PHYSICAL REVIEW D VOLUME 13, NUMBER 1 1 JANUARY 1976

Possible evidence for the quantization of particle lifetimes

Robert Ehrlich
Department of Physics, State University College, New Paltz, New York 12561
(Received 29 January 1975; revised manuscript received 16 July 1975)

An analysis of widths of resonant states supports the hypothesis that particle lifetimes are quantized in units of $\frac{1}{2}$ or possibly $\frac{1}{4}$ the lifetime of the ρ meson: $(4.40 \pm 0.06) \times 10^{-24}$ seconds. The probability that the observed regularity in resonance widths (lifetimes) is simply due to chance is estimated to be less than 2×10^{-4}. Possible ramifications of this result are considered.

Evidence is presented for the quantization of particle lifetimes, based on an analysis of the widths of resonant particle states[1] using the Heisenberg uncertainty principle. Since resonances having full widths, Γ, of 300 to 400 MeV are well established, the uncertainty principle implies that the shortest particle lifetime known is approximately 2×10^{-24} seconds, the lifetime of a 300-MeV-wide resonance. A value half as great could be established if one can show that a possible 600-MeV-wide resonance, i.e., ϵ, can only be parametrized by a single pole, which is now uncertain.[2]

Using the uncertainty relation, we have calculated the lifetimes of all resonant states listed in the 1974 Table of Particle Properties.[1] Since there are no resonances definitely established as having a width exceeding twice the ρ width, and since the ρ width is very well measured, we calculate lifetimes in units of half the lifetime of the ρ meson, i.e., $T=2\Gamma_\rho/\Gamma$, where we use $\Gamma_\rho = 149.3$ MeV as the average full width of the charged and neutral ρ mesons. Since many resonance widths have a large experimental uncertainty, $\Delta\Gamma$, we have calculated asymmetric errors in lifetime, ΔT_+ and ΔT_-, rather than use first-order error propagation. However, in those instances where it is simplest to deal with a single value for the uncertainty in lifetime, we use $\Delta T = \frac{1}{2}(\Delta T_+ + \Delta T_-)$.

In Fig. 1, we display all resonant widths listed in the Table of Particle Properties[1] which are well-measured enough to have an uncertainty in width, $\Delta\Gamma$ listed in that table and which have lifetimes less than 9.0. Each resonance is represented by a point in Fig. 1 whose coordinates are T and ΔT. The zig-zag line which touches the T axis at integral values serves to divide the plane into two regions. Data points above the zig-zag line correspond to resonances having lifetimes, T, which are closer to integral values than their measurement uncertainty, ΔT. From this figure, there does not appear to be a single resonance which is particularly inconsistent with having an integrally valued lifetime, nor are there any inconsistencies among the narrower resonances with $T > 9.0$. Since the resonances with large uncertainty in lifetime are of little help in testing the quantization hypothesis, we tabulate in Table I only those cases for which $\Delta T \leq 0.32$, i.e., those below the horizontal line in Fig. 1. The choice of 0.32 is arbitrary and does yield a conservative result, insofar as all but one of the data points having uncertainties in the range $0.32 < T < 0.50$ are above the zig-zag line, giving some additional support to the quantization hypothesis.

If particle lifetimes actually are quantized, and the shortest one is half of the ρ lifetime, then each of the lifetimes listed in Table I should, within the limits of the experimental errors, be an integer. We note that with the exception of $\Delta(1670)$ and $g(1680)$, this condition is well satisfied. The $g(1680)$ has a lifetime which comes extremely close to satisfying this condition,[3] i.e., $1.65+0.33$ is only a hair below 2.00. This discrepancy in the case of the $\Delta(1670)$ can be explained in terms of the translation from an experimental error expressed simply as a range of values to one expressed as a $\pm$ error. In view of the possible large systematic errors in the determination of isobar widths,[4] it is clearly not warranted, for example, to express the $\Delta(1650)$ $\Gamma = 140$ MeV (140 to 200) as simply $\Gamma = 140^{+60}_{-0}$ MeV, meaning zero error on the low side. Similarly, for the $\Delta(1670)$, the width $\Gamma = 260$ MeV (190 to 270) gives a highly skewed error in $\Delta(1670)$ lifetime only if the location of the width very close to one end of the specified range is taken to literally mean $\Gamma = 260^{+10}_{-70}$ MeV. A symmetric error covering the same full range, i.e., $\Gamma = 260 \pm 40$ MeV, would yield a lifetime for $\Delta(1670)$ equal to an integer within the experimental error: 1.14 ± 0.15.

Among the resonant states not listed in Table I (all of which have larger uncertainties in lifetime) only one, $\Delta(1950)$, has a lifetime which is not equal to an integer within the given experimental error: $1.30^{+0.46}_{-0.20}$. However, the 1.3-standard-deviation difference from an integer for the

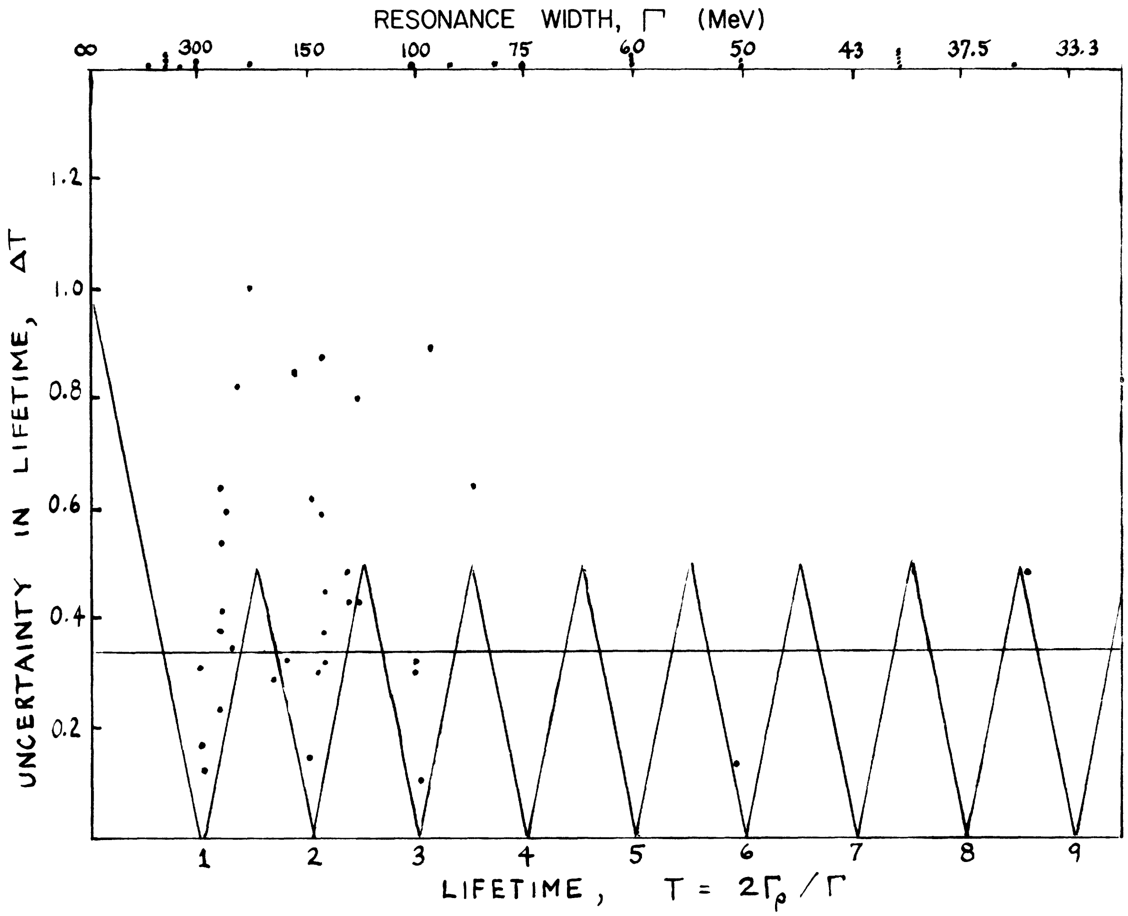

FIG. 1. Resonance lifetime, $T=2\Gamma_\rho/\Gamma$, versus uncertainty in lifetime for all resonances in the Table of Particle Properties which are well-measured enough to have an uncertainty in width, $\Delta\Gamma$, listed in the table, and which have lifetimes less than 9.0. Data points which lie above the zig-zag line correspond to resonances having lifetime, T, which are closer to integral values than their measurement uncertainty, ΔT. The uniform scale in lifetime, T, corresponds to the nonuniform scale in resonance width, Γ, indicated at the top of the figure.

$\Delta(1950)$ is hardly significant.

Since the criterion for listing resonances in Table I is based on the uncertainty in computed lifetime, resonances with a large or possibly unknown uncertainty in width have not been listed. While ϵ has been omitted from the table on this basis, it would be somewhat surprising if its width, $\Gamma \gtrsim 600$ MeV, is actually consistent with 300 MeV. Should it be clearly established that ϵ or other states can only be described by a single Breit-Wigner resonance of 600-MeV width, this would not necessarily conflict with the hypothesized quantization of particle lifetimes noted here, but it might simply require the smallest lifetime to be half as great as the value listed, i.e., $\frac{1}{4}$ the ρ meson lifetime.

One noticeable thing about many of the lifetimes listed in Table I is that they are in fact *too* close to being integers, given the size of the experimental errors. One is tempted to attribute this to a possible tendency of experimenters to quote resonance widths as round numbers, such as 50, 100, 150 MeV. However, an examination of the values given by individual experiments in the data card listings[1] shows this not to be the case, at least as far as the mesons are concerned. The widths listed in Table II are the exact weighted averages of many individual experiments given in the data card listings. For those cases, e.g., $\rho(770)$, $K^*(1420)$, $A_2(1310)$, where widths are listed in Table I as round numbers, the reason is that the weighted average of many experiments which are individually *not* round numbers turns out to give a result very close to a round number, as indicated by the values in Table II. Hence, it appears that the "preference" for round numbers is due to the data themselves rather than the biases of individual experimenters or that of the

TABLE I. Full widths and lifetimes of resonances listed in the Table of Particle Properties (1974), which have an uncertainty in lifetime of 0.32 or less. The lifetimes are expressed in units of half the ρ meson lifetime, i.e., $T=2\Gamma_\rho/\Gamma$, where $\Gamma_\rho=149.3$ MeV.

Resonance	Full width (Γ) in MeV	Lifetime ($T^{+\Delta T_+}_{-\Delta T_-}$)
$N(2200)$	300 (260 to 330)	$0.99^{+0.15}_{-0.09}$
$\Delta(2420)$	300 (250 to 350)	$0.99^{+0.20}_{-0.14}$
$\Delta(1910)$	300 (200 to 340)	$0.99^{+0.50}_{-0.12}$
$\Delta(1670)$	260 (190 to 270)	$1.14^{+0.42}_{-0.04?}$
$g(1680)$	180 ± 30	$1.65^{+0.33}_{-0.24}$
$f(1270)$	170 ± 30	$1.75^{+0.38}_{-0.26}$
$\rho(770)$	150 ± 10	$1.98^{+0.14}_{-0.12}$
$\omega(1675)$	142 ± 20	$2.09^{+0.34}_{-0.26}$
$\Delta(1650)$	140 (140 to 200)	$2.12^{+0.00?}_{-0.64}$
$K^*(1420)$	100 ± 10	$2.97^{+0.33}_{-0.27}$
$A_2(1310)$	100 ± 10	$2.97^{+0.33}_{-0.27}$
$\Delta(1232)$	98.8 ± 3.4	$3.01^{+0.11}_{-0.10}$
$K^*(892)$	49.8 ± 1.1	$5.97^{+0.14}_{-0.13}$

Particle Data Group.

If the true values of the particle lifetimes are indeed integral, then an alternative explanation of the values listed in Table I being "too close" to integers would be that many of the listed experimental errors have been overestimated. When the Particle Data Group finds that there appear to be inconsistencies between some of the experiments used in computing an average value for a resonance parameter, then it lists a value for the error in the parameter in the Table of Particle Properties which in "only an educated guess."[5] The errors listed in the Table of Particle Properties (Table I) are thus often substantially greater than the errors given on the Data Card Listings[1] (Table II). However, this practice of enlarging the experimental uncertainty is followed by the Particle Data Group even when the individual experiments agree quite well, e.g., in the case of $\rho(770)$, $\omega(1675)$, $K^*(1420)$, so as to allow for possible systematic errors.

Should such systematic errors not be present, or be averaged out, then this conservative approach would mean that the measurement errors of a number of states listed in Table I are indeed overestimated.

The widths listed in Table II are obtained using the average widths given in the data card listings, after the average values for different charge states and decay modes of the resonances listed in Table I are averaged. In most cases the values

TABLE II. Full widths and lifetimes of meson resonances listed in Table I obtained from parameters given on the Particle Data Group data card listings. The values in the table are the combined averages for all charge states and decay modes of each resonance, and are in units of half the ρ meson lifetime.

Resonance	Full width (Γ) in MeV	Lifetime ($T^{+\Delta T_+}_{-\Delta T_-}$)
$g(1680)$	152.2 ± 10.7	$1.96^{+0.15}_{-0.13}$
$f(1270)$	172.5 ± 8.4	$1.73^{+0.09}_{-0.08}$
$\rho(770)$	149.3 ± 2.2	$2.00^{+0.03}_{-0.03}$
$\omega(1675)$	142.1 ± 14.6	$2.10^{+0.24}_{-0.20}$
$K^*(1420)$	102.4 ± 4.1	$2.92^{+0.12}_{-0.11}$
$A_2(1310)$	100.5 ± 2.5	$2.97^{+0.08}_{-0.07}$
$K^*(892)$	50.2 ± 0.8	$5.95^{+0.10}_{-0.09}$

for the various decay modes and charge states are quite consistent, as they should be. In some cases, e.g., $g(1680)$, the values are somewhat inconsistent, though not extremely so.[6] In any case, it would be expected that in the absence of known systematic errors the average over decay modes and charge states yields a more reliable width estimete than any individual value.

In view of the greater systematic error in isobar width determinations noted previously, we only show the meson resonances in Table II. We note that errors listed in Table II are significantly less than those in Table I, making the closeness of many of the lifetimes to integral values even more striking. The one exception is $f(1270)$, which is no longer apparently consistent with having an integral lifetime. However, an examination of the separate experimental determinations of the $f(1270)$ width used in finding an average value reveals that out of eleven experiments, the one[7] using a different technique from the rest (automatic spark chambers), gives a value somewhat inconsistent with most of the others. Since this experiment is also listed as claiming the smallest error in $f(1270)$ width, its effect on the average is quite significant. If we compute an average not including this one experiment, the value for the $f(1270)$ width, 163.5 ± 10.4, yields a lifetime which is less than 1.5 standard deviations from being an integer: $1.83^{+0.12}_{-0.11}$.

Since some of the entries in Table II may have unknown systematic errors, we shall obtain a conservative estimate of the probability of the observed regularity being due to chance using only the entries in Table I. However, since the lifetimes in Table II, with the exception of $f(1270)$, are consistent with integral values despite the smaller experimental errors, we may regard

Table II as giving some amount of additional support to the quantization hypothesis.

In order to determine the probability that the lifetimes in Table I are all close to integers simply due to chance, we must not of course include $\rho(770)$, since our system of units requires this to be close to 2.00. The probability that the closeness of the twelve other lifetimes to integral values is due simply to chance is the same as that of twelve random numbers being consistent with integers within the listed experimental errors for lifetimes. This is given by the product of the twelve experimental errors, i.e., $p=\prod_j \Delta Tj$, where ΔTj is the full (upper plus lower) error for each lifetime. This yields a probability of 7×10^{-5}.

In view of the importance of determining the probability of obtaining such a regularity as that in Table I by chance, we calculate the probability against chance by a second independent method.

Let us take the lifetimes listed in Table I modulo the nearest integer, i.e., 0.01, 0.01, 0.01, ..., 0.03. Given that our system of units requires one, i.e., $\rho(770)$ to be integral, the remaining twelve values serve to define a point in twelve-dimensional space whose distance to the origin, R, given by $R^2 = 0.01^2 + 0.01^2 + \cdots + 0.03^2 = 0.2306$, is a measure of the deviation of the set of lifetimes from integral values. The probability that a random set of twelve numbers would give values as close or closer to integral values as those actually found is equal to the ratio of the volume of a twelve-dimensional sphere of radius R to the volume of the twelve-dimensional unit cube, i.e., $p = 2\pi^{n/2}R^n/n\Gamma(\frac{1}{2}n) = 2\times10^{-4}$, where $n=12$, and $R^2 = 0.2306$. The proof is simply based on the fact that twelve randomly generated fake lifetimes give points uniformly distributed inside the twelve-dimensional unit cube, and that only

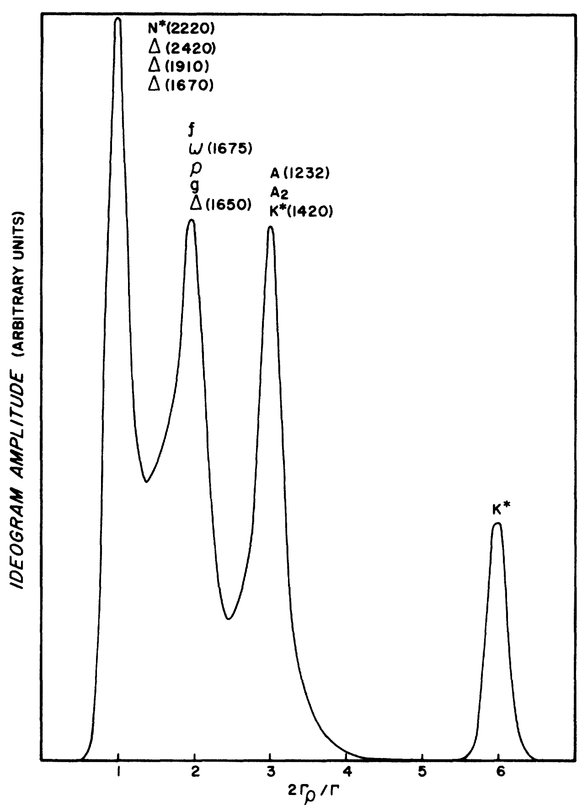

FIG. 2. Ideogram corresponding to the entries in Table I, for which each entry is represented by an equal-area Gaussian peak. The central value of each Gaussian corresponds to a particle's full width and the standard deviation of each Gaussian corresponds to the particle's uncertainty in width. The Gaussian distributions in energy have been transformed to units of time using the relationship: $T = 2\Gamma_\rho/\Gamma$.

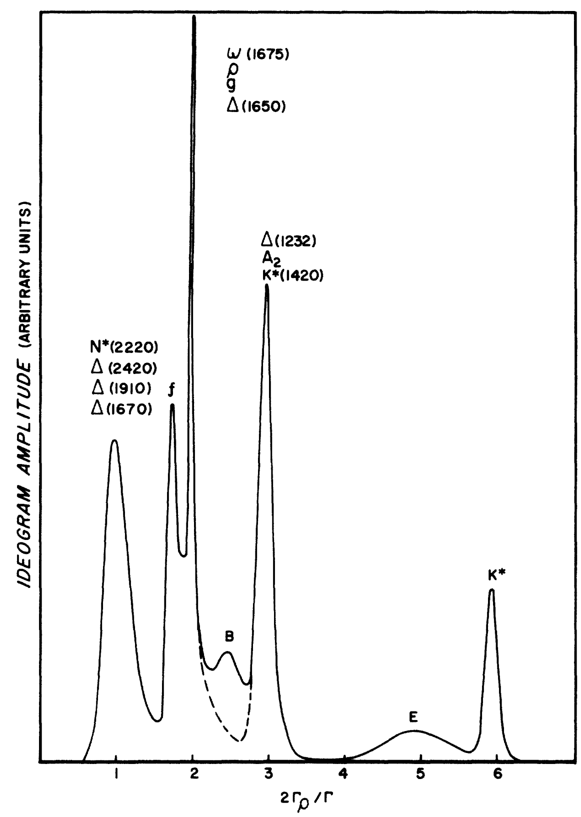

FIG. 3. Ideogram corresponding to the entries in Table II, together with the baryon entries in Table I, for which each entry is represented by an equal-area Gaussian peak just as in Fig. 1. Two particles not appearing in Table II [B(1235) and E(1420)], due to the relativity large measurement uncertainty in their full widths, have also been included in Fig. 2. The dotted portion of the curve shows the ideogram without the B(1235) contribution.

those sets of fake lifetimes closer to integers than the actual set would have a smaller value of R, and would therefore lie inside a sphere of this radius. We note that in obtaining a value for R^2, and therefore p, the fact that "round numbers" were used for some of the widths makes very little difference in the result, since the value of R^2 is dominated by the $g(1680)$ and $f(1270)$ lifetimes, and it would not be significantly altered if the "nonround" values of Table II were used for $\rho(770)$, $K^*(1420)$, $A_2(1310)$, and other widths.

Of the two estimates of the probability against chance it would be prudent to use the larger value, 2×10^{-4}, which still makes the chance hypothesis somewhat unlikely, and thereby gives strong support to the quantization hypothesis. However, we recognize the arbitrary nature of the assumption of a uniform random distribution of lifetimes. It is quite possible that some other random distribution would be consistent with the experimental results with a much higher probability than 2×10^{-4}. Thus the probability estimates should not be taken as a precise indication of the strength of evidence for the hypothesis. One alternative *ad hoc* hypothesis consistent with the observed regularities in Table I, i.e., that resonance widths are integral multiples of about 50 MeV, is refuted by the existence of many resonances having widths below 50 MeV.

A graphical display of the data in Tables I and II may also be of some use in giving one an overall impression of the statistical significance of the result. The curve in Fig. 2 is an ideogram corresponding to the entries in Table I in which a number of equal-area Gaussian peaks having central values and widths corresponding to each particle's full width and uncertainty in width have been transformed to a lifetime distribution, based on the relationship: $T=2\Gamma_\rho/\Gamma$. In Fig. 3, which is an ideogram corresponding to the entries in Table II, we also include two additional particles, $B(1235)$ and $E(1420)$, which were omitted from Tables I and II owing to the criteria used in eliminating particles with large measurement uncertainty. The baryon entries in Table I have also been included in Fig. 3. While the B(1235) peak in Fig. 3 lying between lifetimes of 2.0 and 3.0 is potentially fatal to the quantization hypothesis, we note that the value of the B(1235) width from the Table of Particle Properties, 120 ± 20 MeV, has a sufficiently large uncertainty so that this possible conflict can only be resolved if more accurate values of the B width are obtained.

It is interesting to note, however, that the B(1235) width listed in the Data Card Listings would be significantly more consistent with an integral lifetime if the one experiment with a very asymmetric uncertainty in width. $78.0^{+14.0}_{-46.0}$ MeV, is averaged in with the others in a way that accounts for this asymmetry. In this case, the weighted average of the B(1235) width measurements would be 110.3 ± 7.1 MeV rather than the listed value 118.3 ± 8.1 MeV.

Further tests of the hypothesis of quantization of particle lifetimes could involve the measurement of new resonance widths or a reduction of the experimental uncertainty in existing resonance widths [particularly $f(1270)$, $B(1235)$, and $E(1420)$], either based on new experiments or a more careful analysis of existing data. Finding only one lifetime which is definitely not a multiple of T_0 would disprove the quantization hypothesis, although one might nor be able to eliminate the possibility of two overlapping resonances simulating a single one with nonintegral lifetime.

Defining the shortest particle lifetime as one "chronon" we may use the lifetime of the $\rho(770)$, the resonance with the smallest uncertainty in lifetime, to obtain for the chronon a time, $T_0=(2.20\pm0.03)\times10^{-24}$ seconds, which corresponds to the set of allowed full widths: 298.6, 149.3, 99.5, 74.6, 59.7, 49.8, ... MeV.

It is clear that any particle, e.g., Λ^0, for which a direct lifetime measurement can be made lives for such a large number of chronons that a direct test of quantization of its mean life is not possible. In the present work we only examine evidence for the quantization of particle *mean* lifetimes. For a short-lived particle such as $\rho(770)$, for which each *individual* ρ event has an energy known much more accurately than Γ_ρ, the uncertainty principle requires the uncertainty in individual ρ lifetimes to be much greater than the ρ mean lifetime. Thus, it is not possible to observe a distribution of individual particle times in such a case. Nevertheless, one may conjecture that each individual resonant particle also lives a quantized proper time, or that time itself is quantized in units of chronons. If this is the case, then the distribution of individual particle times would apparently have to be such that both the mean and individual lifetimes are integral. An additional constraint on the nature of the particle lifetime distribution follows from the Breit-Wigner shape of the resonance. Should it be established that no time distribution is consistent with both of the above constraints, this might indicate that individual particle lifetimes are not quantized, though this would not negate the hypothesis of quantized *mean* lifetimes.

While there have been some attempts to formulate theories in which time is quantized[8-11], there are additional theoretical difficulties aside from the one mentioned above. In particular, a chronon on the order of 10^{-24} seconds would apparently be several orders of magnitude too large to be consistent with the present experimental lower limit set on the quantum of distance.[12] On the other hand, it is possible that our reasons for believing that the obvious relation holds between a quantum of distance and a quantum of time may be invalid.[13] One may also speculate that the quantization of time may play a significant role in our understanding of macroscopic phenomena involving extremely intense gravitational fields, e.g., black holes, as well as for elementary patricles.

I would like to thank Dr. Joseph Ratau for starting me thinking about an experimental test of the quantization of time by asking me what it would empirically mean if time were quantized. I am also grateful to Dr. C. N. Yang for his illuminating suggestion.[13]

---

[1]Particle Data Group, Phys. Lett. 50B, 1, 1974.

[2]Particle Data Group, Ref. 1, p. 76.

[3]When all decay modes are averaged using the values given in the data card listings, the lifetime for the $g(1680)$ becomes much more consistent with an integral value, as indicated in Table II.

[4]See, for example, R. J. Plano [rapporteur's review talk given at the International Conference on Elementary Particles, Lund, 1969 (unpublished)] for a list of some of the sources of systematic errors in isobar parameter determinations.

[5]Particle Data Group, Ref. 1, p. 14, footnote 1.

[6]The probability according to the χ^2 test that the values for the various decay modes of the $g(1680)$ would be at least as inconsistent as those actually found is 5%.

[7]G. Grayer *et al*., Nucl. Phys. B46, 134 (1973).

[8]H. Snyder, Phys. Rev. 71, 38 (1947).

[9]H. Snyder, Phys. Rev. 72, 68 (1947).

[10]C. N. Yang, Phys. Rev. 72, 874 (1947).

[11]Yu. A. Gol'fand, in *Proceedings of the Twelfth International Conference on High Energy Physics, Dubna, 1964,* edited by Ya. A. Smorodinskii *et al*. (Atomizdat., Moscow, USSR, 1966), Vol. 2, pp. 242–244.

[12]B. Richter, in *Proceedings of the XVII International Conference on High Energy Physics, London, 1974,* edited by J. R. Smith (Rutherford Laboratory, Chilton, Didcot, Berkshire, England, 1974), p. IV-37.

[13]C. N. Yang, private communication.