the same radius of curvature in the magnetic fields, and all electron paths will be rectilinear elsewhere. Fringing effects will occur principally in the vicinity of the gap between the pole faces **11** and **13** and between the pole faces **12** and **14**. The effect of scatter tends to diffuse the electron stream so as to augment uniformity of irradiation.

Having thus described the method of the invention, together with illustrative embodiments of apparatus for carrying out the method, it is to be understood that although specific terms are employed they are used in a generic and descriptive sense and not for purposes of limitation, the scope of the invention being set forth in the following claims. Throughout the specification and claims hereof, the word "plane" is used in a general sense and not in a precise sense, and includes planes which are neither thin nor flat.

We claim:

1. Apparatus for irradiating an object with high-energy electrons comprising in combination an electron accelerator adapted to produce a beam of electrons whose cross-section is extended in at least one plane, means for supporting an object to be irradiated in the path of said beam, and means for producing two substantially parallel but substantially oppositely oriented magnetic fields in the path of said beam of extended cross section such that the electrons converge upon the object from several aspects.

2. Apparatus for irradiating an object with high-energy electrons comprising in combination an electron accelerator adapted to produce a beam of electrons whose cross-section is extended in at least one plane, means for supporting an object to be irradiated in the path of said beam, and two pairs of opposed magnet pole faces flanking said object, the pole faces of each pair flanking said plane, the polarity of said pole faces being such as to produce two substantially parallel but substantially oppositely oriented magnetic fields in the path of said beam of extended cross section, so that the electrons traveling between the pole faces of each pair are deflected towards the object.

3. Apparatus for irradiating a continuous length of a product or products having a generally circular cross-section, comprising in combination an electron accelerator adapted to produce a beam of electrons whose cross-section is extended in at least one plane, means for drawing said continuous length through the path of said beam in a direction parallel to the longitudinal axis of the continuous length and at an angle to said plane and two pairs of opposed magnet pole faces flanking said continuous length, the pole faces of each pair flanking said plane, the polarity and shape of said pole faces being such as to produce two substantially parallel but substantially oppositely oriented magnetic fields in the path of said beam of extended cross section, so that the electrons traveling between the pole faces of each pair are deflected towards the object.

References Cited in the file of this patent

UNITED STATES PATENTS

2,741,704	Trump et al.	Apr. 10, 1956
2,785,313	Trump	Mar. 12, 1957
2,824,969	Crowley-Milling	Feb. 25, 1958