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$1/f$ noise in the radioactive β^- decay of ^{204}Tl

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An attempt has been made to detect the presence of $1/f$ fluctuations in β^- decay using the Allan variance theorem. For counting periods less than about 800 min, the counting statistics were found to be Poissonian and for periods greater than about 800 min, the statistics were found to be non-Poissonian. $1/f$ fluctuations in the β^- emissions were observed leading to a flicker floor. It was also found that the flicker floor varies with energy of the emitted β^- particles from ^{204}Tl used in the experiment.

INTRODUCTION

The experiment discussed in this paper was undertaken with the hope of confirming Handel's theory of $1/f$ noise.[1] $1/f$ noise is an ubiquitous phenomenon. It has been reported not only in electrical but also in nonelectrical and biological systems.[2] It has also been encountered in music.[2]

Various theories have been put forward to explain the origin of $1/f$ noise, one of these being the quantum theory of $1/f$ noise by Handel.[1] The quantum theory of $1/f$ noise predicts that at low frequencies $1/f$ noise will be present for all processes involving charged particles. It predicts that $\beta^{\pm}$ or α emissions will show $1/f$ noise at low frequencies.[3]

The presence of $1/f$ noise in counting statistics can be determined from a measurement of the Allan variance $A(T)$ of the counts as a function of time interval T for which counting is made.[4] The relative Allan variance[4] $R(T)$ is defined as

$$R(T)=\frac{A(T)}{\langle M_T\rangle^2} ,$$

where

$$A(T)=\frac{1}{2(N-1)}\sum_{i=1}^{N-1}|M_T^i-M_T^{i+1}|^2 ,$$

and $\langle M_T\rangle$, the mean count, is $(1/N)\sum_{i=1}^{N}M_T^i$. Here N is the number of measurements made and M_T^i is the count observed during the ith measurement for a time interval T. For non-Poissonian emissions, the relative Allan variance reaches a fixed value called the flicker floor, which determines the strength of $1/f$ noise.[5] The presence of a flicker floor is therefore a test for the existence of $1/f$ fluctuations in radioactive emissions.

EXPERIMENTAL METHOD

In the present investigation we have studied the quantum $1/f$ noise of the β^- particles emitted by the radioactive source ^{204}Tl. $^{204}_{81}$Tl decays to $^{204}_{82}$Pb with a half-life of 12×10^7 sec ($\simeq$4 yr) by β^- emission. The maximum β particle energy is 0.765 MeV.

The experimental setup is shown in the block diagram of Fig. 1. An NE-102 plastic scintillator was mounted on a photomultiplier. Good optical coupling between the two was achieved by using silicone oil. The output from the photomultiplier was coupled to a preamplifier and then to a linear-pulse amplifier, type PA-521. The amplified pulses were analyzed in a multichannel analyzer, type MCA-38. Except for the plastic scintillator, the whole electronic system is that manufactured by the Electronics Corporation of India Limited, Hyderabad. The ^{204}Tl source was placed above the plastic scintillator, such that the count rate was not in excess of 100 counts/min in any channel.

The β spectra were recorded for various time periods ranging from 10 to 1000 min. Counts for longer time periods were achieved by the "add-up" technique.[6] Data acquisition was continued until a large number of samples were collected for each time interval. The laboratory temperature was also constantly monitored. All the count samples obtained in each channel for a given T were then fed to a personal computer which was programmed to calculate the Allan variance, the mean count, and the relative Allan variance. These calculated values for different times ranging from 10 to 4000 min were used for further analysis. This procedure was repeated for other channels also.

The multichannel analyzer was calibrated by taking

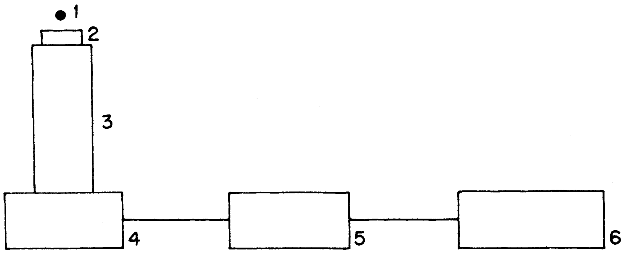

FIG. 1. Block diagram of the experimental setup. 1, ^{204}Tl source; 2, NE-102 plastic scintillator; 3, photomultiplier tube; 4, preamplifier; 5, linear pulse amplifier, type PA 521; 6, multichannel analyzer.

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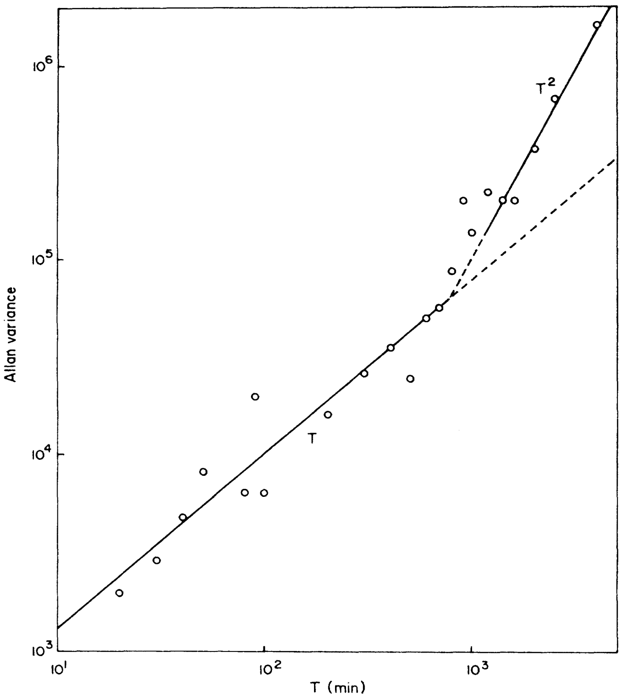

FIG. 2. A plot of Allan variance vs T for β energy of 172 keV.

the Compton electron spectrum of the radioactive source ^{137}Cs. The Compton edge corresponding to the Compton electrons backscattered at 180° was clearly located, which corresponds to 477 keV. This calibration spectrum was taken prior to and after every set of readings. If there were any changes in the location of the Compton edge, that set of readings was rejected.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows experimentally obtained values of Allan variance versus the time interval T over which counting is performed. It can be seen that until $T \simeq 800$ min, it shows a linear dependence on T for the Allan variance, and for $T > 800$ min, the Allan variance deviates, indicating the presence of $1/f$ noise, since it is approximately proportional to T^2 (Ref. 5). This means that the counting statistics for counting time intervals $T > 800$ min shows $1/f$ noise in addition to shot noise and therefore follows non-Poissonian statistics.

Figure 3 shows experimentally obtained values of the relative Allan variance versus the inverse of the counting time interval, i.e., $1/T$. It can be seen that the dependence of $R(T)$ on $1/T$ has deviated from linearity to reach a value called the flicker floor. This value has been determined for different energies of the β spectrum.

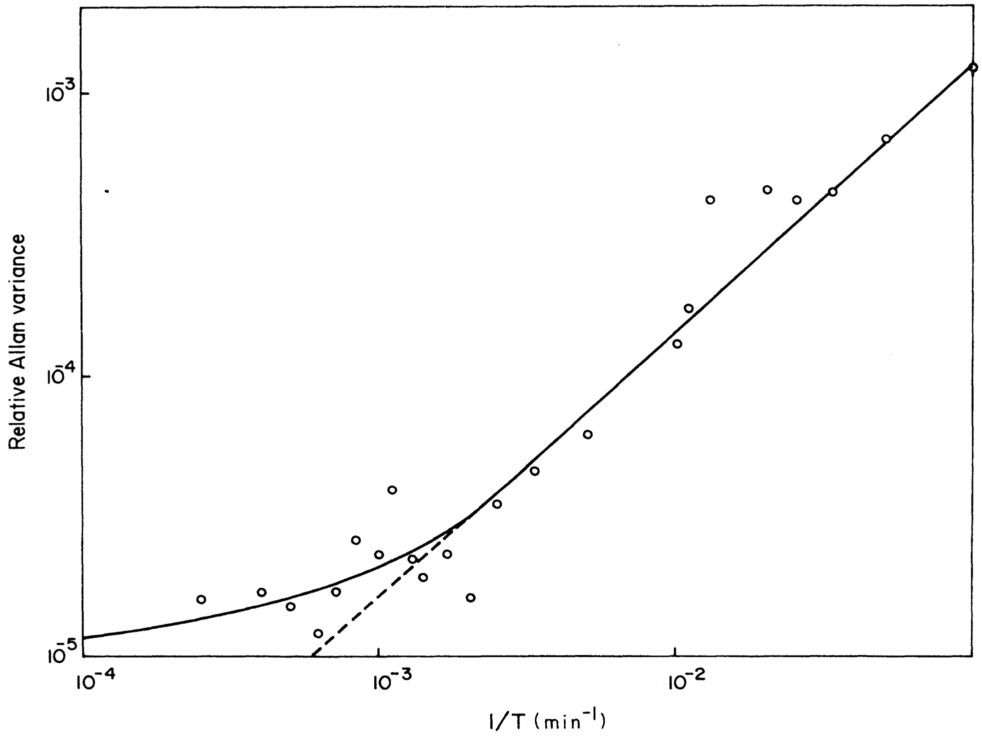

FIG. 3. A plot of the relative Allan variance vs T^{-1} for β energy of 172 keV.

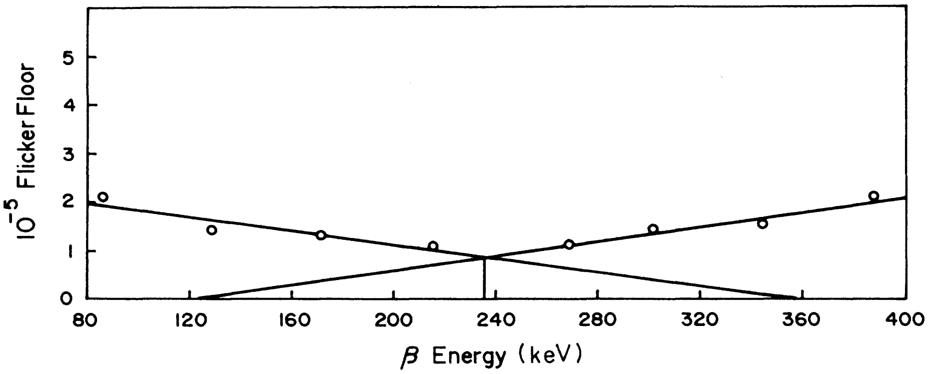

FIG. 4. A plot of the flicker floor vs β energy.

Since the presence of a flicker floor indicates the presence of $1/f$ noise,[5] we infer that $1/f$ noise is present in the β^- emission of ^{204}Tl.

The nature of the variation of flicker floor F with the particle energy E_β has been shown graphically in Fig. 4. F has decreased linearly from $E_\beta=86$ keV to 236 keV, whereas it has increased linearly from $E_\beta=236$ keV to 387 keV. The least-squares-fit lines can be represented as

$$F=-7.209\times10^{-8}E_\beta+2.56\times10^{-5} \quad \text{for } 86\text{ keV}<E_\beta<236\text{ keV},$$

$$F=7.176\times10^{-8}E_\beta-7.965\times10^{-6} \quad \text{for } 236\text{ keV}<E_\beta<387\text{ keV}.$$

From Handel's theory, F is given by the following expression:[5]

$$F=\frac{4\alpha A\zeta\ln2}{K}, \tag{1}$$

where α, the fine structure constant, equals $\frac{1}{137}$ and

$$A=2(\Delta\mathbf{V})^2/3\pi c^2 .$$

Here, $(\Delta\mathbf{V})$ is the velocity change of the particles in the emission process, c is the velocity of light, ζ is the coherence factor, and K is the dielectric constant of the radioactive material. For β particles, $(\Delta\mathbf{V}/c)^2$ is given by

$$(\Delta\mathbf{V}/c)^2=\left[1-\left[1+\frac{E_\beta}{m_0c^2}\right]^{-2}\right],$$

where E_β is the kinetic energy of the β^- particle and m_0c^2 is the rest energy of the electron. Hence from (1),

$$\frac{F}{A}=\frac{F}{\dfrac{2}{3\pi}\left[1-\left[1+\dfrac{E_\beta}{m_0c^2}\right]^{-2}\right]}=\frac{4\alpha\zeta\ln2}{K}=\text{a constant}. \tag{2}$$

Table I shows the experimental values of F and the corresponding values of F/A for different E_β. Only four values of F/A are consistent, and their mean value is 10.4×10^{-5}. The value of the dielectric constant K of Tl_2SO_4 (the enriched ^{204}Tl of which is our source) has been calculated to be 3.5006 using its refractive-index values given in Ref. 7. Hence from Eq. (2) the value of ζ, the coherence factor for β^- emission, is 0.018. For α emission Gong[4] has calculated ζ to be 0.05. The value of the coherence factor for β emission has to be less than that for α emission because of the incoherence introduced due to the neutrino emission.[5] Hence the value of ζ as determined by us looks reasonable.

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