Search for $1/f$ fluctuations in α decay of ^{210}Po

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An experiment to detect the presence of $1/f$ fluctuations in the α-particle decay statistics of ^{210}Po has been conducted. No evidence for such fluctuations has been found, at least for frequencies in excess of 10^{-6} Hz.

INTRODUCTION

The presence of $1/f$ noise has been detected in a variety of systems.[1] This phenomenon is so called because of its spectral density. The spectral density of $1/f$ noise is given by C/f, where C is a constant. Handel's theory[2] shows that any process involving the deceleration or acceleration of charged particles must exhibit $1/f$ fluctuations. One can therefore expect $1/f$ fluctuations in the particle current or counting statistics of radioactive emissions. However, spontaneous radioactive emissions that occur during the decay of heavy nuclei, emitting α particles, is supposed to follow Poisson statistics. Accordingly, the particle current should exhibit only full shot noise (Poissonian noise). The Allan variance theorem[3] links the Allan variance, $A(T)$ of the counts in a period T to the noise spectral density $S_m(\omega)$ of the counting rate as

$$A(T)=\frac{4}{\pi}\int_0^\infty \frac{d\omega}{\omega^2} S_m(\omega)\sin^4\frac{\omega T}{2} \ . \tag{1}$$

It has been shown that $A(T)=\langle M_T\rangle$ for full shot noise, where $\langle M_T\rangle$ is the mean count. For a stationary process, $\langle M_T\rangle=\langle m\rangle T=m_0T$, where m_0 is the average count per minute. $A(T)=k\langle M_T\rangle$ for general shot noise, where k is called the super-Poisson factor. $A(T)=2CT^2\ln 2$ for flicker noise. The relative Allan variance $R(T)$ is defined as $A(T)/\langle M_T\rangle^2$. $R(T)$ for full shot noise, general shot noise, and $1/f$ noise will therefore be $1/\langle M_T\rangle$, $k/\langle M_T\rangle$, and $2CT^2\ln 2/\langle M_T\rangle^2$, respectively. If the particle current consists of general shot noise and $1/f$ noise then

$$R(T)=\frac{k}{\langle M_T\rangle}+\frac{2CT^2\ln 2}{\langle M_T\rangle^2} \ . \tag{2}$$

Noticing that $\langle M_T\rangle=m_0T$,

$$R(T)=\frac{k}{\langle M_T\rangle}+\frac{2C\ln 2}{m_0^2}=\frac{k}{\langle M_T\rangle}+F \ , \tag{3}$$

where $2C\ln 2/m_0^2=2C'\ln 2$ is a constant called the flicker floor F (Ref. 3) and is indicative of $1/f$ noise. General shot noise and $1/f$ noise arise in counting statistics when there is photon emission during radioactive decay and the counting process used to describe this no longer follows simple Poisson statistics, but follows compound Poisson statistics.[4]

Gong *et al.*[5] have experimentally shown that the decay process in ^{241}Am which emits α particles departs from simple Poisson statistics for counting times greater than 200 min. They also showed a flicker floor of 1×10^{-7} due to $1/f$ noise. This estimated value of the flicker floor was found to agree with Handel's theory. But the experimental results of Prestwich *et al.*[6] who studied the presence of $1/f$ fluctuations in the γ decay of ^{241}Am arising out of α emission and those of Gopala and Athiba Azhar[7] who studied the presence of $1/f$ fluctuations in the γ emission arising out of β emission of ^{137}Cs contradicted Handel's theory. The present paper contains the results of our investigation into the α emission of ^{210}Po.

EXPERIMENTAL PROCEDURE

The counting system ACS 4004 from Electronics Corporation of India Limited, Hyderabad, was used to count the α particles emitted from ^{210}Po. ACS 4004 consists of a silver-activated zinc sulfide [ZnS(Ag)] screen,[8] a photomultiplier tube of type EMI 9656, and counting electronics. The instrument was switched on half an hour prior to taking the counts. Counts were recorded for time periods ranging from 8 to 1000 min. Counts for longer time periods were obtained by the "summing-up" technique.[9] For example, the first count for 2000 min was taken as the sum of the first count for 1000 min and the second count for 1000 min, i.e., $M_{2000}^{(1)}=M_{1000}^{(1)}+M_{1000}^{(2)}$, and the second count for 2000 min was taken as the sum of third count for 1000 min and the fourth count for 1000 min, i.e., $M_{2000}^{(2)}=M_{1000}^{(3)}+M_{1000}^{(4)}$ and so on. Summing up of data this way has been shown to give very little error.[9] Data acquisition was continued until a large number of samples were collected hoping thereby to find a correct converging value of the relative Allan variance. These counts were then used to calculate the Allan variance, mean count, and the relative Allan variance as

$$A(T)=\frac{1}{2(N-1)}\sum_{i=1}^{N-1}|M_T^{(i)}-M_T^{(i+1)}|^2 \ , \tag{4}$$

$$\langle M_T\rangle=\frac{1}{N}\sum_{i=1}^{N}M_T^{(i)} \ , \tag{5}$$

$$R(T)=\frac{A(T)}{\langle M_T\rangle^2} \ , \tag{6}$$

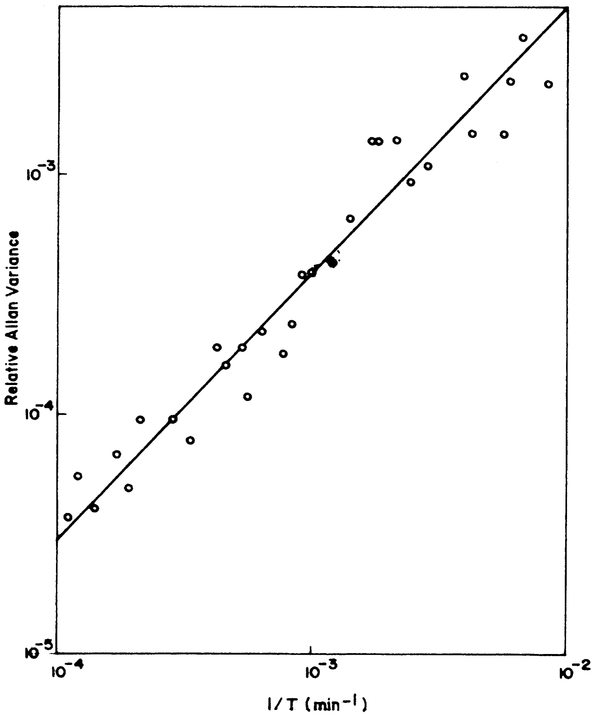

FIG. 1. Plot of relative Allan variance vs T^{-1}.

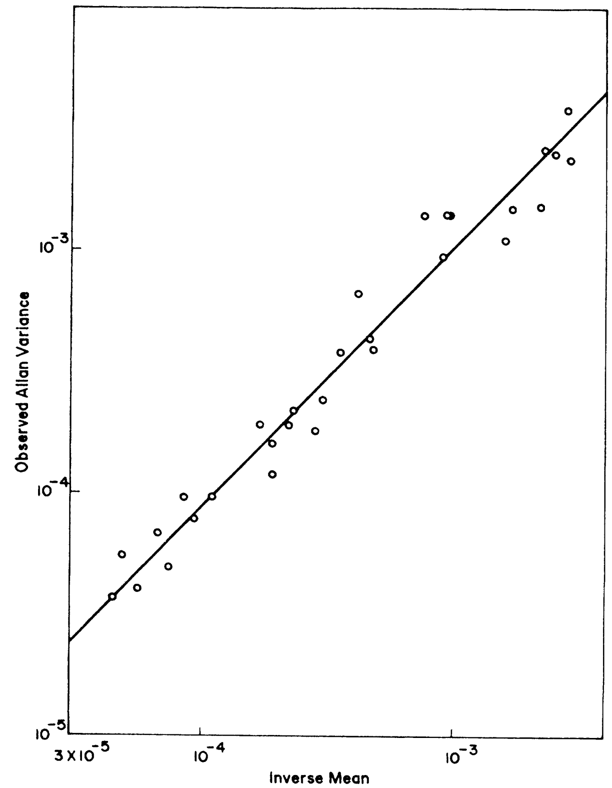

FIG. 2. Plot of observed relative Allan variance vs the expected Poisson value.

where N is the number of measurements made and $M_T^{(i)}$ is the count observed during the ith measurement for a time interval T.

RESULTS AND DISCUSSION

A plot of the relative Allan variance $R(T)$ versus the inverse of the counting time, i.e., $1/T$, is given in Fig. 1. It is seen that there is a linear trend up to 9000 min. The straight line is the least-squares fit to the data with a slope of 1.11. Figure 2 shows the variation of $R(T)$ versus $1/\langle M_T \rangle$. It also shows a linear behavior. The linear least-squares fit to the data yields a slope of 1.08. This shows that the radioactive decay of ^{210}Po shows only full shot noise and so follows only simple Poisson statistics for time interval as long as 9000 min, i.e., at least for frequencies of the order of 10^{-6} Hz.

From Fig. 1 it is clear that if at all a flicker floor occurs, it has to be $<10^{-4}$ and should occur at $T^{-1} < 5\times10^{-7}$ min^{-1}, i.e., $2C'\ln 2 < 5\times10^{-7}$ or

$$C' < 3.6067\times10^{-7} , \tag{7}$$

but

$$C' = \frac{2\alpha A \zeta}{K} , \tag{8}$$

where α is the fine structure constant, $\frac{1}{137}$; K is the dielectric constant of the radioactive medium; ζ is the coherence factor,[3] and A is a constant given by

$$A = \frac{2(\Delta \mathbf{V})^2}{3\pi c^2} \tag{9}$$

where (ΔV) is the change in velocity of the particles during their emission and c is the velocity of light. A literature survey on polonium nitrate (the enriched polonium of which is our source) indicated that its dielectric constant has not been determined. Since the chemical structure of lead nitrate is similar to that of polonium nitrate, we have used the dielectric constant of lead nitrate which is 17 (Ref. 10). Hence $C' = (5.17\times10^{-7})\xi$. Therefore from Eqs. (7) and (8) $\zeta < 0.7$, which is reasonable. We therefore infer that $1/f$ fluctuations are not present in the decay of ^{210}Po for frequencies at least in excess of 10^{-6} Hz.

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