Search for $1/f$ fluctuations in α decay

W. V. Prestwich, T. J. Kennett, and G. T. Pepper
Department of Physics, McMaster University, Hamilton, Ontario, Canada L8S 4K1
(Received 11 August 1986)

An experiment to detect the existence of $1/f$ fluctuations in α-particle decay rates has been performed. No evidence for such fluctuations has been found.

INTRODUCTION

Approximately a decade after the discovery of radioactivity, evidence[1,2] was cited indicating that the decay process, and particle counting associated with its observation, are well approximated as simple Poisson processes. In the past two decades it has been discovered that many natural processes exhibit $1/f$ noise. A theory of quantum self-interference has been advanced[3] as the causative mechanism for this phenomenon in microscopic processes. It has further been suggested[4] that α-particle emission rates are quantities which would exhibit such $1/f$ fluctuations due to quantum self-interference. This implies that α emission is in fact not a simple Poisson process, and the results of particle counting will not be adequately described by Poisson statistics. An α-particle counting experiment in which the observations depart from Poisson statistics has recently been described.[5] The results of this experiment provide evidence for the existence of $1/f$ fluctuations in α-particle emission rates.

For a result of such fundamental importance, further experimental investigation is warranted. The direct detection of the α particles emitted involves the transmission of short-range particles from the source material. In such an arrangement both the decay process and the subsequent interaction between the α particle and its surroundings are involved. In the experiment reported here, the α decay rate is measured by observation of γ rays deexciting the states formed following α emission. If $1/f$ fluctuations occur in the α decay rate then the statistics of the photon counting process should be altered.

EXPERIMENTAL PROCEDURE

The nucleus ^{241}Am decays predominantly to the second excited state of ^{237}Np. The latter decays to the ground state via the emission of a 59.5 keV γ ray with a branching ratio of 35.7%.[6] Since the lifetime of the excited state in ^{237}Np is short compared to that of ^{241}Am, equilibrium conditions prevail and the emission rate of the γ ray reflects that of the α particle. The source used in this experiment consisted of 520 MBq of ^{241}Am oxide, sealed in a stainless-steel capsule 3 mm in diameter and 10 mm high. The capsule was mounted in a plastic cylinder 2.5 cm in diameter and 10 mm high. This was attached rigidly to the face of the detector, upon which had been placed an absorber consisting of a 500 mg/cm^2 thick copper disc 2.5 cm in diameter. This was used to control the counting rate.

The γ-ray emission rate was measured with a detector consisting of a 2.5 cm diameter by 1.3 cm high CsF crystal integrally mounted on a Hamamatsu R1398 ten-stage photomultiplier. Cesium fluoride is characterized by a 5-nsec decay time[7] and is thus especially suited to high-rate γ counting applications. The photomultiplier was operated with the cathode at negative potential (-1400 V) so that the anode signal could be directly coupled to a 100 Mhz wide-band amplifier located in the tube base assembly. The amplifier is capable of driving dual 50 Ω outputs. In the configuration used in performing the experiment, one output was sent to a constant fraction discriminator (Ortec model 583) while the other was terminated in 50 Ω. For setup purposes the second output was coupled to a fast linear gate and stretcher after an appropriate delay. The pulse spectrum of the output of this unit gated by the discriminator was observed in a multichannel analyzer so as to ascertain the precise setting of the discriminator threshold. This was adjusted to a level corresponding to 20 keV events so that the fraction of the total spectrum counted was approximately 80%. Since preliminary investigation indicated that the detector gain was temperature sensitive, the assembly was contained in a plastic jacket through which circulated water from a temperature-controlled bath. To further minimize residual temperature effects the experiment was performed in a darkroom which was found to provide the most stable environment accessible to us. The need to maintain a relatively constant temperature throughout the data acquisition period was the limitation in this experiment.

The output from the discriminator was connected to an 85-MHz model 1952a Fluke digital counter. The event rate was 6.4×10^5 sec^{-1}. The system resolution was determined to be 20 nsec. The data which resulted from sampling for preset times of 0.1 or 1 sec were transferred through the serial port to an IBM personal computer. Longer integration times were achieved by summing the data in blocks to obtain the final count. A record was made of each count, the room temperature, and the time the count was taken. Data acquisition was continued until 200 samples had been accumulated. In a separate experiment the discriminator output width was increased to 50 nsec and an event rate of 3×10^6 sec^{-1} was used.

RESULTS AND DISCUSSION

The counting data form a discrete time series sequence $\{M_i, i=1,\ldots N\}$, where M_i is the count observed for the ith interval, and N is the number of intervals in the sequence. As discussed previously,[4] a parameter which may be used to test for the presence of a $1/f$ component in the fluctuation power spectrum is the relative Allen variance. This quantity is defined as

$$R=\sum_{i=1}^{N-1}(M_{i+1}-M_i)^2/2(N-1)\langle M\rangle^2 , \quad (1)$$

where

$$\langle M\rangle=\sum_{i=1}^{N} M_i/N . \quad (2)$$

For a simple Poisson process, the relative Allen variance has as its expectation the inverse of the mean count. In this case also, the Allen variance is itself a sample from the χ^2 distribution with $N-1$ degrees of freedom. For $N=200$ the statistics may be described as normal with a coefficient of variation of 10% to a good approximation. The additional variation introduced in the relative Allen variance by substitution of the sample mean, $\langle M\rangle$, for the true mean is thus negligible for mean values greater than 10^4. These conditions are applicable in this experiment.

In the case of a compound Poisson process, in which the intensity or rate parameter is no longer constant but also fluctuates, an additional contribution to the variance is made. In the particular case in which the rate-parameter-fluctuation power spectrum varies inversely with frequency it can be shown[4] that

$$R=F+1/M . \quad (3)$$

In the above equation, M is the true mean and F is a constant referred to as the flicker floor.

In practice, the observed variance may depart from the idealized value because of instrumental effects. Instabilities in the counting system will produce additional fluctuations, so that a contribution from an instrumental variance will alter Eq. (3). It should be noted that there is no "averaging out" for the variance as there is for the mean value. Such instabilities are equivalent to variations in the system efficiency and thus also lead to a compound Poisson process. The detailed behavior of the observed variance will depend upon the power spectrum of the efficiency fluctuations. For long-term drifts, however, it is quite likely that the contribution would be experimentally indistinguishable from the $1/f$ component being investigated.

A second source of departure from ideality is the finite resolving time of the system. The effect of this quantity is to alter the pulse spacing distribution. The influence of the response time on the variance has been examined for the general p-type counter by Takacs.[8] For the nonparalyzable counter ($p=0$), the value expected for the relative variance of the observed count in a simple Poisson process is reduced by a constant factor. For a resolving time τ and instantaneous rate r, the expected variance is reduced by the factor $(1+r\tau)^{-2}$.

The results obtained in this investigation are presented in Table I and Fig. 1. The data have been corrected for the finite response time by multiplication by the correction factor for nonparalyzable counters as described above. The correction factor amounted to only 2% for the data taken using an instantaneous rate of 6×10^5. For the high-rate experiment with increased response time the correction factor was 40%. For all except the two smallest entries the data were obtained from sequential records consisting of 200 samples. In the latter case the data were obtained from the weighted average of two sequential records each such that the total number of samples in the combined records was 200. The two values averaged for each entry were weighted according to the number of

TABLE I. Comparison of experiment with predictions for a Poisson process. Numbers in square brackets represent powers of ten by which the values are to be multiplied.

Expected Poisson value	Observed[a] Allen variance
1.54[−04]	1.67[−04]
3.09[−05]	3.55[−05]
1.54[−05]	1.61[−05]
3.09[−06]	2.88[−06]
1.48[−06]	1.48[−06]
1.13[−06]	1.07[−06]
7.47[−07]	6.63[−07]
4.97[−07]	4.97[−07]
2.95[−07]	3.00[−07]
2.49[−07]	2.32[−07]
1.13[−07]	9.50[−08]
7.47[−08]	8.69[−08]
4.92[−08]	5.20[−08]
3.73[−08]	3.83[−08]
2.95[−08]	2.98[−08]
1.13[−08]	1.06[−08]
7.47[−09]	7.51[−09]
5.03[−09]	4.77[−09]
2.52[−09]	2.70[−09]
1.13[−09]	1.09[−09]

[a]All values have a 10% coefficient of variation.

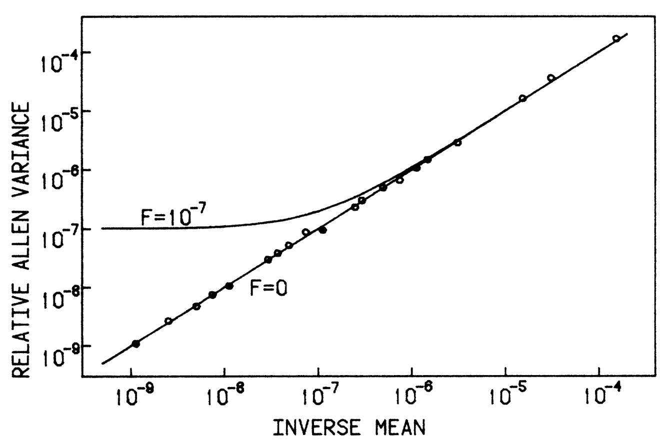

FIG. 1. Comparison of measured Allen variance with predictions of a simple process, and a compound process with a flicker floor of 10^{-7}. The open circles correspond to data taken at a rate of 6.4×10^5 sec^{-1}. For the closed circles, the rate was 3×10^6 sec^{-1}.

samples in the individual record. The results obtained are seen to be statistically consistent with a simple Poisson process, and do not appear to require an additional contribution such as is provided by a flicker floor. In order to make a quantitative estimate a least-squares analysis of the data to the model represented by Eq. (3) was performed. The value obtained for the flicker floor is $F=(0.9\pm2)\times10^{-10}$. This would indicate that the flicker floor for the process studied here is less then 0.5×10^{-9} at the 95% confidence level. The upper limit observed here is more than 2 orders of magnitude lower than the value of 10^{-7} reported in the previous α-counting experiment.[5]

It would appear from these results that there are no significant $1/f$ fluctuations in the α decay process of ^{241}Am for frequencies in excess of approximately 2×10^{-3} Hz. Physically significant $1/f$ fluctuations observed in direct α counting leading to a flicker floor, in excess of that observed here, would be attributable to particle propagation through the surrounding medium. Because of the difficulty of these measurements and the importance of the results we feel that the α-counting experiments should be repeated.

CONCLUSIONS

The statistical properties of the α decay rate of ^{241}Am have been studied by observation of the cascade γ ray with high-speed counting equipment using a CsF scintillator. The results indicate no significant departures from the behavior predicted for a simple Poisson process for event totals approaching the 10^9 level. A measurable contribution from $1/f$ fluctuations as predicted by quantum self-interference effects was not observed, although it would be expected to become important at the 10^7 level. Since such a contribution has been reported for α-particle counting of the same nuclide,[5] further work is necessary to delineate the details of the effect.

ACKNOWLEDGMENTS

The authors acknowledge financial assistance from the Natural Sciences and Engineering Research Council of Canada and the Province of Ontario.

[1]H. Bateman, Philos. Mag. J. Sci., Ser. 6 **20**, 704 (1910).
[2]E. Marsden and T. Barratt, Proc. Phys. Soc. London 23, 367 (1911).
[3]P. H. Handel, Phys. Rev. A **22**, 745 (1980).
[4]C. M. Van Vliet and P. H. Handel, Physica **113A**, 261 (1982).
[5]J. Gong, C. M. Van Vliet, W. H. Ellis, G. Bosman, and P. H. Handel, *Noise in Physical Systems and 1/f Noise*, edited by M. Savelli, G. Lecoy, and J. P. Nougier (Elsevier, New York, 1983).
[6]*Table of Isotopes*, 7th ed., edited by C. M. Lederer and V. S. Shirley (Wiley, New York, 1978).
[7]W. J. Van Sciver and R. Hofstadter, Phys. Rev. **87**, 522 (1952).
[8]L. Takacs, *Introduction to the Theory of Queues* (Oxford University Press, London, 1962), p. 265–266.