Memoirs of the College of Science, University of Kyoto, Series A,
Vol. XXV, Nos. 3 & 4, Article 27, 1949.

A Type of Geiger-Müller Counter suitable for the Measurement of High Energy Gamma-Rays

By

Masateru SONODA

(Received December 15, 1949)

Introduction

The Geiger-Müller tube counter is widely used in the nuclear experiments for measuring β-particles, γ-quanta and cosmic rays. The properties and the counting mechanism for the counter have been investigated by many workers,[1-13] but are not yet decidedly known. It is, however, a most important problem to construct a stable counter which can reliably be used for a long time. In order to obtain such a counter, it is necessary to pay careful attentions to every constituent part of the counter, especially to the insulation and the state of the internal electric field. Thus we could construct a very stable counter which had a wide plateau, gave no spurious counts and could be reliably operated for a long time. This counter could satisfactorily be used for the γ-rays of comparatively low energies.

On the other hand, we have investigated for these several years the properties and the various effects of the high energy γ-quanta such as emitted by the (Li–p) or (F–p) reactions.[34-37] It became necessary to construct a reliable counter which has a high efficiency for these high energy γ-quanta and does not response to the scattered or secondary rays produced by the surrounding materials. A type of Geiger-Müller counter of comparatively thick wall of lead was found to be suitable for our purpose. Then the counting efficiency was calculated theoretically for various energies of γ-quanta, since the values are essentially useful for the determination of the absolute cross sections of various photo-nuclear reactions.

Construction

A brass counter, mainly used for measuring the γ-rays of lower energies, is shown in Fig. 1. A brass tube of 2 mm in thickness,

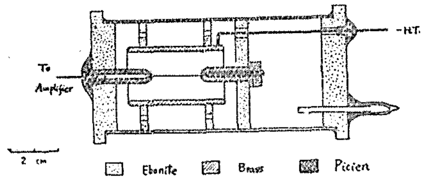

Fig. 1.

having the inner diameter of 2 cm and the length of 4 cm is mounted by the ebonite insulators in an outer cylinder of 1 mm in thickness, the diameter and the length of which are 4.4 cm and 10 cm respectively. The small wire of tungsten or piano wire is stretched along the axis of the inner tube. The outer cylinder is grounded and is used to shield the counter from the outer electric disturbances. Furthermore, since the surface leakage along the ebonite insulators from the inner tube on which the negative high voltage is applied is always earthed by this outer cylinder, it cannot give rise to any spurious pulse on the central wire which is connected in usual manner to the grid of the first valve of the amplifier. After several tests, the diameter of the central wire from 0.2 mm to 0.1 mm was found to be suitable for our counter. Since, however, the larger diameter gives the pretty wider range of plateau, we choose usually 0.2 mm diameter. The wire is supported at both ends by the poles of about 6 mm diameter which jet out 1 cm into the inner tube. In the counter of ordinary type the central wire is merely stretched along the axis of the tube, and therefore the electric field in the counter is distorted at the ends of the tube, resulting in the spoiling of the counter properties. In our counter, such a disadvantage is avoided. The effective length of the counter may be thought to be practically equal to the length between the tops of the poles and nearly 2 cm in our case. The central wire is tied at the one end to a small spiral spring of steel wire set inside the pole and can always be stretched tight, so that the length of the wire is constant throughout the experiment of a long time. The ebonite plugs which support the central poles are not directly fitted to the inner tube. If the insulator plugs are directly contacted in usual manner with the counter wall on which the negative high voltage is applied, the surface charge built up on the insulator may influence the field inside the counter and distort its uniformity. To avoid such disadvantages we adopted the type described above. The ebonite insulators supporting the inner tube must have fairly large surface to minimize the leakage along the surface, since this leakage may cause the spurious counts by the electric induction.

A hole at the end of the pipe through which argon gas and alcohol vapor are filled, is situated on the side of the pipe to avoid the corruption of the insulation of the ebonite surface by the impairment due to the impinging of the stream of alcohol vapor on the surface.

On the practical mounting of the counter, various attentions must be carefully payed. The tungsten wire must be cleaned adequately with benzine and heated in Bunsen flame to remove the undesirably contaminated matter on its surface. The wire is then inspected by a microscope. The inner surface of the counter tube was carefully treated with metal polishing powder and afterwards cleaned with benzine and distilled water untill there were no irregular scars and traces of grease. The ebonite surface was also carefully prepared and a very high surface resistance was obtained.

The counter thus constructed had the very good characteristics and gave no spurious counts due to bad insulation of the materials used and external electric disturbances. It was found excellent for the measurement of the γ-quanta of comparatively low energies.

In dealing, however, with the high energy γ-quanta such as emitted by (Li–p) or (F–p) reactions, the secondary electrons emitted from the outer shield cylinder and the surrounding materials are able to penetrate through the counter wall and enter into the effective space of the counter and give rise to additive counts. It is therefore very difficult to obtain the absolute intensity of the γ-ray with such a counter. A more reliable counter must be constructed for the measurement of the γ-rays of such high energy region.

The lead counter of comparatively thick wall was found to be suitable for our purpose. The one used in the experiments with 17.6 MeV γ-ray from (Li–p) reaction, was shown in Fig. 2. The construction is almost the same as the brass counter described above. The outer shield cylinder is made of aluminium of 1 mm thickness to minimize the absorption of the γ-ray to be measured. The counting part is a lead tube of 6.5 mm thickness whose inner diameter and length are 2 cm and 4 cm respectively.

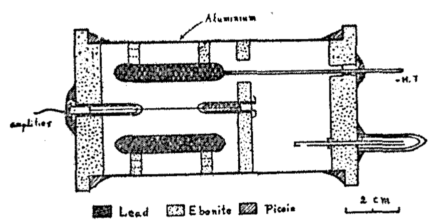

Fig. 2.

The reason of selecting lead of 6.5 mm thickness is that the lead wall of this thickness can just prevent those electrons of 17 MeV or less from entering into the effective space which may be emitted from the surrounding materials by this 17 MeV γ-ray. The counts are all due to the secondary electrons emitted from the lead wall and therefore the counting efficiency of the counter can theoretically be calculated. Further this thickness is nearly equal to the maximum range of the secondary electrons produced by the 17 MeV γ-ray and so the efficiency is possibly high for these γ-ray quanta.

As is shown in the later paragraph, the counter is found to be reliably used for the experiments of determining the absolute number of high energy γ-ray quanta emitted from a γ-ray source.

Amplifier Circuit

The amplifier used by us is shown in Fig. 3. It is an ordinary resistance capacity coupling circuit of 2 stages, but many filter condensers are effectively used to prevent the electrical disturbances from entering into the valves. The central wire of the counter is connected to the control grid of the first valve UZ 77, 6C6 or 6SJ7 through the minute condenser of about 20 pF. The high resistance, through which the central wire is grounded is of the order of $10^8 \sim 10^9$ ohms.

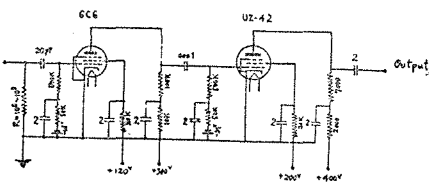

Fig. 3.

This high resistance was carefully prepared in the following manner. A fine silk thread was immersed in the alcoholic suspension of colloidal carbon for about two days, wound on a pyrex tube of about 6 mm diameter after having been dried and covered with bee wax. The resistance thus prepared was found to be very stable and scarcely affected by the atmospheric conditions, if it had been perfectly dried.

Each of the stages of the amplifier was mounted separately in the iron box of 1 cm thick and thus the electrical disturbances from the neighbouring electrical devices could be perfectly eliminated which may cause the spurious counts. This precaution is necessary for the counter to be used in the high tension laboratory.

The output from the power valve was supplied to the scale-of-16 counting system with a mechanical recorder. It was found that the counter system could be reliably operated up to the number of the kicks of about 8000 per minute.

Gas Mixture

Many workers[4, 9-18] studied the gas filled in the counter. A. Trost[1] succeeded to diminish considerably the duration of pulse and improve the characteristics of the counter by using the mixture of the vapor of an organic substance and a rare gas. It is found also in our laboratory that the good characteristics with a wide flat plateau is obtained if argon gas is mixed with the vapor of ethylalcohol. Such a counter can be used for a long time without any failure.

Before the filling up of the gas mixture, the counter must be evacuated continuously for more than fifty hours and the vapors or gases must be perfectly removed which may be absorbed in the counter materials. If this treatment is not perfect, the characteristics of the counter is not good and the life time is very short.

The argon gas and the vapor of ethylalcohol to be filled was dehydrated in the drying vessel containing the phosphorus pentoxide and calcium oxide, respectively, for 2 days at least and thus the moisture was perfectly removed.

After many tests it was found that the best characteristics was obtained when the mixture of 90 % argon and 10 % ethylalcohol was used. The slight change of this ratio or of the total pressure, however, does not seem to affect appreciably the properties of the counter except for the displacement of the characteristic curve as a whole.

Characteristic Curve

The characteristic curve of the so-called self quenching counter described above has been investigated by many workes.[1,4,10] The results obtained in our laboratory are also consistent with those of the other authors. They are shown in the following.

Fig. 4 shows the characteristic curve of the lead counter for several values of the high resistance R through which the central wire of the counter is grounded. As is shown, the length of the plateau is short for smaller values of R and becomes wider for larger R. It can be seen from the figure that R must be greater than 100 MΩ at least.

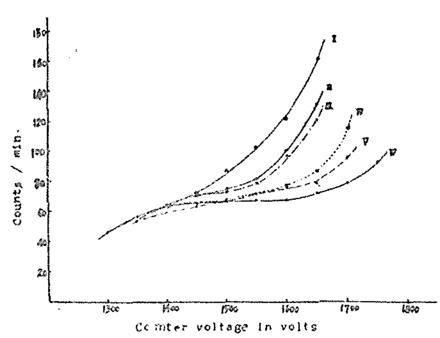

Fig. 4.

I $R = 0.1$ MΩ
II $R = 1$ MΩ
III $R = 10$ MΩ
IV $R = 50$ MΩ
V $R = 100$ MΩ
VI $R = 370$ MΩ
(Ar 9 cmHg+Alcohol 1 cmHg)

In the practical use, the measurments are made in the wide range of counting rate and therefore it must be ascertained whether the counter has a good characteristics at each counting rate. This was shown in Fig. 5, in which the characteristic curves were taken for several counting rate by changing the distance between the counter and the 1 mg Radium source. The radium source was filtered 13.6 mm lead and placed at the distances of 45, 90, 180 and 253 cm respectively. It is seen that the counter has a good characteristic curve independent of the counting rate.

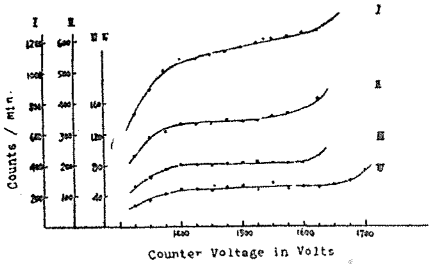

Fig. 5.

Ar 9 cmHg+Alcohol 1 cmHg
$R=23\times10^8\,\Omega$
1 mg Ra (filtered with 13.9 mm Pb) was placed at
I 45 cm II 90 cm III 180 cm IV 253 cm

Figs. 6 and 7 show the change of the counter properties with the gas pressure in the counter. The relative efficiency for Radium γ-rays and the length of the plateau are plotted against the total pressure of the gas when the vapor pressure of alcohol is kept at 1 cm Hg. The relative efficiency is smaller for the lower pressure. It increases gradually at first with the pressure and then remains constant at the pressure greater than about 10 cmHg. The length of the plateau is also small at first and it increases almost linearly with the pressure. The threshold voltage also increases linearly with the pressure.

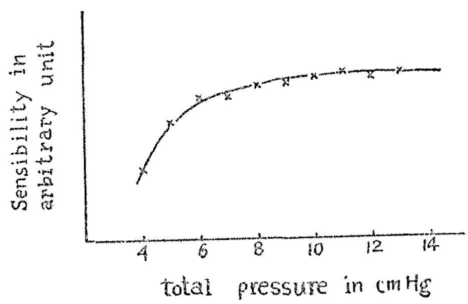

Fig. 6.

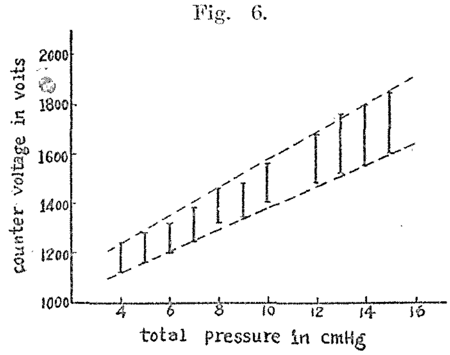

Fig. 7.

From the above results, it is concluded that our counter has the satisfactorily good characteristics and can be reliably used when the total pressure of the gas is about 10 cmHg$\sim$15 cmHg (90 % Ar + 10 % alcohol) and R is greater than

100 MΩ.

Efficiency of Counter

In order to obtain the absolute number of the incident γ-quanta from the measurement with counter, it is always necessary to determine the efficiency of the counter. A few workers[20-27,38] studied this problem for the γ-rays of comparatively low energies up to about $5\,mc^2$ and some results were obtained for the brass or aluminium counter. There is, however, no reliable knowledge for the high energy γ-rays such as emitted by the (Li–p) or (F–p) reactions. The author has tried to calculate theoretically the efficiency of the above-mentioned lead counter for the high energy γ-rays, since the experimental determination belongs to a very difficult thing in the present state of matter.* The calculation was made at first for the rectangular counter with the same thickness of wall as the cylindrical one for the sake of simplicity and afterwards the correction due to the oblique incidence was considered.

According to the quantum mechanical calculation,[29,30] the great majority of electrons are expected to be emitted in the forward direction in the processes of the pair creation and the Compton effect by such high energy γ-rays. Then the efficiency $\eta_a(h\nu,\ t)$ of the rectangular counter of the thickness t for the γ-quantum of energy $h\nu$ may be given by the following expression: **

$$\eta_a(h\nu,\ t) = \int \exp[-\tau(t-x)]dx \int [\sigma_c(h\nu,\ E)p(E,\ x)$$
$$+ \{2\sigma_p(h\nu,\ E)p(E,\ x) - \sigma_p(h\nu,\ E)p(E,\ x)p(h\nu-E,\ x)\}]dE,$$

where τ is the absorption coefficient of the γ-quantum considered,

x is the distance from the inner surface of wall where the secondary electron is produced,

$\sigma_c(h\nu,\ E)$ and $\sigma_p(h\nu,\ E)$ are the probability for the production of secondary electron of energy E by the incident γ-quantum of energy $h\nu$ by the Compton effect and the pair

* The author made a preliminary calculation of the efficiency of the thick walled lead counter described above, disregarding the effects of the multiple scattering and the radiation loss of the secondary electrons for the sake of simplicity.[28]

** A preliminary report of this calculation was given at the meeting of the Institute for Chemical Research, Kyoto University, November 1949. (Rep. Inst. Chem. Res. Kyoto Univ. **20** in press) The details of the calculation will be published soon. (Journ. Phys. Soc. Japan) creation process respectively,

and $p(E, x)$ is the probability with which the electron of energy E can penetrate through the thickness x of the wall.

The probabilities for the production of the secondary electron σ_c and σ_p can be given by the ordinary theory of quantum mechanics. To calculate the penetration probability $p(E, x)$, we must consider the effects of the multiple scattering and the radiation loss of the secondary electrons.

Fowler and others [31] studied the effect of the multiple scattering of electron in aluminium by the method developed by W. Bothe.[32] We have made a similar calculation for the case of the lead counter.

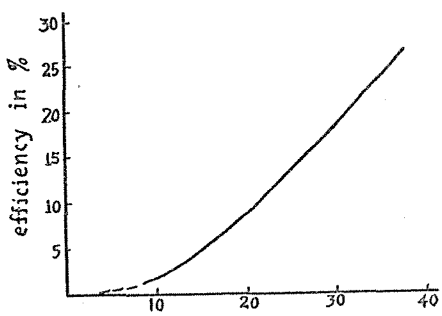

Fig. 8.

As to the radiation effect, the theory of the cosmic ray shower [33] has been applied, since the similar multiplication process is supposed to occur when a secondary electron of high energy penetrates through the wall of the counter.

The final results after making the correction due to the cylindrical shape, are listed in Table 1 and shown in Fig. 8.

TABLE 1. The Efficiency of the Cylindrical Counter (inner diameter : 2 cm)

Wall thickness in cm	Energy of γ-ray quantum in mc^2 12	20	25	30	34
0.20	3.7%	9.7%	13.6%	16.0%	17.4%
0.30	3.5	10.4	15.2	19.1	21.8
0.40	3.4	10.2	15.0	19.8	23.5
0.50	3.2	9.7	14.4	19.6	23.7
6.60	3.1	9.0	13.8	18.8	23.2
0.65	3.0	8.7	13.5	18.3	22.3

In conclusion, the author wishes to express his cordial thanks to Prof. B. Arakatsu, Prof. K. Kimura and other members of our laboratory for helpful suggestions on experiments and to Prof. M. Kobayasi for valuable discussions on theoretical calculations.

References

(1) A. Trost: ZS. f. Phys. **105** (1937), 399.
(2) C. G. Montgomery and D. D. Montgomery; Phys. Rev. **57** (1940), 1030.
(3) H. G. Steven: Phys. Rev. **59** (1941), 765; **61** (1942), 38.
(4) O. Minagawa: Proc. Imp. Acad. Tokyo, **18** (1942), 460, 468, 644; **19** (1943), 19, 246, 377; **20** (1943), 77, 288, 291.
(5) C. H. Collie and D. Roaf: Proc. Phys. Soc. **52** (1940), 186.
(6) R. D. Present: Phys. Rev. **72** (1947), 243.
(7) S. H. Liebson: Phys. Rev. **72** (1947), 602.
(8) H. Kumagai and others: Journ. Phys. Soc. Japan, **4** (1949), 39, 44, 48.
(9) H. Geiger and W. Müller: Phys. Zeits. **29** (1928), 859; **30** (1928), 489.
L. F. Curtiss: Bur. Stand. Journ. Res. **4** (1930), 601; **5** (1930), 115.
(10) W. Schultz: ZS. f. Phys. **78** (1932), 99.
(11) C. Bosen: Ann. d. Phys. **19** (1934), 65.
(12) C. L. Haines: R. S. I. **7** (1936), 411.
(13) O. S. Duffendack, H. Lifschutz and M. M. Slawsky: Phys. Rev. **52** (1937), 1231.
(14) S. C. Brown: Phys. Rev. **58** (1940), 1121.
(15) I. S. Allm and L. W. Alvarez: R. S. I. **6** (1935), 329.
(16) J. A. Bearden and C. L. Haines: Phys. Rev. **40** (1932), 1048.
(17) A. S. Keston: R. S. I. **14** (1943), 293.
(18) S. H. Liebson: Phys. Rev. **72** (1947), 181.
(19) H. Aoki and others: Proc. Phys.-Math. Soc. Japan, **22** (1940), 746; **23** (1941), 861.
(20) H. J. v. Baeyer: ZS. f. Phys. **95** (1935), 429.
(21) G. F. v. Droste: ZS. f. Phys. **100** (1936), 529.
(22) G. J. Sizoo and H. Willemsen: Physica **5** (1936), 105.
(23) F. Norling: Phys. Rev. **58** (1940), 277.
(24) J. v. Dunworth: R. S. I. **11** (1940), 107.
(25) I. Nonaka: Proc. Phys.-Math. Soc. Japan, **25** (1943), 227.
(26) K. Buchmann: Phys. Zeits. **38** (1937), 817.
(27) H. Yukawa and S. Sakata: Sci. Pap. Phys-Chem. Res. **31** (1937), 187.
(28) M. Sonoda: Journ. Phys. Soc. Japan, **5** (1950), 53.
(29) See, for example, W. Heitler: Quantum Theory of Radiation (1936).
(30) H. Bethe: Proc. Cambr. Phil. Soc. **30** (1934), 524.
(31) W. A. Fowler, C. C. Lauritsen and T. Lauritsen: Rev. Mod. Phys. **20** (1948), 258.
(32) W. Bothe: Handbuch der Physik XX II/2 (1933).
(33) See, for example, B. Rossi and K. Greisen: Rev. Mod. Phys. **13** (1941), 240.
(34) B. Arakatsu and others: Proc. Phys.-Math. Soc. Japan, **23** (1941), 440.
(35) B. Arakatsu and others: ibid. **23** (1941), 633,
(36) B. Arakatsu and others: ibid. **25** (1943), 173.
(37) B. Arakatsu and others: Journ. Phys. Soc. Japan, **1** (1943). 24.
(38) A. Roberts, J. R. Downing and M. Deutsch: Phys. Rev. **60** (1941), 544.

Institute of Physics,
University of Kyoto.