Sept. 5, 1950 A. H. SNELL ET AL 2,521,133

SECONDARY ELECTRON MULTIPLIER

Filed April 5, 1949 3 Sheets-Sheet 1

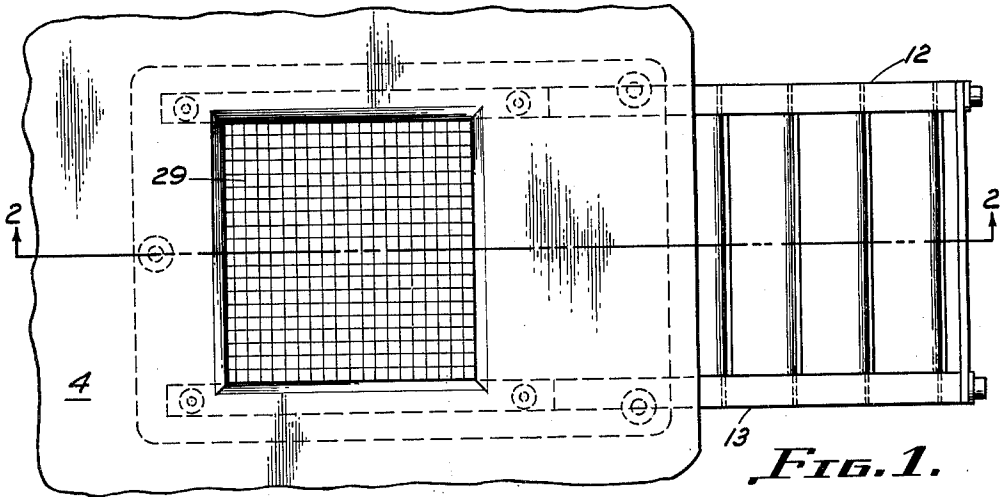


FIG. 1.

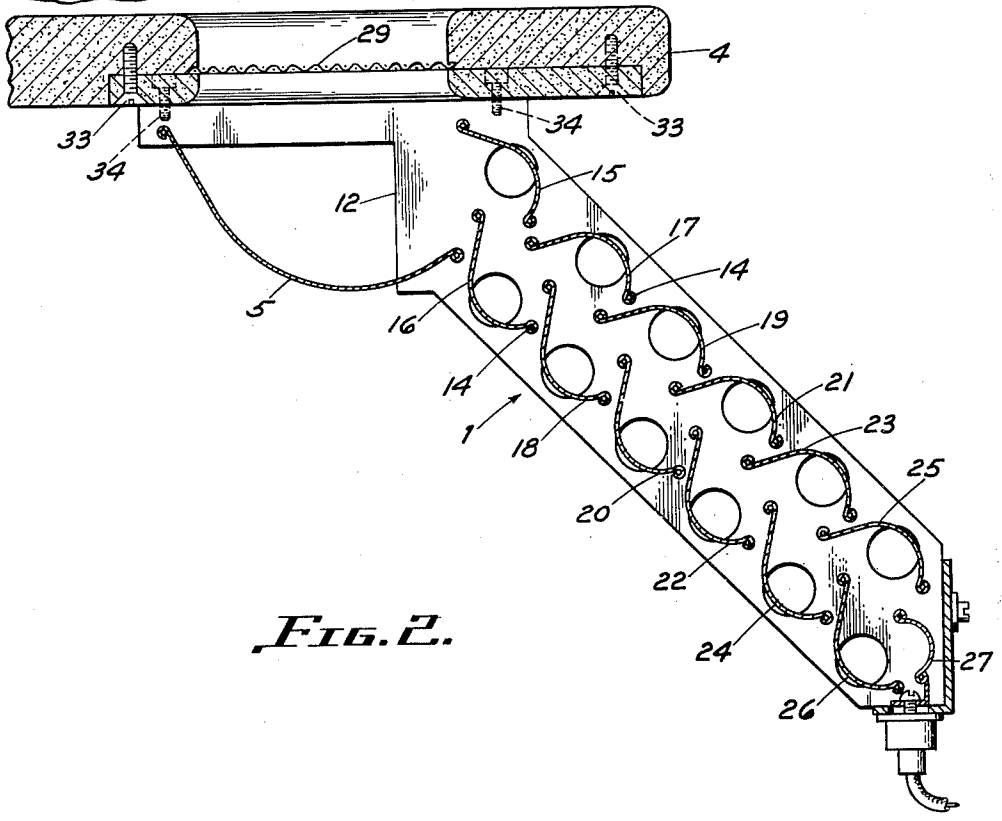


FIG. 2.

INVENTORS
ARTHUR H. SNELL
LEONARD C. MILLER, DECEASED,
BY URI MILLER, ADMINISTRATOR
Roland A. Anderson
ATTORNEY

Sept. 5, 1950 A. H. SNELL ET AL 2,521,133

SECONDARY ELECTRON MULTIPLIER

Filed April 5, 1949 3 Sheets-Sheet 2

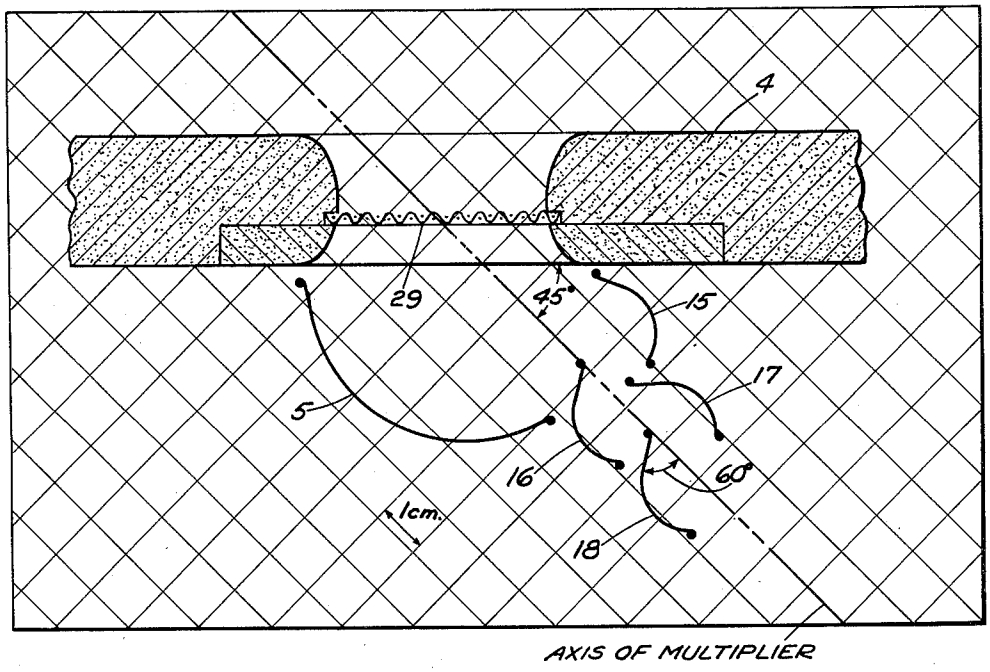


FIG. 3.

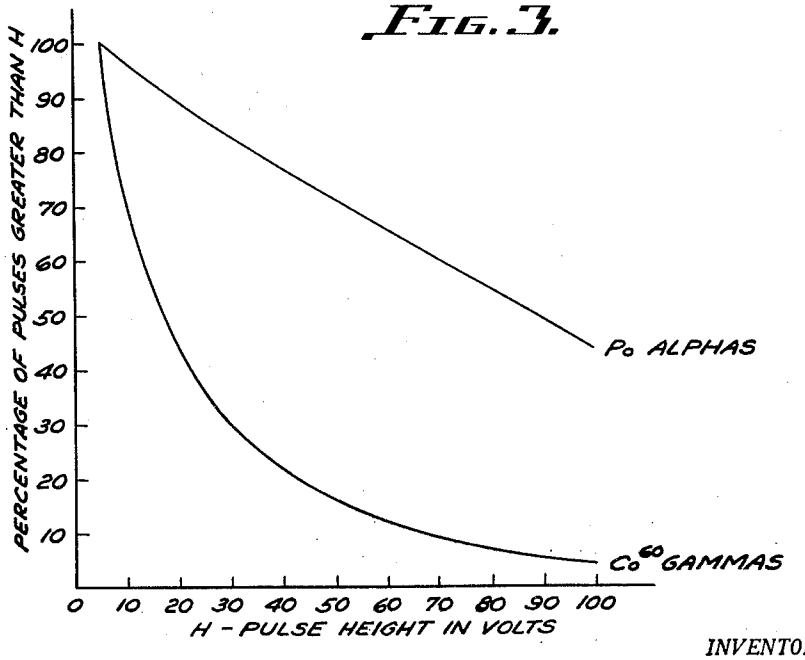


FIG. 5.

INVENTORS
ARTHUR H. SNELL
LEONARD C. MILLER, DECEASED,
BY URI MILLER, ADMINISTRATOR
Roland A. Anderson
ATTORNEY

Sept. 5, 1950 A. H. SNELL ET AL 2,521,133

SECONDARY ELECTRON MULTIPLIER

Filed April 5, 1949 3 Sheets-Sheet 3

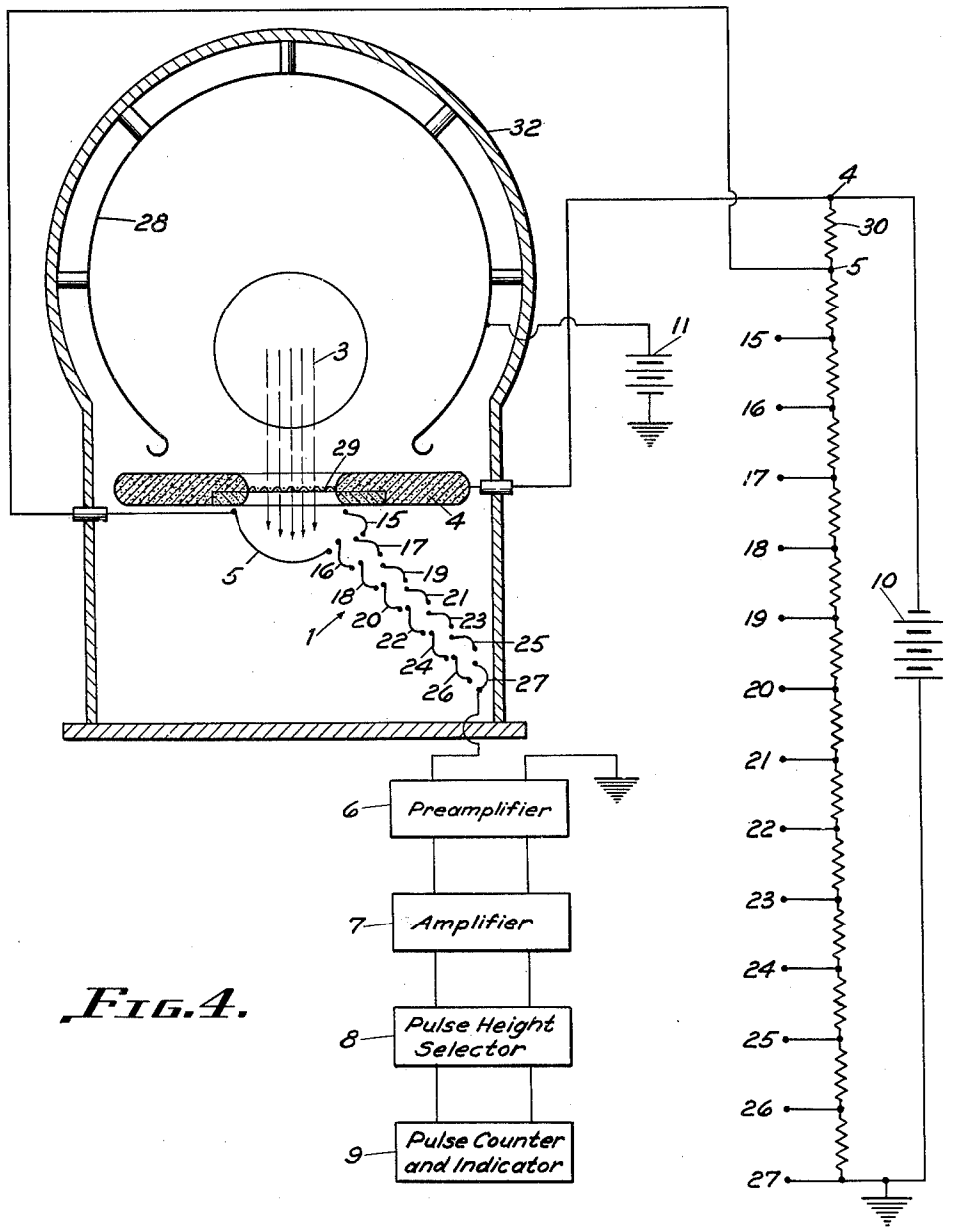


FIG. 4.

INVENTORS
ARTHUR H. SNELL
LEONARD C. MILLER, DECEASED,
BY URI MILLER, ADMINISTRATOR
Roland A. Anderson
ATTORNEY

Patented Sept. 5, 1950

2,521,133

UNITED STATES PATENT OFFICE

2,521,133

SECONDARY ELECTRON MULTIPLIER

Arthur H. Snell, Oak Ridge, Tenn., and Leonard C. Miller, deceased, late of Oak Ridge, Tenn., by Uri Miller, administrator, Baltimore, Md., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application April 5, 1949, Serial No. 85,668

8 Claims. (Cl. 250—83.6)

1

This invention relates to secondary electron multipliers, and especially to a method of and apparatus for counting radioactive radiations utilizing secondary electron multipliers.

The secondary electron multiplier, generally, consists of a series of dynodes, or secondary electron emissive metallic electrodes, located in such relative positions and maintained at such potentials that when an electron strikes the first electrode, secondary electrons are emitted by that electrode, and these electrons are electrostatically or electromagnetically focused to strike the second electrode. The secondary electrons emitted by the second electrode are focused to strike the third electrode, and so forth, until the collecting electrode, or anode, finally collects the electron beam. Because each emissive electrode gives up several electrons for each one striking it, a large number of electrons are collected at the final electrode for each electron impinging on the first electrode.

Use of the secondary electron multiplier as a particle counter has been suggested, and a successful counter built and tested. See Review of Scientific Instruments, 18, 739.

In using the multipliers of the type described therein for the measurement of radioactive radiation, we have encountered two serious difficulties. First, these multipliers, if subjected simultaneously to more than one type radiation, may produce a number of voltage pulses proportional to the total incident radiation intensity; but they have at most a very limited ability to discriminate between different radiations, or between radiations of different energies. If, for example, it were desired to count only the protons present in a beam of nuclear radiations, to the exclusion of the other radiations, prior multipliers could not be used. If, for a further example, a multiplier of the prior art were subjected to a beam of gamma radiation containing some protons, the output of the multiplier would be meaningless as regards proton counting; its output would contain pulses of various magnitudes, and the magnitude distribution would not be in direct proportion to the type of incident radiation or to the energy of the radiation.

Accordingly, it is an object of our invention to provide a secondary electron multiplier system for radiation detecting which is capable of discriminating between incident radiations, and which produces an output signal having its magnitude distribution substantially proportional to the number of incident quanta of a particular radiation.

2

The second problem in use of the multipliers of the prior art arose in attempting to count radiations present in a broad, ill-focused beam, typical of so many artificially produced radiation beams. The very narrow opening and first dynode of prior multipliers (about ⅜ in. wide), made counting of the entire beam impossible. But rather than enlarge the entire multiplier approximately four times to receive our wide beam, making it prohibitively expensive and bulky, we have found that by enlarging only the first dynode and the entrance aperture, and relocating slightly the subsequent dynodes, we can provide a multiplier able to count satisfactorily a wide beam of radiations.

Accordingly, another object of our invention is to provide a relatively small and inexpensive secondary electron multiplier for radiation counting adapted to receive a relatively wide, ill-focused radiation beam.

The novel features characteristic of our invention are set forth with particularity in the appended claims. The invention will best be understood from the following description of certain specific embodiments thereof, when read in connection with the accompanying drawings, in which:

Fig. 1 is a plan view of a preferred construction of our electron multiplier.

Fig. 2 illustrates a sectional view of that preferred form of our electron multiplier.

Fig. 3 shows the exact arrangement to scale of the entrance aperture and first five electrodes of the multiplier of Figures 1 and 2.

Fig. 4 is a schematic representation of a radiation detecting and counting system with which one form of our multiplier may be utilized.

Fig. 5 presents curves of counting rate vs. pulse height for the electron multiplier of Figures 1 and 2.

Referring now to Figures 1, 2, and 3, slabs 12, 13 of fired lavite or other ceramic material form the side plates of our multiplier and are adapted to receive and maintain in their relative positions Nichrome wire electrode supports 14. The electrodes 5 and 15—26 may be cut from beryllium-coated nickel, heat treated in vacuum, and assembled in air, after the manner described in Review of Scientific Instruments, supra, and may have their edges crimped over the supporting wires 14 so as to remain firmly in place. The relative position of the electrodes and the electrostatic voltages impressed thereon are critical, as is well known in electron-multiplier art. A satisfactory method used to determine the exact

spacing and arrangement of said electrodes is described by Zworykin et al., in Electron Optics, Wiley and Sons, 1945, p. 418, and consists essentially of rolling steel balls on a stretched rubber sheet, parts of which are elevated to correspond to given electrical potentials. The exact spacing of the first five dynodes is shown diagrammatically in Figure 3. The aperture for admitting radiation to the multiplier is cut in a conductive graphite plate **4** which bridges the slabs **12**, **13** adjacent the enlarged electrode **5**. This aperture may be approximately 1½ by 3 in., and is so located as to admit a radiation beam passing therethrough to fall entirely upon said electrode **5**. Across said aperture is bridged a grid of fine wire **29**, which may be 50 mesh copper wire, and which serves to aid the plate **4** in establishing the configuration of the electrostatic field within the multiplier. Each electrode is 2⅞ in. in length, perpendicular to the plane of the paper in Figure 2. To facilitate mounting screen **29**, a recess may be milled in plate **4**, the screen inserted, and a graphite frame of recess dimensions placed therein and fastened to the larger plate **4** with screws **33** and to the lavite with screws **34**.

Electrical potential may be supplied to the said plate **4** and each of the successive electrodes by means of a conventional regulated electronic negative power supply furnishing, for example, 4500 volts, and a voltage divider network, but for simplicity battery **10** furnishing 4500 volts to a divider network is illustrated. Interstage voltages of substantially 280 volts are maintained between each stage from **16** to **27** by means of the 250,000 ohm resistors connected therebetween. 500,000 ohm resistors between dynodes **5**—**15** and **15**—**16** cause a voltage drop of substantially 560 volts between each of those electrodes. The potential between plate **4** and dynode **5** may be established at different values, as will be described hereinafter. All resistors except that between plate **4** and dynode **5** may be connected between the wire supports **14**.

Referring now to Figure 4, our electron multiplier **1** may be disposed as a radiation detector within a vacuum chamber **32** cast from aluminum, for example, in which is maintained a pressure of from 10^{-4} to 10^{-6} mm. of mercury, by conventional vacuum pumping equipment not shown. Protons from the beam **3** which may come from a nuclear reactor may be attracted to and electrostatically focused upon the first dynode **5** in the multiplier through the aperture in plate **4**, because of the electrostatic field established by the large potential difference between plate **4** and focusing electrode **28**, and this radiation beam initiates a flow of electrons in the electron multiplier, culminating in a voltage pulse at anode **27**.

The pulses occurring at anode **27** may be amplified by a pre-amplifier **6** and linear amplifier **7**, which may be the A–1 amplifier and A–1 pre-amplifier described in Review of Scientific Instruments, 18, 703, having a self-contained power supply, and which may be operated at a gain of the order of 60,000. The amplified pulses are fed to a pulse height selector incorporated in the A–1 amplifier unit, and those pulses of greater magnitude than the bias of the selector feed a pulse counting and indicating unit **9** of conventional design, which may indicate on a register the rate of occurrence of the large pulses selected. A satisfactory pulse counting and indicating unit is commercially avialable from the Atomic Instrument Company, Boston, Massachusetts, and has a self-contained power supply.

It is frequently desired to change the potential maintained between plate **4** and dynode **5**. To facilitate this operation, leads from each may be brought out of the chamber **32** through insulated bushings. The interstage dropping resistor **30** may be removed and a different value resistor inserted to obtain the desired change. For a potential of 280 volts, a resistor of 250,000 ohms may be employed while to obtain a 40 volt potential difference, the resistance should be substantially 33,000 ohms.

Figure 5 shows two curves, serving to best illustrate the difference in the magnitude distribution of pulse spectrum at the output of amplifier **7** for for different radiations, the upper curve representing alpha-induced pulses, the lower curve, gamma-induced pulses. To obtain each curve, a constant potential difference was maintained between plate **4** and electrode **5**, and the multiplier tube was exposed to a constant-intensity radiation source. The bias on pulse height selector **8** was varied, and the counting rate was obtained for each step in the bias variation. Then a curve was plotted, using the said bias as abscissa and the percentage of pulses counted out of the known counting rate of the sample as ordinate.

A better understanding of the characteristics exhibited by the electron multiplier radiation detector of our invention and its mode of operation may be gained from the following additional example illustrating a method of employment of the multiplier in nuclear research.

Suppose it be desired to count the protons in a beam comprising both 8 Kev. protons and S^{35} beta rays, which is focused to pass through the aperture plate **4** and to fall upon the dynode **5**. Secondary electrons may be emitted from the dynode in proportion to the energy and number of particles incident upon the dynode **5**. The mean energy of the secondary electrons may differ: those liberated by the beta rays may be much more energetic than those liberated by the protons. The potential difference V between plate **4** and dynode **5** will substantially affect the shape of the electrostatic field, and so will affect the number of emitted electrons which are focused on the dynode **15**, and the number which are simply repelled to the emitting surface of dynode **5**. Those electrons which are focused upon dynode **15** by the electrostatic field existing within the multiplier cause secondary electron emission by that dynode, and those electrons are in turn focused upon dynode **16**. The number of electrons emitted becomes larger at each successive dynode **16**, **17**, **18**, **19**, **20**, **21**, **22**, **23**, **24**, **25** and **26**, until a copious quantity of electrons is collected at anode **27**, and a voltage pulse appears at the input to pre-amplifier **6**. The rate of occurrence of these pulses may be measured and indicated by means of pre-amplifier **6**, amplifier **7**, pulse height selector **8**, and counting circuit **9**, and will be proportional to the rate of incidence of radiation upon the dynode **5**. But since the potential difference V existing between aperture plate **4** and dynode **5** affects the number of secondary electrons which are repelled to said dynode, it affects the quantity of electrons collected at anode **27** and therefore affects the size voltage pulse there produced. We have discovered that changing the potential V and the consequent change in electric field configuration does not affect all secondary electrons produced from dynode **5** by radiations of different

energies and different types equally. We have found that there is an optimum potential V for repelling the secondary electrons emitted under 8 Kev. proton bombardment, for example, and that potential is different from the optimum potential for repelling electrons emitted under S^{35} beta ray bombardment. The potential will be a function of the energy of the radiation, the work function of the emitting surface, and the strength and configuration of the electrostatic field of the multiplier.

The effect produced by varying the potential V may be utilized to enable us to exercise control over the discrimination of our multiplier between various kinds of radiations. The following table shows the change in sensitivity to three types of particles as V is changed from 280 to 40 volts. The sensitivity is given as the ratio of number of very large pulses (those greater than 16.7 millivolts at the multiplier output stage 27) to the number of very small pulses (less than .25 millivolt at the stage 27) and the data may be obtained in the manner described for obtaining data for the curves in Figure 5.

Kind of Particle	Potential Difference V	
	280 Volts	40 Volts
Po alphas	0.90	0.36
S^{35} betas	0.28	0.096
8 Kev. protons	0.057	0.57
Co^{60} gammas	0.17	0.044

Thus, if it is desired to count protons in the presence of the S^{35} betas, the potential V would be set at a relatively low value, for example, 40 volts, and the bias setting adjusted to a large value, for example, 100 volts. From the table, it is seen that only a negligible number of beta-induced pulses will be counted, while a definite and much greater percentage of the proton-induced pulses, 57 per cent, will be counted.

Hence it becomes apparent that by proper adjustment of the said critical potential difference V and counting only the relatively large pulses, we can substantially eliminate all pulses due to a second radiation from the measured pulse count of a beam comprising the said second radiation and a first radiation we desire to measure. The measured pulse count must then be multiplied by a calibration factor, obtained from tables such as that given above, to determine the absolute disingration rate. Such tables can be readily made for any group of radiations it is desired to measure, and serve as a calibration of the electron multiplier and a guide to the optimum potentials for operating under each particular set of conditions.

What is claimed is:

1. Electron multiplying apparatus comprising: a pair of lateral support members, a plurality of secondary electron emissive electrodes, an electron collecting electrode, all of said electrodes being disposed between said support members in spaced relationship one to another, an electrically conducting plate having an aperture therein, said plate being disposed such that said aperture lies in directive relation to the first of said emissive electrodes, a grid structure across said aperture and conductively connected to said plate, said first secondary electron emissive electrode being of substantially greater surface area than the remainder of said electrodes, and means for maintaining between said plate and said electrodes an electric field of predetermined configuration for energy-selective focusing of secondary electrons.

2. Apparatus for radiation detection, comprising: a pair of lateral supporting members, an electrically conductive plate having an aperture therein and disposed in spaced relationship with said members, a grid structure across said aperture conductively connected to said plate, a source of variable electrical potentials, a primary electrode adapted to emit electrons over a spectrum of energies responsive to incident radioactive radiations, and disposed in directive relation to said aperture, a plurality of successive secondary electron emissive electrodes, an electron collecting electrode, all of said electrodes arranged in spaced relationship between said support members, said plate, said primary electrode, said grid, and at least one of said successive electrodes being connected to said source and arranged to define an energy-selective secondary electron filter.

3. Electron multiplying apparatus for radiation detection in a substantial vacuum, comprising: a pair of supporting side plates, an electrically conductive member having an aperture therein, said member being bridged across said side plates near one end thereof, a grid structure across said aperture conductively connected to said member, a plurality of secondary electron emissive electrodes and an electron collecting electrode arranged in spaced relationship within said envelope, the first of said electrodes being substantially larger than the remainder of the electrodes, and being arranged in directive relationship to the aperture in said conductive member, and means for focusing a selected group of the electrons emitted by said first electrode upon a second of said electrodes.

4. The method of utilizing a secondary electron multiplier to detect a particular type of radiation in the presence of an additional type of radiation comprising the steps of disposing the emissive surface of the first emissive electrode of the multiplier in the path of said particular type of radiation, counting the pulses occurring at the collecting electrode of the multiplier which exceed a critical magnitude, and adjusting the electrical field within the multiplier to a predetermined configuration such that secondary electrons liberated by the said particular type radiation are focused onto the second emissive electrode while substantially all the electrons liberated by the said additional type of radiation are not focused thereon.

5. The method of detecting a particular type of radiation in the presence of an additional type of radiation with a secondary electron multiplier having a conductive member disposed in fixed relation to the entrance aperture for altering the configuration of the electrical field within the multiplier, comprising the steps of disposing the entrance aperture of the multiplier in the path of the said particular type of radiation, counting the pulses which occur at the collecting electrode of the multiplier which exceed a critical magnitude, and impressing a predetermined critical potential difference between said conductive member and the first electrode of the multiplier, whereby substantially all electrons emitted by incidence of the said particular radiation are focused onto the second electrode in the multiplier and secondary electrons emitted by other radiations are not focused onto said second electrode.

6. The method of detecting and counting a particular type of radiation in the presence of other radiations, substantially in a vacuum, with

a secondary electron multiplier having a conductive member disposed in fixed relation to the aperture and electrodes thereof comprising the steps of: exposing the aperture and first electrode of said multiplier to a beam of radiations including said particular type, applying a potential difference between the aperture plate and the first of said secondary emissive electrodes, applying further potential differences between successive electrodes, counting the number of pulses occurring at said collecting electrode which exceed a predetermined value; and adjusting said potential difference between said plate and said first electrode to a predetermined value such that the number of pulses produced by said particular type of radiation which exceed said predetermined value is a maximum.

7. The method of detecting and counting with a secondary electron multiplier having a conductive member disposed in fixed relation to the entrance aperture and electrodes thereof protons present in a beam comprising protons and gamma rays involving the steps of: exposing the aperture of the electron multiplier to said beam; applying a potential difference between said member and the first of the secondary emissive electrodes, applying further differences in potential between successive electrodes, including said collecting electrode; counting the pulses occurring at said collecting electrode which exceed a predetermined magnitude; and adjusting said potential difference between said member and said first electrode to a predetermined value such that the number of proton-induced pulses which exceed said predetermined magnitude is a maximum.

8. Electron multiplying apparatus comprising: a pair of ceramic supporting side plates, an electrically conducting member having an aperture therein disposed across said plates, a plurality

of secondary emissive electrodes and a collecting electrode positioned in spaced relation between said side plates and supported in fixed relation thereto, a grid structure across said aperture and conductively connected to said member, a source of electrical potential, a voltage divider connected thereacross, certain points on said voltage divider being electrically connected to said plate and to each of said electrodes, respectively, for impressing accelerating voltages thereon, amplifying means having input and output circuits, said input circuit including said collecting electrode, pulse height discriminating means having input and output circuits and adapted to pass only pulses greater than a predetermined height to its output circuit, said input circuit of said discriminating means being conductively connected to the output circuit of said amplifier and pulse-counting means connected to the output circuit of said discriminating means adapted to provide an indication of the rate of occurrence of said pulses in said pulse height discriminator output circuit.

ARTHUR H. SNELL.
URI MILLER,
Administrator of the Estate of Leonard C. Miller, Deceased.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,157,585	Zworykin et al.	May 9, 1939

OTHER REFERENCES

Farago: Nature, vol. 161, p. 60 (1948).
Allen: Nucleonics, vol. 3, No. 1, p. 34 (1948).