A PORTABLE SCINTILLATION COUNTER

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Complete technical details on a nuclear radiation counter that, although not too simple, can be constructed at home.

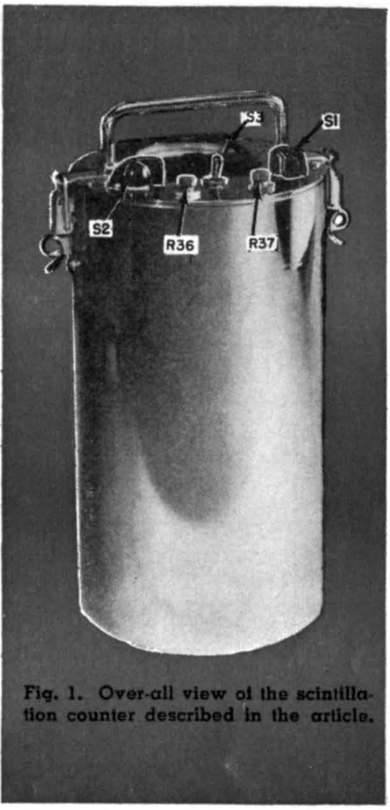


Fig. 1. Over-all view of the scintillation counter described in the article.

DURING the past few years, since it became apparent that uranium prospecting is profitable, the demand for prospecting instruments has increased tremendously. The Geiger counter has become rather well known to many, with details of its operation and construction available from many sources.

More recently, and particularly during the past twelve months, a relatively new instrument has become popular. This is the scintillation counter. Because of its greater sensitivity, this instrument has met wide acceptance and virtually replaced the Geiger counter in all but the more rudimentary surveys. Although widely accepted, the scintillation counter remains a stranger to most persons. Specific information concerning the principles of operation and general construction has not been readily available.

In order to correct this situation, this article offers detailed information on the electrical and mechanical construction of such a device along with a brief discussion of the basic principles of operation. See Fig. 1.

Principle of Operation

The principle of scintillation counting is not entirely new. Counting the occurrence of ionizing particles, alpha and beta emanations, was originally accomplished by visually counting the scintillations that the human eye could see. This process was slow and the accuracy of the count was determined by the skill of the person watching the medium—which was zinc sulphide or a similar luminescent material.

The introduction of Geiger counters, the first of the pulse ionizing devices, coupled to electronic counters practically eliminated the application of this type of counting. Since 1944, however, highly efficient luminescent materials which are sensitive to gamma rays plus light sensitive photomultiplier tubes have been used for radiation detection, measurement, and analysis.

Fig. 2 is the schematic diagram of a portable scintillation counter, the major sections of the circuit being outlined in dotted boxes. The detector assembly may be roughly described as a combination of a luminescent crystal and a light-sensitive photomultiplier tube. Optically coupling the crystal to the photocathode section of the tube allows light emitted with the occurrence of gamma rays to be converted to electrical current. Each pulse of light causes a pulse of current to pass through the tube.

EDITOR'S NOTE: *In view of the many requests from our readers for a scintillation counter, your Editors have finally worked up an article on the construction of such a unit that can be home-built. We do want to caution our readers that this is not a simple construction job. Only the trained technician should attempt this project. In addition, before buying any of the parts for this instrument, the over-all cost of the unit should be considered. For example, the photomultiplier tube will cost $50.00 and up and the smallest practical crystal (1" x ½") will run around $40.00.*

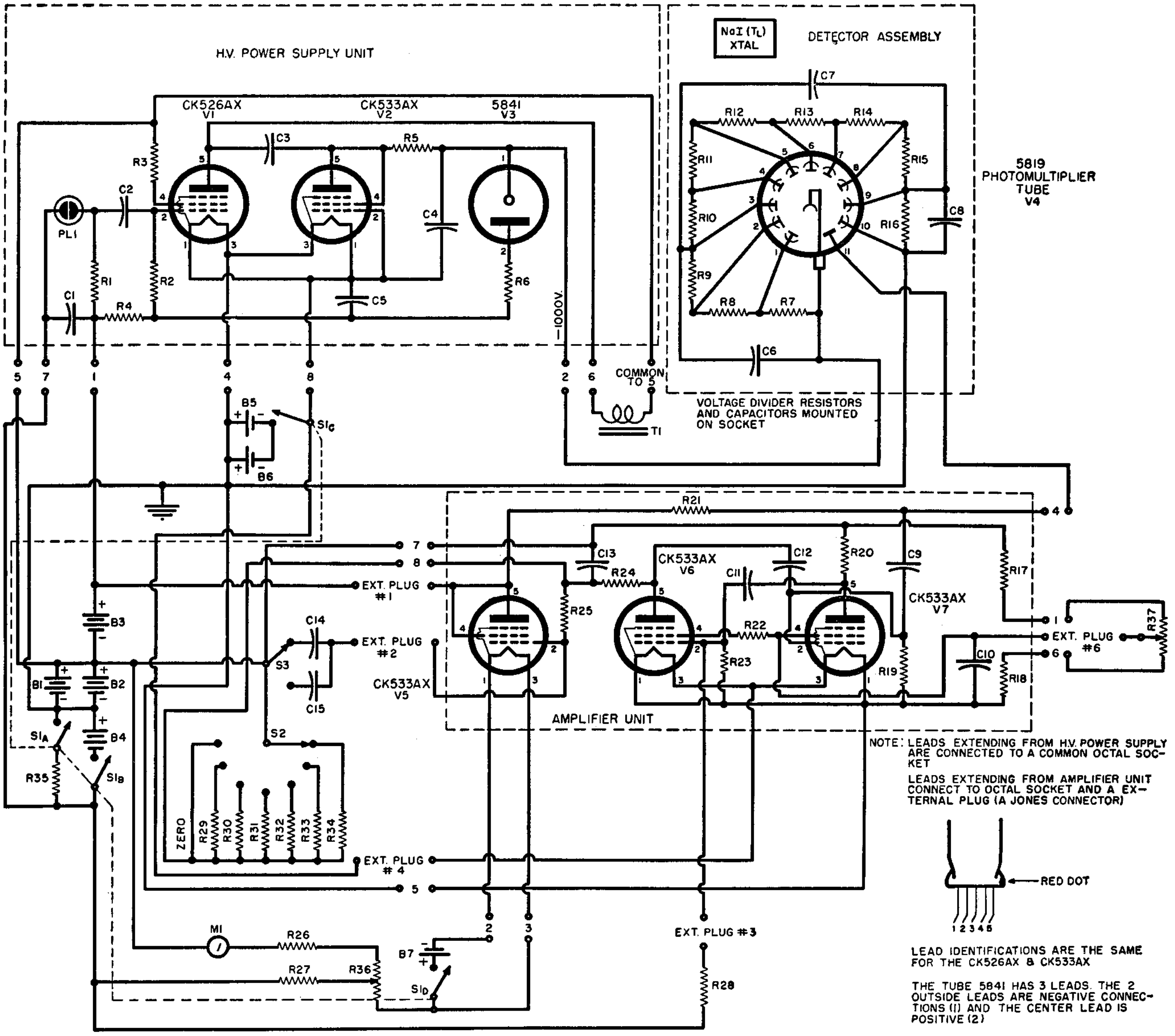
The photomultiplier tube is similar in operation to the ordinary phototube, but has ten additional elements between the usual cathode and anode. These elements are known as "dynodes" and serve to "multiply" the current flow started as photoelectrons at the cathode. The tube used in this circuit has an amplification factor of up to 1,000,000. In order to serve its function, each individual element above the cathode must be raised approximately 100 volts above the preceding element. A source of 100 volts could be coupled between each of the elements, but this is obviously impractical.

The most efficient and practical method of supplying the proper potential to each element is through the use of a suitable divider network, as shown. A 1000 volt potential across the network may be provided by any good d.c. supply. For use in a portable instrument, the high voltage supply should be as compact and light as possible.

A suitable high-voltage supply is shown in the schematic. Being of simple construction and because it uses commercially-available, portable-radio batteries and standard components, it is practical, efficient, and reliable. The combined voltages of B_1, B_2, B_3, and B_4 are applied across capacitor C_1, connected in parallel with a neon glow lamp, PL_1. When the voltage across C_1 reaches the firing potential of PL_1, the capacitor discharges, producing a pulse in the grid circuit of V_1. This relaxation oscillator produces pulses of fairly constant amplitude at a frequency of about 100 cps. V_1 is alternately conducting and non-conducting, pulling surges through the reactor in its plate circuit. Thus a high voltage is developed across this inductance and passed on to V_2. V_2 is a simple rectifier and V_3 is a glow-discharge regulator. The rectified and regulated high voltage appears as a negative 1000 volts with respect to ground.

Pulses appearing in the plate circuit of the photomultiplier tube as a result of light falling on its photocathode must be changed to some apparent indication to be of any value to the user of this device. The section of the circuit labeled "Amplifier Unit", coupled to a meter, accomplishes this function. Pulses are coupled to the grid of V_5, amplified and passed on to V_6 where they are further amplified. A simple feedback is used for greater efficiency. A 1 megohm potentiometer, R_{37}, is employed to control the amplitude of the pulse output of this amplifier. V_7 is connected as a simple rate meter, ac-

Fig. 2. Complete schematic diagram of the scintillation counter. The potentiometers R_{36} and R_{37}, as used by the author, were of the type designed to be used with a small knob. These are apparent in the photograph of Fig. 1. Since these controls are used for calibration and occasional adjustment only, they could be of the slotted shaft type. Since the construction of this unit is so compact, it is imperative that the smallest sizes of such components as fixed capacitors, potentiometers, and resistors, be obtained.



NOTE: LEADS EXTENDING FROM H.V. POWER SUPPLY ARE CONNECTED TO A COMMON OCTAL SOCKET

LEADS EXTENDING FROM AMPLIFIER UNIT CONNECT TO OCTAL SOCKET AND A EXTERNAL PLUG (A JONES CONNECTOR)

LEAD IDENTIFICATIONS ARE THE SAME FOR THE CK526AX & CK533AX

THE TUBE 5841 HAS 3 LEADS. THE 2 OUTSIDE LEADS ARE NEGATIVE CONNECTIONS (1) AND THE CENTER LEAD IS POSITIVE (2)

R_1, R_2—4.7 megohm, ½ w. res.
R_3—68,000 ohm, ½ w. res.
R_4, R_5, R_6, R_{30}—10 megohm, ½ w. res.
R_7—44 megohm, ½ w. res. (two 22 megohm res. in series)
R_8, R_9, R_{10}, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, R_{16}, R_{25}—22 megohm, ½ w. res.
R_{17}, R_{18}—220,000 ohm, ½ w. res.
R_{19}—470,000 ohm ½ w. res.
R_{20}—150,000 ohm, ½ w. res.
R_{21}, R_{32}—1 megohm, ½ w. res.
R_{22}—27,000 ohm. ½ w. res.
R_{23}—270,000 ohm, ½ w. res.
R_{24}—56,000 ohm, ½ w. res.
R_{26}—33,000 ohm, ½ w. res.
R_{27}—680,000 ohm, ½ w. res.
R_{28}—1.5 megohm, ½ w. res.
R_{29}—20 megohm, ½ w. res.
R_{31}—2 megohm, ½ w. res.
R_{33}—200,000 ohm, ½ w. res.
R_{34}, R_{35}—100,000 ohm, ½ w. res.
R_{36}—50,000 ohm linear taper pot
R_{37}—1 megohm linear taper pot
C_1—.002 µfd., 150 v. capacitor
C_2—200 µµfd. mica capacitor
C_3, C_4—.0047 µfd., 1500 v. capacitor
C_5—.1 µfd., 200 v. capacitor
C_6, C_7, C_8—100 µµfd., 600 v. mica capacitor
C_9—15 µµfd. mica capacitor
C_{10}, C_{13}, C_{14}—.01 µfd., 150 v. capacitor
C_{11}—56 µµfd. mica capacitor
C_{12}—5 µµfd. mica capacitor
C_{15}—.1 µfd., 150 v. capacitor
PL_1—NE-2 neon glow lamp
S_1—4-pole, 2-pos. rotary switch
S_2—S.p. 7-pos. rotary switch
S_3—S.p. 2-pos. rotary or toggle switch
B_1, B_2—67½ volt battery (Burgess K45)
B_3, B_4—22½ volt battery (RCA VS084)
B_5, B_6, B_7—1½ volt flashlight cell
T_1—300 hy. reactor (UTC 0-13 "Ouncer," or P-13 in plug-in type)
M_1—0-50 µa. meter, ruggedized (size optional)
V_1—CK526AX (Raytheon)
V_2, V_5, V_6, V_7—CK533AX (Raytheon)
V_3—5841 voltage regulator (Victoreen Instrument Co., 3800 Perkins Ave., Cleveland 14, Ohio)
V_4—Type 5819 (or 6199 smaller size) (RCA) This is the photomultiplier tube with photocathode in end of the glass envelope; operating potential 100 volts per stage.
1—6-conductor socket (Cinch-Jones S-306-AB)
1—Plug (Cinch-Jones P-306-FHT)
2—Octal tube sockets
2—Turret Plugs (Vector C-12T)
5—Battery mounting brackets for B_3, B_4 (#14, 50c each), B_5, B_6, B_7 (#7, 60c each) Available from Acme Model Engineering Co., 8120 7th Ave., Brooklyn, N. Y.
Crystal—Thallium activated sodium iodide, no smaller than 1" diameter and ½" thick, sealed in airtight container with a transparent window to allow light scintillations to be transmitted to the photocathode of the photomultiplier tube. Available complete and ready for mounting on phototube from The Harshaw Chemical Co., 1945 E. 97th Street, Cleveland 6, Ohio. When ordering, the supplier should be informed that the crystal will be used in a portable instrument and what type of photomultiplier tube is being used (the manufacturer's name and type number). This crystal is supplied with instructions covering coupling between its window and the end of the phototube. The constructor must place the crystal so that it will not change position with respect to the tube and so that no outside light will enter. Good mechanical support may be afforded and light kept out by the use of Scotch Type 33 tape. This black plastic tape should be wrapped around tube envelope, around junction between tube and crystal, and around the crystal itself.

cepting the amplified pulses applied directly to its grid. Each pulse allows V_7 to conduct momentarily in proportion to the amplitude of the pulse. The voltage drop across a resistance, R_{27} and R_{36}, in the cathode circuit of this tube appears as a deflection of the meter connected to the bottom of the resistor.

The intensity of a given field of gamma radiation, at least when measured with a scintillation counter, is usually expressed as being equivalent to a certain number of counts per unit of time, such as counts per second. Most other expressions, when applied to scintillation counting, are rather ambiguous. Therefore, this rate meter circuit must be calibrated with reference to a certain meter deflection being an indication of a certain frequency of pulses appearing in the plate circuit of the photomultiplier tube. This rate meter circuit is both frequency and amplitude sensitive to the pulses appearing at the grid of V_7. We may, therefore, calibrate and extend the limits of the meter deflections to a very wide range of frequencies by merely controlling the amplitude of the pulses as they appear to V_7.

As an example, if pulses of a given amplitude occurring at the grid of V_7 at a frequency of 100 cps cause the meter to deflect to full scale, we may cut the amplitude of the pulses in half and reduce the meter deflection to half scale. Naturally, if the amplitude remains the same and the frequency is decreased by one-half, the effect will be the same. S_2 is a frequency range selector for the rate meter circuit, since it linearly affects the amplitude of the pulses that are coupled from the output of V_5 and V_6.

Through the selection of the various ranges, the full-scale meter deflection of the meter may be used to indicate a wide range of frequencies from approximately 50 cps to 10,000 cps in six steps. The seventh position of S_2 has no resistance in it. This position places the rate meter circuit in a "no-signal" stage, allowing V_7 to be biased so that no current flows through the meter, effecting a "zero".

Close frequency calibration of the rate meter is also dependent upon the amplitude of the pulses impressed upon the grid of V_5. The output amplitude of this amplifier will be proportional to the amplitude of the input. R_{37} is, therefore, the master frequency calibration control of the instrument since it will directly control the output amplitude of the amplifier tubes.

Nuclear emanations from radioactive materials occur at random intervals so that any indication of their frequency of occurrence is merely an average indication. Counting an average frequency may be more accurately accomplished if the count is taken over a rather long period of time, especially if the frequency is quite low. In order to provide the user with a method of making precise frequency measurements and also allow him to note sudden changes, two time constants are provided. S_3 may be used to select either a fast or slow meter response or a short or long time constant.

Construction

Fig. 4 is a photograph of the portable scintillation counter without its case. The largest single component visible is the cylindrical detector assembly. Housed in a 20 gauge, 2¼" diameter steel tube which serves as a magnetic shield for the photomultiplier as well as a mechanical support, this assembly is larger than would ordinarily be used because of the large size of the crystal in this particular instrument.

Designed and used for aerial prospecting, the subject of the photograph employs a 2" crystal and a photomultiplier tube having a maximum diameter of 2¼" and a length of nearly 6". The tube socket may be seen extending from the top of the assembly. Adjacent to the detector assembly are the two *Vector* turrets housing the high voltage and amplifier units.

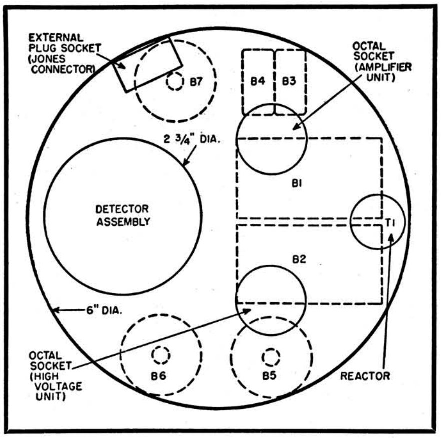
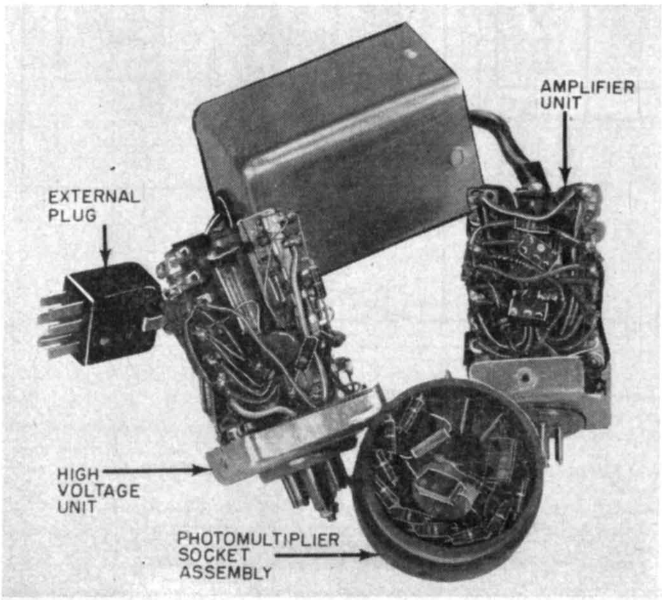
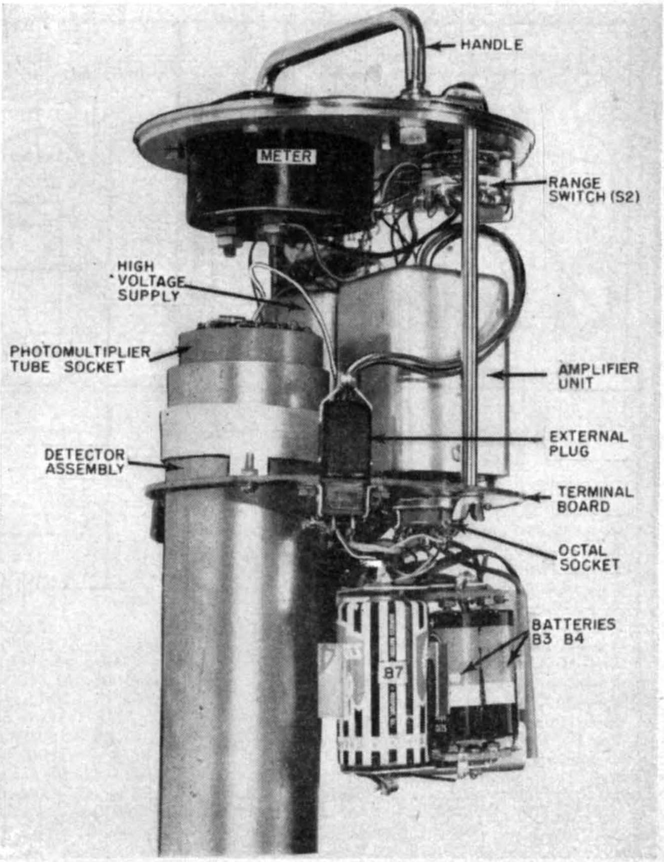


Fig. 3. Top view of mounting board, showing general layout of the component parts.

Fig. 4. Two internal views of the counter showing the various mechanical and electrical circuit elements. The photo below shows details of the high-voltage unit, the photomultiplier socket assembly, amplifier unit, and external plug. From the photograph, it is obvious that because of the super-compact assembly technique, the wiring of this unit will not be easy. In addition to the problems which will be encountered in the electrical circuitry, there are certain mechanical details which will require considerable effort. Although the circular type of construction is most convenient under normal operating conditions, it is not imperative that it be followed. Any desired shape or size of housing can be used equally as well.





The octal sockets for the plug-in turrets, the socket for the external connecting plug of the amplifier unit, the reactor (not visible), the detector assembly, and the battery mounting bracket assembly are all mechanically supported by a phenol-impregnated fiber terminal board 6" in diameter. A single, 16-conductor cable connects all of the panel-mounted switches and controls to the rest of the units.

The 3" meter and carrying handle are also mounted on the panel which serves as the cover for the case. Two steel rods connect the upper and lower parts of the instrument. By attaching the rods to the terminal board with butterfly head screws, service access is simplified. The layout diagram for the terminal board, Fig. 3, illustrates the position of the batteries and other components not shown in the photograph. Because this layout, requires a cylindrical case, the constructor may find it inconvenient. All component units may be laid out differently to accommodate the shape of whatever container is available to the individual. One must remember, however, that any material placed between the radioactive source and a detector is going to absorb some rays, thereby cutting down the efficiency of the instrument. Because of this, it is important that the wall that will come between any incident radiation and the crystal be of lightweight material such as aluminum. If the only case available is made of heavy material, such as thick steel, cut a hole of suitable size and cover it with a lightweight "window".

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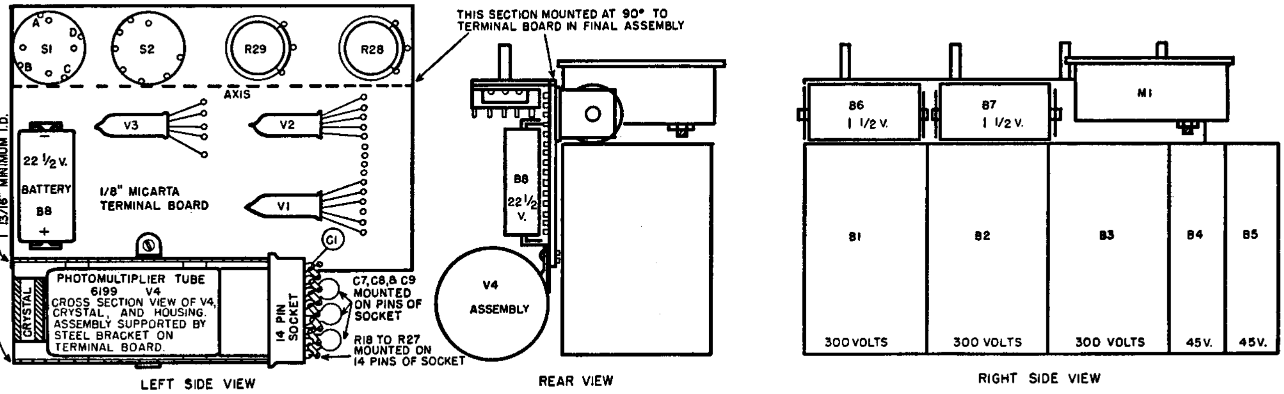
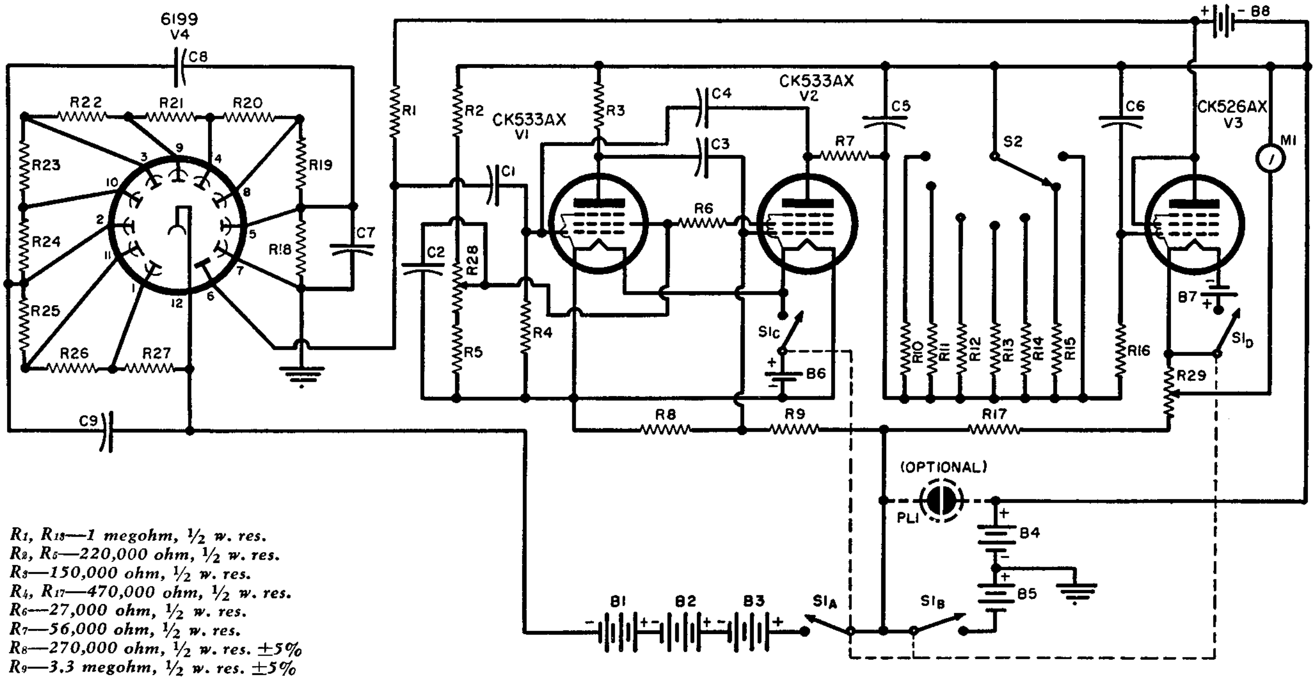
Schematic diagram and mechanical details of a somewhat simpler form of scintillation counter that has been tried and tested. The author, in this case, has built the unit in a rectangular form instead of the circular arrangement in the initial unit. Basically, the changes consist of using a smaller photomultiplier tube and using 900 volts of battery instead of a power supply for the high voltage. A few additional points are in order. An optical coupling fluid (Dow Chemical Co.) must be used to couple the glass window of the crystal package to the end of the 6199 photomultiplier tube. Sponge rubber strips should be used between the glass envelope of the 6199 and the steel tube shield. The crystal should be held in place against the 6199 by means of "Scotch" electrical tape. The electrical coupling from pin 6 of the 6199 to the grid of V_1 should be kept as short as possible. The subminiature tubes, V_1, V_2, and V_3, may be held in place by any suitable mechanical means. Any housing can be used in this construction providing heavy walls do not surround the portion of the 6199 assembly where the crystal is located.





R_1, R_{13}—1 megohm, ½ w. res.
R_2, R_5—220,000 ohm, ½ w. res.
R_3—150,000 ohm, ½ w. res.
R_4, R_{17}—470,000 ohm, ½ w. res.
R_6—27,000 ohm, ½ w. res.
R_7—56,000 ohm, ½ w. res.
R_8—270,000 ohm, ½ w. res. ±5%
R_9—3.3 megohm, ½ w. res. ±5%
R_{10}—20 megohm, ½ w. res.
R_{11}—10 megohm, ½ w. res.
R_{12}—2 megohm, ½ w. res.
R_{14}—200,000 ohm, ½ w. res.
R_{15}—100,000 ohm, ½ w. res.
R_{16}, R_{18}, R_{19}, R_{20}, R_{21}, R_{22}, R_{23}, R_{24}, R_{25}, R_{26}—22 megohm, ½ w. res.
R_{27}—44 megohm, ½ w. res.
R_{28}—100,000 ohm linear taper pot
R_{29}—50,000 ohm linear taper pot
C_1—150 µµfd., 600 v. capacitor
C_2, C_5, C_6—.01 µfd., 600 v. capacitor
C_3—560 µµfd., 600 v. capacitor
C_4—500 µµfd., 600 v. capacitor
C_7, C_8, C_9—100 µµfd., 600 v. capacitor
PL_1—NE-51 neon bulb
B_1, B_2, B_3—300 volt battery (Eveready 493 or Burgess U-200)
B_4, B_5—45 volt battery (Eveready 455)
B_6, B_7—1½ volt battery (Eveready D99)
B_8—22½ volt battery (Eveready 412)
S_1—4-pole, 2-pos. switch (Mallory 3242J)
S_2—S.p. 7-pos. rotary switch (Mallory 31112J 12-pos. unit was used)
M_1—0-50 µa. meter
1—Mount for PL_1—(Drake No. 101N)
Misc.—Mounting brackets and connectors for batteries are available where batteries are purchased.
V_1, V_2—CK533AX tube (Raytheon)
V_3—CK526AX tube (Raytheon)
V_4—6199 photomultiplier tube (RCA)
Crystal—See parts list, Fig. 2