April 27, 1937. V. K. ZWORYKIN ET AL 2,078,304

ELECTRIC DISCHARGE DEVICE

Filed Oct. 30, 1935 2 Sheets-Sheet 1

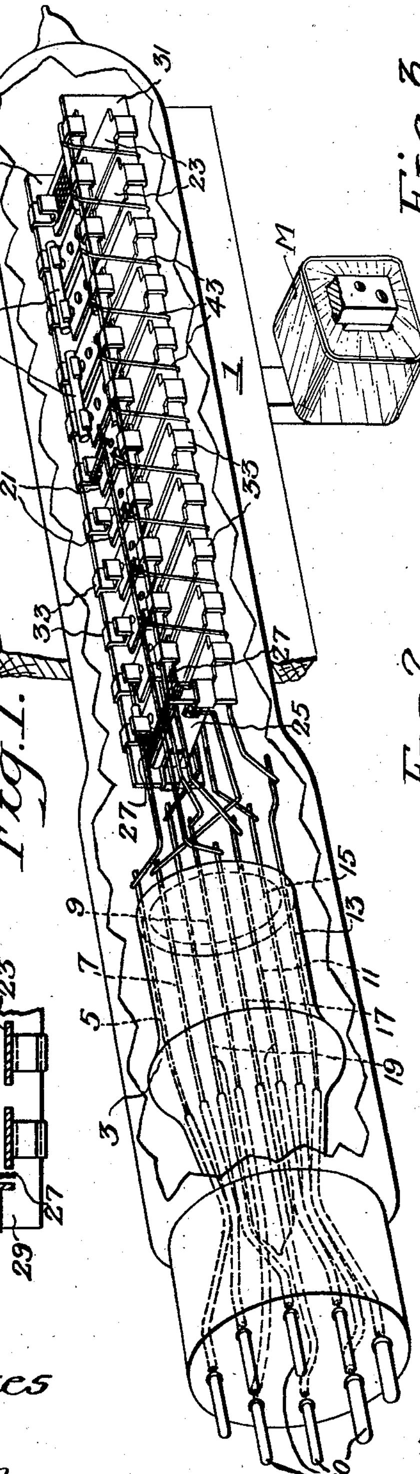

Fig. 1.

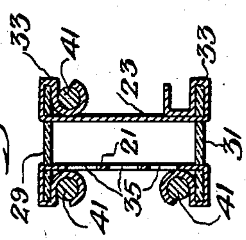

Fig. 3.

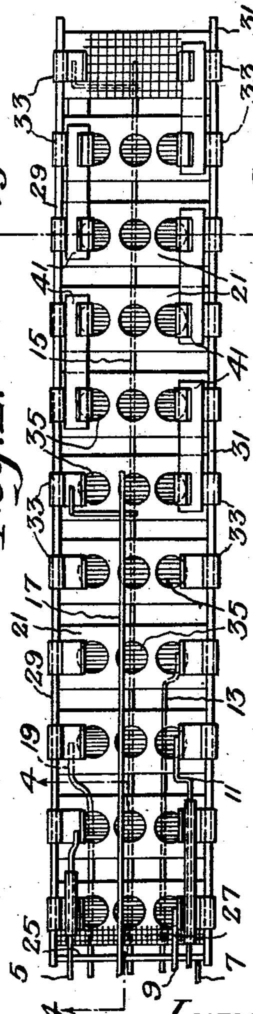

Fig. 2.

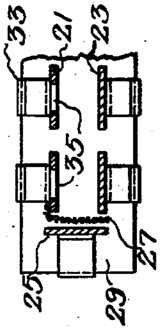

Fig. 4.

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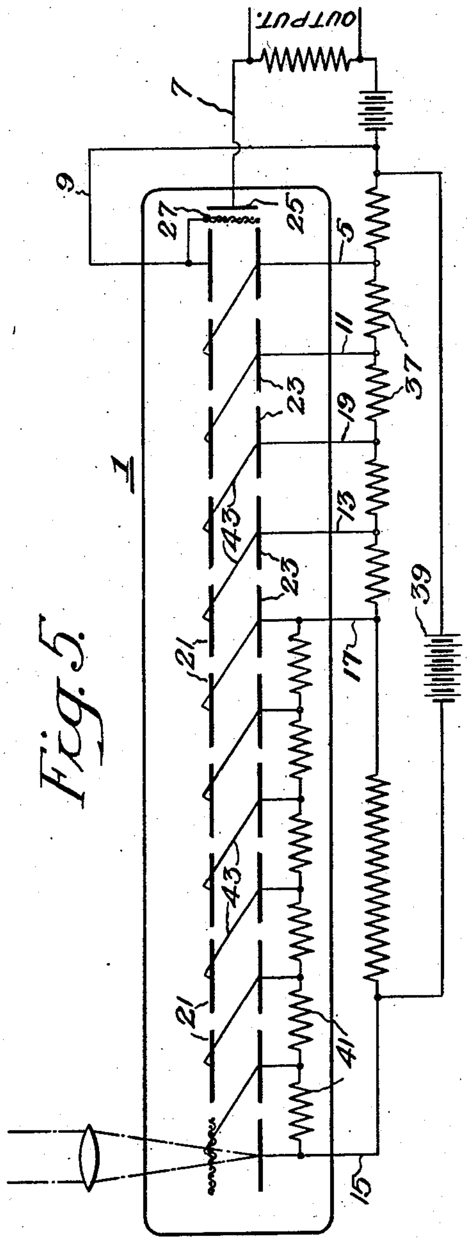

Fig. 5.

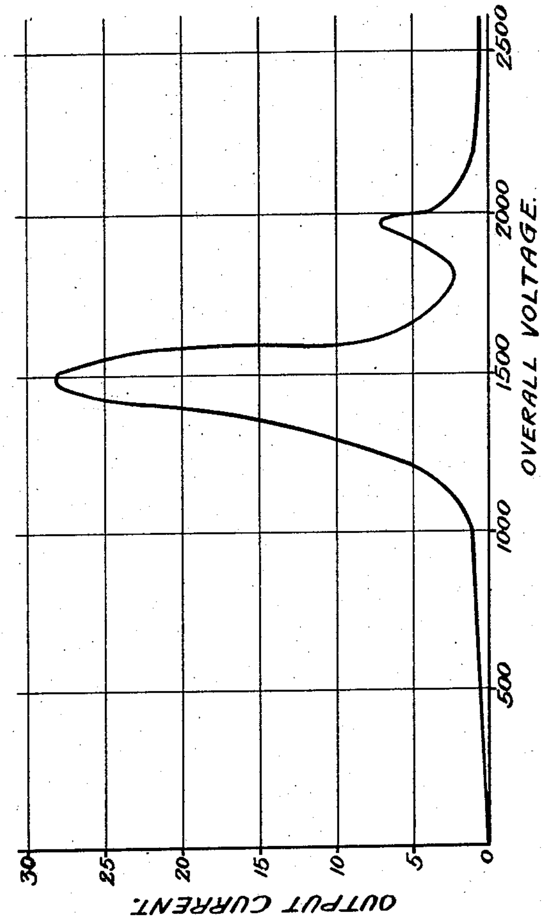

Fig. 6.

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ELECTRIC DISCHARGE DEVICE

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Application October 30, 1935, Serial No. 48,982

9 Claims. (Cl. 250—27.5)

Our invention relates to electric discharge devices and more specifically to devices of the type wherein amplification of a primary electric current is obtained through utilization of the phenomenon of secondary emission.

More specifically, our invention relates to improvements in the construction of electron multipliers of the general type disclosed in the copending application of Ernest A. Massa et al., Serial No. 33,996, filed July 31, 1935 and assigned to Radio Corporation of America.

In the Massa application there is disclosed a multi-stage electron multiplier constituted by a plurality of pairs of opposed electrodes axially disposed in an evacuated container with their faces lying in parallel planes. For convenience, the electrodes may be designated, respectively, "upper" or "accelerating" and "lower" or "multiplying". Preferably, the faces of the multiplying electrodes are specially treated, as by photo-sensitization, to enhance their ability to emit secondary electrons and a primary electron source, photo-electric or thermionic in character, is provided. In addition, electro-magnetic means are provided for the purpose of causing the electrons to describe approximately trochoidal paths from each lower electrode to the next adjacent electrode, thus permitting the use of high accelerating potentials on the upper electrodes without the disadvantages resulting from the space charges encountered in a device constructed according to the prior art.

The ratio of the number of secondary electrons to the number of primary electrons depends, in part, upon the character of the surface and upon the potential difference between the surface and the source of the electrons that impinge upon it. This ratio can be made considerably greater than unity. For example, a ratio of five or more secondary electrons to one impinging electron is readily obtainable with metallic surfaces treated in known ways and subjected to discharges at potentials of 200 to 400 volts.

If the secondary electron current, in turn, is caused to impinge with sufficient velocity upon a further electrode with a suitably treated surface, the ratio of secondary emission from the second multiplying electrode may also be greater than unity. Hence, one is able to obtain with "n" multiplying electrodes in cascade, for example, an amplification of the original or primary modulated or unmodulated electron current equivalent to the amplification per electrode raised to the nth power.

A multi-stage electron multiplier is capable of giving an amplification of three million times the primary current. Its utilization in apparatus where space is at a premium, however, involves difficulties on account of the large number of external connections heretofore required to supply differing electron-accelerating potentials to the electrodes. For that purpose it has been customary to provide an external potential source and an external potential divider to which the majority of the electrodes must individually be connected. Such mode of connection, obviously, necessitates a large number of lead-in wires, each of which must be hermetically sealed into the press or into the container, necessarily complicating the manufacturing process and giving rise to many "rejects".

It is, accordingly, an object of our invention to provide an improved electron multiplier that shall require the minimum number of potential-supply connections for satisfactory operation.

Again referring to the Massa multiplier, some difficulty has been experienced in properly activating the lower electrodes after the electrode-assembly has been sealed into the container.

Another object of our invention, therefore, is to provide an improved electrode-assembly that may easily be activated after it has been introduced into the container.

A still further, and ancillary, object of our invention is to provide an electron multiplier that shall allow simplification of the adjustment of external potential sources during the operation thereof.

In accordance with our invention, means are provided within the container to permit the automatic establishing of a satisfactory potential gradient between certain of the electrodes when the device is in operation. Specifically, we prefer to interconnect neighboring upper or lower electrodes, usually in the vicinity of the primary electron source, by means of resistors and to connect the primary source to the next adjacent lower electrode by means of a similar resistor. Such resistors, because high current carrying capacity is not required, may be quite small and, consequently, they may be built into the electrode assembly itself before it is mounted within the container.

To facilitate the admission of caseium to the lower electrodes during the activation of the device, we prefer to provide a number of openings in each of the upper electrodes.

The novel features that we consider characteristic of our invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment thereof, when read in connection with the accompanying drawings, in which—

Fig. 1 is a view in perspective of our improved device, a portion of the container wall being broken away to more clearly show the electrode structure,

Fig. 2 is a top plan view of the electrode structure,

Fig. 3 is a cross-sectional view taken along a line corresponding to line 3—3 in Fig. 2,

Fig. 4 is a fragmentary vertical cross-sectional view taken along a line corresponding to the line 4—4 in Fig. 3,

Fig. 5 is a diagrammatic view of our improved device illustrating the manner in which certain of the electrodes are interconnected internally of the tube, and

Fig. 6 is a curve showing the relationship between output current and overall potential, the excitation of the first photo-electrode being maintained constant and with a fixed magnetic field.

An electron multipler constructed according to our invention, referring now to Fig. 1 of the drawings, may conveniently be constituted by an elongated evacuated container 1 of glass or the like having an annular or cylindrical press 3 in one end, circumferentially around and through which the stem wires 5, 7, 9, 11, 13, 15, 17 and 19 are sealed. The stem wires are shown as terminating externally in the prongs 20 of a plug-in socket of conventional design.

In the particular embodiment illustrated there are twenty-three electrodes; eleven "upper" or "accelerating" electrodes 21, eleven lower electrodes 23, ten of which are "multiplying" electrodes and the eleventh one, nearest the end of the container farthest from the stem, is the primary electron emitter. The primary emitter may be thermionic in character, and a grid (not shown) or other electron-control means may be associated with it, if desired.

The accelerating electrodes are disposed in axially spaced relation in a single plane. The lower electrodes are paired with those of the upper set, i. e., they are similarly arranged in a second, parallel plane. An output electrode 25 is disposed adjacent to the pair of electrodes nearest the stem, and the accelerating electrode of the said pair has an extension 27, which may conveniently be of wire cloth, bent downwardly towards but not touching the lower electrode. This extension is for the purpose of accelerating the electrons toward the output electrode 25 and for preventing internal "feed-back".

The electrode-supporting assembly comprises a pair of outwardly extending, oppositely located, parallelly arranged strips 29 and 31 of mica or other insulating material. These insulating strips are preferably pre-fabricated and suitably orificed to accommodate the oppositely located lugs 33 of the several electrodes. Increased rigidity may be ensured by bending the lugs over the edges of the insulating strips, as indicated in Fig. 3.

As clearly shown in Figs. 1 and 3, the insulating strips, together with the respective upper and lower sets of electrodes, form a box-like conduit for the electrons. The electron-confining effect of this conduit is due in part to the mechanical presence of the insulating side strips. The mica walls also serve to focus the electrons in a lateral direction as they travel down the axis of the tube. This focusing is accomplished by virtue of the negative charge which is built up on the surface of the mica due to the electrons which strike it. As soon as a sufficient charge is built up on the surfaces of the strips, further electrons will be repelled from them and they will be constrained to travel near the axis of the tube, thus preventing any electron loss due to lateral spreading.

Another feature of our invention resides in the provision of a plurality of openings 35 in each of the upper electrodes. These openings, during manufacture of the device, permit the caesium vapor to thoroughly bathe the lower electrodes, causing them to be more uniformly activated for secondary emission and photosensitivity than heretofore.

As shown in Figs. 1 and 5 of the drawings, each of the lower electrodes, with the exception of the primary emitter, may be operated at a potential corresponding to that of the upper electrode of the next adjacent pair toward the free end of the container. The connections between electrodes of similar potential may conveniently be made by short jumpers 43, anchored, as by welding to the several electrodes.

Heretofore, during utilization of an electron multiplier, it has been customary to provide each of the lower electrodes with an externally extending lead-in connection for the purpose of applying suitable potentials thereto from an unidirectional source. Such mode of connection is exemplified in Fig. 5 of the drawings by the lead-in wires 5, 11, 19, 13 and 17, a potential divider 37 and a potential source 39.

When separate connections are supplied for each of the lower electrodes, the output electrode and the upper electrode nearest thereto, the process of manufacture of the device is complicated and the device itself is awkward to use.

Having in mind, therefore, our discovery that the upper electrodes in the neighborhood of the primary electron source draw but a small amount of current, we have dispensed with the greater part of the external potential divider. Instead, as clearly shown in Fig. 1 and as exemplified in Fig. 5, we have interconnected certain of the mentioned electrodes, internally of the container, by resistors 41. These resistors may be quite small and, accordingly, they may be held in mechanical position and in electrical contact with the electrodes by the lugs 33 of the electrodes, as shown in Figs. 1, 2 and 3.

The multiplying electrodes are of .005″ nickel, plated with .001″ layer of silver. To get a securely adhering silver layer, the nickel must be cleaned, and copper-plated very slightly. We found that when plating about a dozen electrodes (¼″ x ½″), a five-minute stay in a copper-plating bath (CuCN) at about 100 m. a., and about an hour stay in a sliver-plating bath (AgCN) at the same plating current produced a very good silver surface.

The accelerating electrodes may be nickel without any plating. Two or more ⅛″ holes are punched in the accelerating electrodes to facilitate viewing oxide colors on the multiplying electrodes and the admission of caesium. The first accelerating electrode consists of a 20-mesh screen which is used to admit light to the photo-surface. Fig. 1 shows the various electrodes.

The screen 27 is preferably 30-mesh nickel and it is welded to the last accelerating electrode. The collector or output electrode 25 is made of

.0025" tantalum (carbonized with camphor) and its dimensions are 1/4" x ½". Fig. 4 shows, in section, a detail of the screen and collector electrode mounted on mica.

The mica walls consist of strips of mica .005" thick, 1/16" wide, and having a length depending on the number of stages (3⅜" for 10 stages).

The potential gradient resistors, 1/10 watt, 1 megohm, are ⅜" long x ⅛" diameter with copper sprayed ends and free of paint and soldered leads.

The method of assembly of our improved electrode structure is as follows:

A strip of mica, already punched, is set on an appropriate stand and the electrode lugs are inserted in the slots. The screen and collector are not assembled in this operation. A metal mandrel is next placed between the two rows of electrodes, with a thin sheet of mica (about .001") on the side next to the silver, to prevent scratching the silver on the surface of the multiplier electrodes. Another mandrel of the same size is placed behind each row. These three mandrels serve to hold the two rows of electrodes while the top strip of mica (which is punched similar to the lower strip) is fitted in place. The protruding ⅛" tabs or lugs of the electrodes are then bent around the edges of the mica walls, and are welded to the backs of the electrodes, as indicated in Fig. 1. The screen and collector are then assembled.

The resistors 41 are next mounted as shown in Fig. 1. The resistors may be held in place with the .008" nickel wire used for connecting the upper and lower electrodes.

For best operating conditions, the first accelerating electrode is tied to the first multiplier electrode, the second accelerating electrode is tied to the second multiplier electrode, etc., all the way down the tube. Jumper connections 43 are made with .008" nickel wire by welding onto the tabs that remain erect on back side of the electrodes. The resistors may be anchored in place by the jumpers.

Two short pieces of .020" nickel wire are welded on the photo-cathode and sixth accelerating electrode. Press wires welded to these wires on the electrodes mentioned above, serve to support the tube on the press. To make the unit more rugged, a glass bead is welded to one of the end multiplying electrodes and to the press wire which goes to the photo-cathode. The assembly can be made vibrationless by using mica washers, as used in ordinary vacuum tubes, although we have never been bothered by the slight vibrations which may arise.

The complete unit is then mounted on a 1", 8-wire circular press which has a 1¼" overall length of glass from flare to top end of wire-to-glass seal. The unit is mounted, as described, so that the end of the mica walls is about ¼" away from the end of the press.

Connections from various electrodes are made to the proper remaining press wires, which are cut to a length of about ¼", by means of .020" nickel wire enclosed by small glass tubing which acts as an insulator. The wire is welded to the same tabs described above. In order to get the minimum voltage between pins in the base, the connections are made as shown in Fig. 2.

The unit, now mounted on a 1" press, is sealed into a 1" glass tube whose length depends on the number of stages (5" long for 10 stages). The tube is then sealed onto a pump and baked at 475° C. for two to three hours.

After the tube is cooled, the nickel electrodes and collector electrode are heated with a high-frequency induction coil to a dull red in order to drive out all absorbed gases. Care must be taken not to get the silver electrodes too hot during this process because silver will evaporate over the mica walls. When all is cleaned and the tube cool again, the system is trapped off, and by heating a side tube on the system containing HgO, a millimeter of oxygen is admitted into the tube. Each silver electrode is oxidized to any color between the first blue and second green; all multiplier electrodes, however, must be oxidized to the same color. The first 5 to 6 multiplier electrodes must be oxidized with a high-frequency oscillator; the others may be either oxidized individually with a series of condenser (.25 mf.) discharges of about 800 V., or with an oscillator as above.

When oxidation is completed, the trap is opened and oxygen pumped out of the system. The tube is torched very slightly to drive off any absorbed oxygen from the glass walls. Caesium is then admitted from both ends of the tube, a small quantity at a time, and the tube is baked ten minutes at 210° C. After each bake, the tube is cooled and the photo-emission is checked. This process is continued until maximum photosensitivity is reached. With a fixed tube size and a fixed oxide film thickness, the quantity of caesium necessary for maximum photosensitivity may be found, and activation of subsequent similar tubes can be completed by one caesiation. In fact, the caesium pellets may be placed in convenient places inside the tube proper, as is done in present photo tube production.

The thicker the oxide film on the silver, the greater is the quantity of caesium necessary for complete activation and the less critical is this amount of caesium. Lead oxide may be used to prevent over-caesiation.

It has been found that the peak in the secondary emission vs. quantity of caesium curve lies just behind the photosensitive peak. Instead of measuring the photosensitivity of each multiplier electrode, the overall amplification can be measured on the system and the tube sealed off the system as soon as this amplification is maximum. The tube may then be based.

In operation of our device, a single magnetic field is employed for the purpose of concentrating the electrons from the emitting electrodes and for constraining them to impinge upon the next adjacent receiving electrode. The magnet partially shown in perspective in Fig. 1 is constituted by a V-shaped element of magnetically permeable material on which is mounted an energizing coil M and to each upstanding portion of which is affixed a plate N also of permeable material. Any convenient means may be utilized for this purpose, keeping in mind the fact that the magnetic field is to be parallel to the opposed faces of the electrodes and is to be transverse of the long axis of the container. The magnetic structure may be of the permanent or electromagnetic type.

From the foregoing it will be seen that we have provided a simplified electron multiplier that readily lends itself to a variety of uses, wherever high amplification of a primary electron stream is desirable.

The single embodiment of our invention was chosen solely for illustration. We are aware of numerous modifications thereof that will be apparent to those skilled in the art and our invention, therefore, is to be limited only by the prior art and by the spirit of the appended claims.

We claim as our invention:

1. An electrode structure for an electron-multiplier constituted by a pair of elongated insulating members disposed in parallelism and constituting a pair of opposed electron-confining walls, a plurality of electrodes supported by said members, the faces of the said electrodes lying in parallel spaced apart planes, the said electrodes being spaced apart from each other in the direction of extension of the insulating members, and a plurality of individual resistor elements supported by said insulating members and interconnecting certain of said electrodes for establishing a potential gradient therebetween.

2. The invention set forth in claim 1, wherein certain of the electrodes are provided with openings therethrough whereby the remaining electrodes opposed thereto may be more thoroughly activated during the process of manufacture of an electron multiplier wherein the electrode structure is employed.

3. A multi-electrode electron multiplier device comprising an elongated container, a pair of insulating strips mounted in parallel relation on opposite sides of the long axis of said container, a plurality of sets of electrodes supported by said insulating strips, the electrodes of one set being paired with the electrodes of another set, one electrode of one pair being conductively connected to another electrode of another pair, a plurality of current carrying support wires for said electrode assembly, and means for establishing potential gradients, between certain of the electrodes of at least one set, the said means being disposed interiorly of the container.

4. A multi-electrode electron multiplier device comprising an elongated container, a pair of insulating strips mounted in parallel relation on opposite sides of the long axis of said container, a plurality of sets of electrodes supported by said insulating strips, the electrodes of one set being paired with the electrodes of another set, one electrode of one pair being conductively connected to another electrode of another pair, a plurality of current carrying support wires for said electrode assembly, means for establishing potential gradients between certain of the electrodes and one set, and means for establishing potential gradients between certain of the electrodes of the other set, the said means being disposed interiorly of the container.

5. An electron multiplier comprising a plurality of pairs of opposed electrodes disposed within a container, a resistor element in said container interconnecting like electrodes of certain adjacent pairs, a conductive lead common to said interconnected electrodes, and individual leads for other of said like electrodes.

6. An electron multiplier comprising a plurality of pairs of opposed electrodes disposed within a container, one member of each pair comprising an electron emissive electrode, a resistor element in said container interconnecting the emissive electrodes of certain adjacent pairs, a conductive lead common to said internally connected emissive electrodes, and an electrode lead for each of the other of said emissive electrodes.

7. An electron multiplier comprising a plurality of pairs of opposed electrodes disposed within a container, one member of each pair comprising a non-emissive electron-accelerating electrode, a resistor element in said container interconnecting the accelerating electrodes of certain adjacent pairs, a conductive lead common to said internally connected accelerating electrodes, and other electrode leads for the other of said accelerating electrodes.

8. An electron multiplier comprising a plurality of pairs of opposed electrodes disposed within a container, one member of each pair comprising an electron-emissive electrode and the other a non-emissive electron-accelerating electrode, a resistor element in said container interconnecting the emissive electrodes of certain adjacent pairs, a second resistor element in said container interconnecting the accelerating electrodes of certain adjacent pairs, conductive leads individual respectively to said resistor-connected like electrodes, and a plurality of electrode leads for the non-resistor-connected emissive and accelerating electrodes.

9. The invention as set forth in claim 8, wherein an accelerating electrode of one pair is conductively connected to the emissive electrode of the pair adjacent thereto.

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