

March 25, 1941.

W. SHOCKLEY

2,236,012

ELECTRON DISCHARGE DEVICE

Filed Aug. 6, 1933

2 Sheets-Sheet 1

FIG. 1

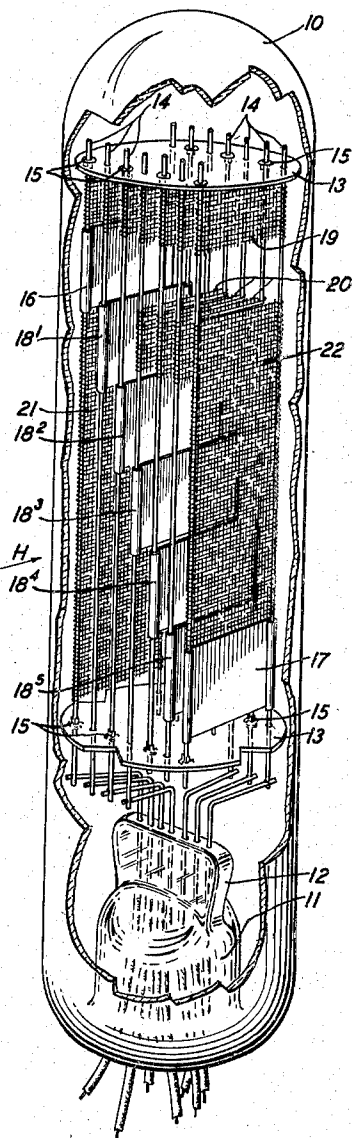


FIG. 2

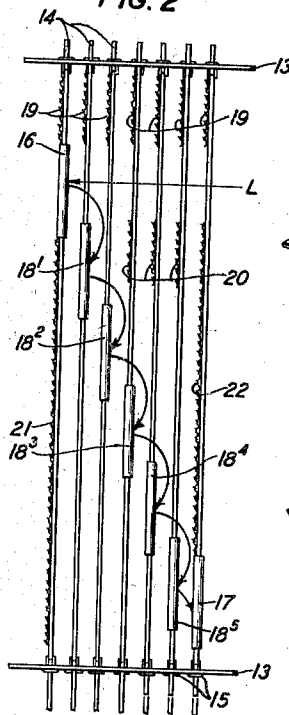


FIG. 6

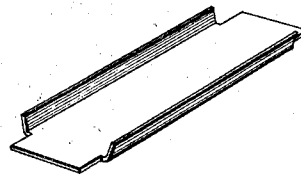


FIG. 7

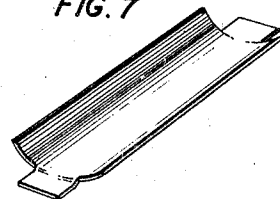


FIG. 8

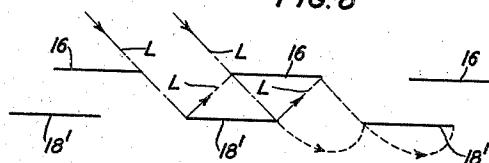
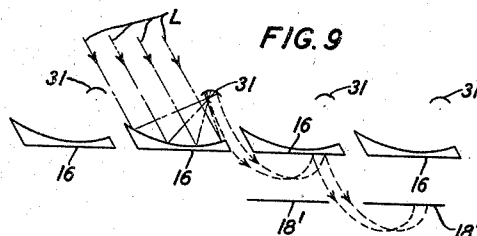


FIG. 9



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2 Sheets-Sheet 2

FIG. 3

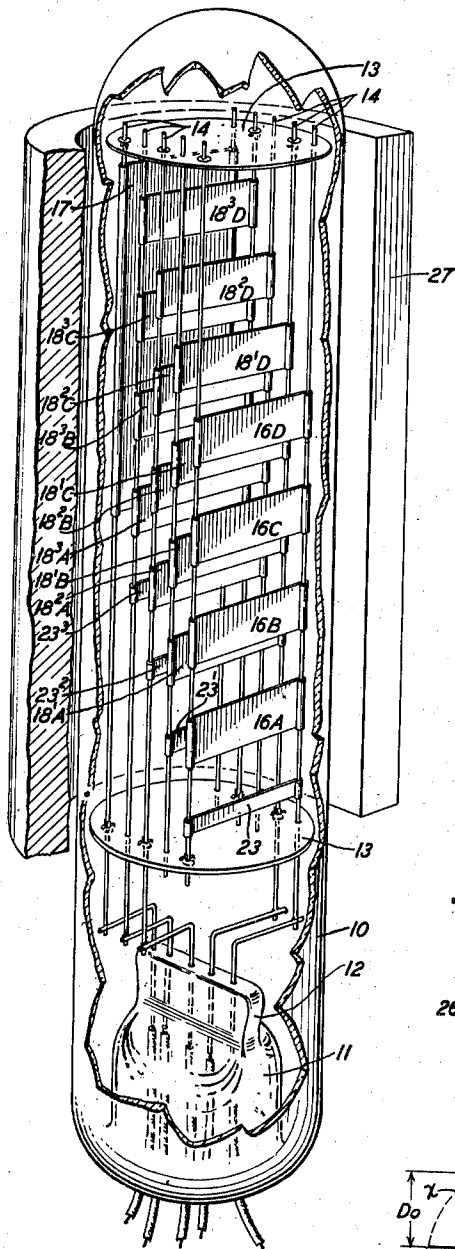


FIG. 4

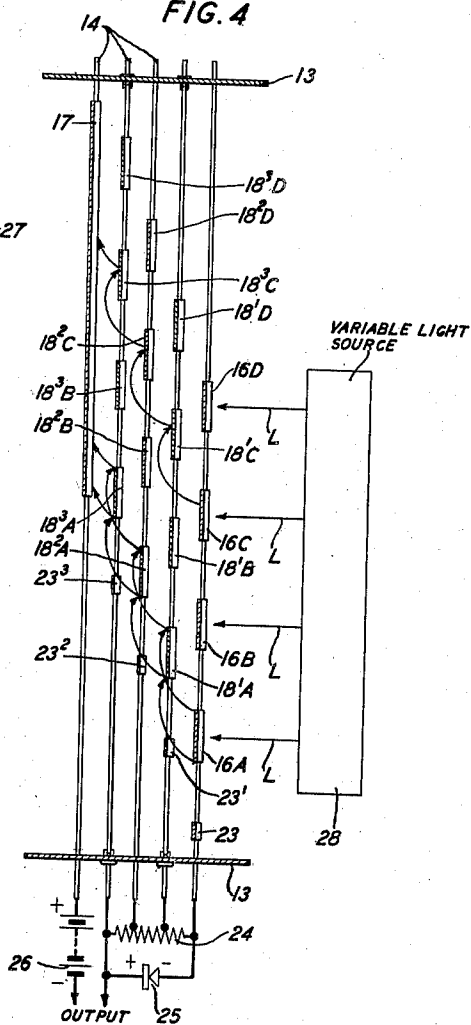
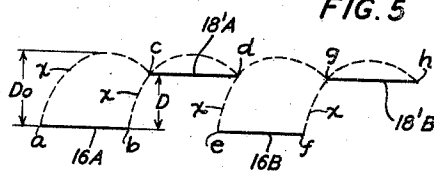


FIG. 5



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ELECTRON DISCHARGE DEVICE

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Application August 6, 1938, Serial No. 223,399

14 Claims. (Cl. 250-175)

This invention relates to electron discharge devices and more particularly to such devices having one or more secondary electron emitting electrodes and generally known as electron multipliers.

One general object of this invention is to improve the operating characteristics of electron multipliers.

A more specific object of this invention is to obtain substantially uniform electron transit times between the electrodes in a multistage electron multiplier.

Another object of this invention is to attain strong and substantially uniform electrostatic fields adjacent the electron emitting members in an electron multiplier.

A further object of this invention is to facilitate the construction of electron multipliers to have predetermined and readily calculable electron trajectories between successive electrodes.

A still further object of this invention is to facilitate the attainment of desired convergence of the several electron streams in an electron multiplier.

Still another object of this invention is to produce a compact, easily fabricable electron multiplier of high power capacity.

In one illustrative embodiment of this invention, an electron multiplier comprises a plurality of electron emitting members, for example, metallic strips or sheets, located in spaced or superposed planes, each member being displaced in its plane a predetermined distance with respect to the member in the next preceding or lower plane. Preferably the various electron emissive members are so positioned and dimensioned that corresponding edges of the members in each two successive planes lie on spaced portions of a surface traced by a cycloidal curve. A collector electrode or anode is provided adjacent one of the end electron emissive members.

Means, such as metallic screens, are provided each being substantially coplanar with one of the electron emitting members and opposite or adjacent one or more other electron emitting members for assisting in providing fields of the desired direction and intensity between successive electron emitting members.

The invention and the various features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings wherein:

Fig. 1 is a perspective view of an electron multiplier illustrative of one embodiment of this invention, a portion of the enclosing vessel being

broken away to show the electrodes more clearly;

Fig. 2 is a side elevational view of the electrode assembly in the electron multiplier shown in Fig. 1;

Fig. 3 is an elevational view of an electron multiplier illustrative of another embodiment of this invention, a portion of the enclosing vessel being broken away, and showing in part an external magnet for producing a magnetic field adjacent the various electrodes;

Fig. 4 is in part a side view of the electrode structure of the multiplier illustrated in Fig. 3 and in part a circuit diagram illustrating one manner in which the multiplier may be operated;

Fig. 5 is a detail diagrammatic view illustrating the space relation of the cathode elements in the multiplier shown in Figs. 3 and 4;

Figs. 6 and 7 are enlarged detail views showing other forms of the electron emissive members which may be utilized in the electron multiplier shown in Figs. 1 and 3; and

Figs. 8 and 9 are diagrammatic detail views illustrating two ways in which the first or primary electron emitting members in an electron multiplier of the general construction shown in Figs. 3 and 4 may be energized.

Referring now to the drawings, the electron multiplier shown in Figs. 1 and 2 comprises an elongated evacuated enclosing vessel 10 having at one end thereof an inwardly extending stem 11 terminating in a press 12 from which a unitary electrode assembly is supported. This electrode assembly comprises a pair of spaced parallel insulating members 13, such as mica discs, having extending therebetween a plurality of metallic uprights or rods 14 which are fitted in suitable apertures in the members or discs 13 and some of which may be locked to the members or discs as by eyelets 15. The pairs of uprights or rods 14 are located substantially in equally spaced, overlying parallel planes.

Mounted upon one end pair of the uprights or rods 14 is a primary cathode 16, which may be a strip or sheet of metal having its ends or sides bent about and affixed to this pair of uprights. The inner surface of the cathode 16, that is, the surface thereof to the right in Fig. 2, may be treated or coated to render it photoelectrically active. For example, the cathode 16 may be formed of a strip or sheet of silver and the inner surface thereof may be treated to provide thereon a coating or matrix including silver, caesium oxide and some free caesium.

The other end pair of rods or uprights 14 supports a collector electrode or anode 17, which may be a strip or sheet of metal having its ends bent around and affixed to these rods or uprights.

A plurality of substantially identical auxiliary or secondary cathodes 18¹ to 18⁵, inclusive, are mounted upon the other pairs of rods or uprights 14, each of these cathodes being formed, for example, of a strip or sheet of metal having its ends or sides bent around the corresponding rods or uprights, and having the surface thereof toward the collector electrode or anode, that is, the surface to the right in Fig. 2, adapted to emit secondary electrons. For example, the secondary cathodes 18, similarly to the cathode 16, may be formed of strips of silver and having on the proper surface thereof a coating or matrix including silver, caesium oxide and some free caesium.

As shown clearly in Fig. 2, the several auxiliary or secondary cathodes 18 are substantially parallel and are displaced or offset diagonally toward the anode or collector electrode 17 equal distances with respect to the next preceding electrode, that is, the preceding electrode to the left in Fig. 2, but overlapping the preceding electrode. Preferably, the electrodes are so mounted and spaced that the corresponding ends of successive cathodes lie on spaced points of corresponding cycloids. That is to say, for example, the cathodes 16 and 18¹ preferably are so spaced that the upper edges (in Fig. 2) of these cathodes lie on spaced points of a cycloid the base of which is in the plane of the cathode 16. The lower edges (Fig. 2) of the cathodes 16 and 18¹ pass through spaced points on a second similar cycloid the base of which also is in the plane of the cathode 16. The other cathodes 18² to 18⁵, inclusive, are mounted and spaced in like manner. Mounted upon the uprights or rods 14 are a plurality of metallic screens 19, 20, 21 and 22, each screen being mounted on one pair of rods and substantially coplanar with the electrode carried by the same pair of rods. The screens 19, which are substantially identical, overlie one another and abut the upper insulating member or disc 13, the screen 19 carried by the rods 14 on which the primary cathode 16 is mounted extending entirely between the upper disc 13 and the cathode.

The screens 20, which also preferably are substantially identical, are aligned and overlie the secondary cathode 18¹. The screen 21, which is mounted upon the same uprights or rods 14 as the primary cathode 16, extends from this cathode to immediately adjacent the lower insulating member or disc 13. The screen 22, which is mounted on the same uprights or rods 14 as the collector electrode or anode 17, extends from the collector electrode or anode to a point opposite the upper edges (Fig. 2) of the screens 20.

The screens 19, 21 and 22, it will be seen, form a cage or partial enclosure which shields the electrodes, and particularly the secondary cathodes 18, from extraneous fields, which might affect the electron emission from the cathodes and alter the trajectories of the electrons, and produce a substantially uniform electric field within the cage. The screens 20 assist in this shielding action and, together with the screen 22, assist in producing strong fields away from the emissive surfaces of the primary cathode and the secondary cathode 18¹.

During operation of the multiplier shown in Figs. 1 and 2, the several secondary cathodes 18

and the anode or collector electrode 17 are maintained at successively higher positive potentials. For example, the secondary cathode 18¹ may be maintained at a potential of the order of 100 volts positive with respect to the primary cathode 16 and each of the secondary cathodes 18² to 18⁵, inclusive, may be maintained of the order of 100 volts positive with respect to the cathode having the next lower superscript. The anode or collector electrode 17 may be maintained at a potential of the order of 100 volts positive with respect to the secondary cathode 18⁵.

Means are provided for producing a substantially uniform magnetic field adjacent and parallel to the emissive surfaces of the cathodes 16 and 18, the direction of the field being indicated by the arrow H in Fig. 1.

When the primary cathode 16 is energized, as by a beam of light indicated by the arrow L in Fig. 2, primary or photoelectrons are emitted therefrom and these electrons, under the influence of the magnetic field and the electrostatic fields produced by the screens 19, 20 and 22 and by the secondary cathode 18² flow to and impinge upon the emissive surface (the right-hand surface in Fig. 2) of the secondary cathode 18¹, the electron trajectories being indicated generally by the arrow in Fig. 2. The impinging electrons cause the release of secondary electrons from the cathode 18¹ and, because of the treating or coating of the cathode 18¹ as described heretofore, the secondary electron current from this cathode will be several times as great as the primary electron current thereto. Hence, an electron multiplication and a corresponding amplification of the signal represented by the light beam is obtained. The secondary electrons emanating from the cathode 18¹, under the influence of the magnetic and electrostatic fields extant between this cathode and the cathode 18², flow to and impinge upon the cathode 18², whereby a further electron multiplication and corresponding amplification are obtained. This action is repeated at each of the cathodes 18³ and 18⁵, and the secondary electrons emanating from the cathode 18⁵ flow to the anode or collector electrode 17 and constitute the output current.

It has been found that the electron trajectories between the cathodes are substantially cycloidal so that, because of the relative positions of the cathodes described heretofore, all of the electrons emanating from each cathode will flow to and impinge upon the emissive surface of the next succeeding cathode whereby a high efficiency and uniform and stable operation are obtained. The multiplier shown and described enables the attainment of strong and uniform fields away from the emissive surfaces of the several cathodes so that uniform electron transit times are obtained and space charge effects are minimized.

In the electron multiplier shown in Figs. 3 and 4, which is generally similar to that illustrated in Figs. 1 and 2 and described above, each of the cathodes 16 and 18 comprises a plurality of spaced coplanar similar elements, A to D, inclusive, electrically connected by the corresponding pair of uprights or rods 14. There are thus provided in effect a plurality of multi-stage multiplier sections connected electrically in parallel. The various cathodes 18 may be similar to the secondary cathodes of the multiplier shown in Figs. 1 and 2, the faces thereof toward the anode or collector electrode 17, that is, the surfaces thereof to the left in Fig. 4, being treated or

coated to assure copious emission of secondary electrons therefrom.

The primary cathodes 16 may be formed of strips or sheets transparent to light and having the surfaces thereof toward the secondary cathodes 18¹ treated or coated, as described heretofore, to render them photoelectrically active. For example, the cathodes may be formed of metallic mesh material. Alternatively, these cathodes may be composed of a transparent insulating material and the photoelectric coatings thereon electrically connected to the uprights or rods 14 on which the primary cathodes are mounted.

The several cathodes are mounted and spaced so that each element, A to D, inclusive, of each of the secondary cathodes 18 has its edges cycloidally located with respect to the corresponding edges of the corresponding element of the preceding cathode. For example, as illustrated in Fig. 5, the element A of the secondary cathode 18¹ has its edges *c* and *d* lying on points on similar cycloidal traces *x*, on which there lie also the edges *a* and *b* of the element A of the primary cathode 16, the base of the cycloids being in the plane of the element A of the primary cathode. Similarly, the element B of the secondary cathode 18² has its edges *g* and *h* lying on points on similar cycloidal traces *x*, on which there lie also the edges *e* and *f* of the element B of the primary cathode 16.

It will be noted that the edge *c* is cycloidally located with respect to both the edges *a* and *b* and that likewise the edge *g* is cycloidally located with respect to both the edges *e* and *f*. Hence, it will be appreciated that all of the electrons emanating from the elements A and B of the primary cathode may flow to and impinge upon the corresponding elements of the secondary cathode 18¹.

The remaining elements of the primary cathode 16 and secondary cathode 18¹, and also the elements of the cathode 18² and 18³ are spaced in the same manner as described with respect to the elements illustrated in Fig. 5.

In general, it is desirable that the distance between opposed edges of successive elements of the cathodes be substantially equal to the spacing of the edges of each element; that is to say, for example, in Fig. 5, the distance between the edges *d* and *g* preferably is substantially equal to the spacing of the edges *c* and *d*, and *g* and *h*.

It is preferable also that the height of the cycloids on which corresponding edges of successive electrode elements lie be greater than the spacing between successive planes in which the cathodes lie but less than twice this spacing; that is to say, referring to Fig. 5, the height *D*₀ preferably is greater than *D* but less than twice *D*.

A plurality of auxiliary electrodes 23 to 23³, inclusive, are provided opposite the lower end of each of the cathodes, each auxiliary electrode being substantially coplanar with and supported on the same pair of uprights or rods 14 as a corresponding one of the cathodes. For example, the auxiliary electrodes may be metallic strips having ends bent around and affixed to the uprights 14. These electrodes assist in producing strong uniform fields of the proper direction adjacent the emissive surfaces of the members A of each of the cathodes.

During operation of the multiplier shown on Figs. 3 and 4, each secondary cathode is maintained at a positive potential, for example, of the order of 100 volts, with respect to the next pre-

ceding cathode. The requisite potentials may be obtained, for example, from a voltage divider including a resistance 24 and a direct current source, such as a rectifier 25, the cathodes being connected to equally spaced taps on the resistance 24. The anode or collector electrode 17 may be maintained at a potential of the order of 100 volts positive with respect to the secondary cathode 18³ by a source such as a battery 26.

A magnetic field parallel to and adjacent the emissive surfaces of the cathodes may be produced by a suitably-shaped horseshoe magnet 27 having its poles on opposite sides of the envelope 10.

If desired, screens similar to the screens 19 to 15² in Figs. 1 and 2 may be provided in the multiplier illustrated in Figs. 3 and 4 to assist in producing accelerating fields and to shield the electrodes from extraneous fields.

The primary cathode 16 may be energized to cause emission of photoelectrons from the several elements A to D thereof, as by beams of light emanating from a variable light source 28. The operation of the multiplier shown in Figs. 3 and 4 is generally the same as described heretofore in connection with Figs. 1 and 2, the trajectories of the electron streams being indicated by the arrows in Fig. 4.

Although a single source 28 has been shown in Fig. 4, it will be understood that a number of sources, each energizing one or more of the elements of the primary cathode 16, may be employed. These sources may be energized by impulses corresponding to the same signal or may be energized by different signals, the output current in the latter case corresponding to the aggregate amplified currents. Likewise, although but a single anode or collector electrode has been shown, a number of anodes or collector electrodes may be employed and connected in various ways. For example, a number of anodes or collector electrodes may be so connected and a plurality of sources 28 employed and so energized that push-pull amplification is obtained.

As shown in Figs. 6 and 7, the elements of the cathodes 16 and 18 in Figs. 1 and 2 and 3 and 4 may be dished or curved, the inner or concave surface thereof being adapted to emit electrons and facing toward the plane of the anode or collector electrode. Such form of the cathode elements augments convergence or confinement of the electron streams and assists in obtaining a desired direction of the electrostatic fields adjacent each of the emissive surfaces whereby all of the electrons emanating from each element will flow to and impinge upon the emissive surface of the corresponding element of the next succeeding electrode.

Another way of energizing the elements of the primary cathode 16 in the multiplier shown in Figs. 3 and 4 is illustrated in Fig. 8. The upper surfaces of the elements of the secondary cathode 18¹, which correspond to the right-hand surfaces in Fig. 4, are polished or otherwise treated and serve as mirrors for reflecting the light rays *L* incident thereon to the photoelectrically active surfaces of the elements of the primary cathode 16. The trajectories of the electrons emanating from the elements of the cathode 16 are indicated by the dotted lines in Fig. 8. The upper surfaces of the cathode elements 18¹ may be concave to concentrate the reflected light beams upon the cathode elements 16.

The elements of the primary cathode in the multiplier shown in Figs. 3 and 4 may be ener-

gized to cause emission therefrom in still another way as shown in Fig. 9. As indicated in this figure, the upper or outer surfaces of the cathode elements 16 are shaped to constitute lenses which reflect the light beams L and concentrate and focus them upon auxiliary photoelectric members 31. The members 31, in turn, are shaped to concentrate the electron streams emanating therefrom and to direct them between adjacent edges of the primary cathode elements 16, the electron trajectories being indicated by the dotted lines in Fig. 9.

It will be appreciated that the primary cathode 16 in Figs. 1 and 2 also may be energized in the manners illustrated in Figs. 8 and 9.

Although several embodiments of this invention have been shown and described, it will be understood, of course, that these embodiments are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, and a plurality of secondary cathodes mounted in succession in equally spaced parallel planes between said primary cathode and said collector electrode, said secondary cathodes having corresponding surfaces thereof electron emissive and being offset diagonally with respect to the next preceding electrode, and corresponding opposite edges of successive secondary cathodes lying on points of cycloids of a height greater than the spacing between said planes and less than twice said spacing.

2. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a secondary cathode between said primary cathode and said collector electrode and obliquely offset toward said collector electrode with respect to said primary cathode, and a screen electrode outside of the electron path between said secondary cathode and said collector electrode, overlying said secondary cathode and electrically integral with said collector electrode.

3. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode and diagonally offset with respect thereto, a plurality of secondary cathodes mounted in succession between said primary cathode and said collector electrode and each displaced toward said collector electrode with respect to the next preceding cathode, and a screen member electrically integral with said collector electrode and opposite said secondary cathodes.

4. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode and offset diagonally with respect thereto, a secondary cathode between said primary cathode and said collector electrode and displaced from said primary cathode obliquely toward said collector electrode, a second secondary cathode between said first secondary cathode and said collector electrode and offset obliquely with respect to said first secondary cathode, and a screen electrically integral with said secondary cathode and opposite said first secondary cathode.

5. An electron multiplier comprising an electron emitting electrode, a collector electrode spaced from said electron emitting electrode, a plurality of spaced secondary cathodes suc-

cively mounted between said electron emitting and collector electrodes, each offset obliquely with respect to the next preceding cathode, and a plurality of screen members opposite the cathode nearest said electron emitting member, each screen member being electrically integral with a corresponding one of said cathodes.

6. An electron multiplier in accordance with claim 5 comprising a screen electrically integral with said collector electrode and opposite said secondary cathodes.

7. An electron multiplier comprising an electrode structure including a collector electrode at one end of said structure, a primary cathode remote from said one end, a plurality of secondary cathodes mounted in spaced longitudinal planes between said primary cathode and said collector electrode, successive secondary cathodes being positioned at increasingly greater distances toward said one end, from said primary cathode, a screen electrode extending from said one end, and a second screen electrode extending from said collector electrode and away from said one end.

8. An electron multiplier in accordance with claim 7 comprising a plurality of screen members each electrically integral with a corresponding one of said secondary cathodes mounted remote from said one end and beyond said primary cathode.

9. An electron multiplier in accordance with claim 7 comprising a plurality of screen members each electrically integral with a corresponding one of said secondary cathodes and opposite the secondary cathode nearest said primary cathode.

10. An electron multiplier comprising a plate member having a photoelectric surface, a second plate member having a light reflecting surface facing toward said photoelectric surface, and an electron receiving member substantially coplanar with said second plate member, in co-operative relation with said photoelectric surface and having a secondary electron emissive surface facing away from said photoelectric surface, said first plate member being offset diagonally with respect to said second plate member in the direction of said electron receiving member.

11. An electron multiplier in accordance with claim 10 wherein said light reflecting surface is concave and has its focal point adjacent said photoelectric surface.

12. An electron multiplier comprising a collector electrode, a primary cathode including a plurality of spaced coplanar elements, and a secondary cathode including an equal number of spaced coplanar elements between said primary cathode and said collector electrode, corresponding elements of said primary and secondary cathodes being substantially parallel and having corresponding opposite edges lying on spaced points of cycloids.

13. An electron multiplier comprising a primary cathode having a plurality of substantially coplanar elements, a collector electrode substantially parallel to said elements and diagonally offset with respect to said primary cathode, and a plurality of spaced secondary cathodes each including a plurality of substantially coplanar elements mounted in planes substantially parallel to the plane of said primary cathode elements, each element of each of said secondary cathodes being displaced in the plane thereof away from the corresponding element of the next preceding

cathode, and said corresponding elements being equally spaced.

14. An electron multiplier comprising an electron emitting member, a collector electrode, and a secondary cathode diagonally offset with respect to said member and in a plane parallel to

the plane of said emitting member, corresponding edges of said member and said cathode lying in spaced points of cycloids having a height greater than the spacing between said planes and less than twice said spacing.

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