records of the Blake, Cobb and Gilsa event. Despite these differences, the two databases are overall rather similar in terms of the distribution paths. For instance, Valet *et al.* also find that 43% of the records lie over the Americas and 20% in the antipodal band, and this makes a net 63% in the two longitudinal bands, which is almost exactly the number given by Tric *et al.* The different conclusions of the two groups thus arise from different analysis of the data.

Tric *et al.*[2] interpreted their results based on the visual impression given by rose diagrams, a standard technique of displaying circular distribution in which each record has equal weight. Although this did not introduce any bias towards the most detailed records, a rigorous statistical treatment is clearly desirable.

Valet *et al.*[1] first considered each record individually, and obtained a mean VGP longitude with a statistical weighting of the record. Then they divided the data into longitudinal bins and used the χ^2 test, with 18 sectors of 20° width, to assess their conclusions. It is, however, well known that the χ^2 test can be used only if the expected frequencies in each bin are at least equal to a minimum, which most authors set to five. The approximation improves with larger values, but significant errors are expected below this limit. If k denotes the number of groups, n must be at least $5k$. Some authors even suggest $10k$. In the calculation of Valet *et al.* the expected frequencies in each sector are 30/18 = 1.67 (for the interval 0–2 million years), and 44/18=2.44 for the 0–12-Myr interval, well below the acceptable limit for the χ^2 test to be valid. With 30 data, the maximum number of groups should be six, leading to 60° sectors, with 44 data it should be 8.8, leading to eight 45°, or nine 40° sectors. Interestingly, Valet *et al.* find χ^2 values rejecting the random hypothesis when 40 and 60° sectors are used.

Finally, when using the χ^2 test in binned circular statistics, the results must not depend on a particular (and possibly subjective) choice of the group interval. With the data of Valet *et al.*, if a series of eight 45° sectors is displaced in steps of 5°, so that after nine successive displacements the initial configuration is retrieved, different values of χ^2 are obtained for each of the sector orientations, four of which reject the random hypothesis while five do not. Clearly, the binned χ^2 statistics loses information and therefore requires many more observations than there are available to reach a robust conclusion.

After discussion with Professor S. Rao of the University of California, Santa Barbara, we now think that it is more appropriate to use the methods of circular statistics which, although somewhat unfamiliar to palaeomagnetists, are widely used in biology (see, for example, ref. 5). These methods do not require any *a priori* partitioning of the data into longitudinal bins, thus avoiding subjective choices of the width and position of intervals on the circle. Furthermore, they allow one to judge whether a given nonrandom circulation distribution is unimodal or bimodal. This is particularly relevant because we want to test the hypothesis that there are two antipodal preferred bands of longitudes.

We have applied three of the most usual tests of circular statistics, the Rayleigh, Rao and Watson's tests, to the database of Valet *et al.* When the data are tested for unimodality, the results of the three tests are slightly contrasting, especially when only the 0–2 Myr period is considered. In contrast, when the data are tested for bimodality the results are clear: all three tests reject the hypothesis of random distribution at the 1% level for the 0–12 Myr period, and the Rayleigh and Watson tests also reject it for the 0–2 Myr period. Thus, when all the available data are used, circular statistics applied to the data set of Valet *et al.* support the hypothesis that there are two preferred bands of longitude over the Americas and its antipode.

The main problem is clearly the paucity of good transitional records. It may well be that future results will upset our conclusions. However, with the data available today, the suggestion of the two preferential bands of longitude for transitional VGPs appears as a reasonable hypothesis which requires a physical explanation, either as a sedimentary artefact, as has been suggested[6], or as a true geomagnetic phenomenon, as we believe. This latter view seems to be supported by recent results based on volcanic rocks[7,8].

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1. Valet, J. P., Tucholka, P., Courtillot, V. & Meynadier, L. *Nature* **356**, 400–407 (1992).
2. Tric, E. *et al. Phys. Earth planet. Int.* **65**, 319–336 (1991).
3. Laj, C., Mazaud, A., Weeks, R., Fuller, M. & Herrero-Bervera, E. *Nature* **351**, 447 (1991).
4. Ruocco, M. *Geophys. Astrophys. Fluid Dyn.* **60**, 141–148 (1991).
5. Batschelet, E. *Circular Statistics in Biology* (Academic, 1981).
6. Langereis, C., van Hoof, A. A. M. & Rochette, P. *Nature* **358**, 226 (1992).
7. Hoffman, K. A. *Nature* **354**, 273–277 (1991).
8. Constable, C. *Nature* **358**, 230 (1992).

Questions in particle theory

SIR — The criticism by Kennedy[1] of Maddox's discussion[2] of an attempt to deal with the divergences of quantum field theories illustrates how entrenched present theoretical orthodoxy has become. It is certainly true that the renormalization procedures have dealt with the infinite integrals that appear in the quantum field theoretic algorithm. But to say that this *post hoc* procedure poses "no problem of principle" and that efforts to deal with this problem are "misguided and physically unnecessary" is simply to state the party line with which particle theorists are now trained.

The renormalization of electric charge in which factors of the form $e^2\ (1-K)$, where e is the so-called bare electron charge and K is a logarithmically divergent function, are simply defined to be equal to the observed value of the electron charge[3] cannot fail to disturb the disinterested observer and is symptomatic of conceptual difficulties at the heart of present theory. We all know that quantum electrodynamics is a formidably accurate computational algorithm. But we all also know that quantum field theories are an uneasy way to satisfy the requirements of quantum mechanics and the special theory of relativity, while the progeny of the liaison — the standard model and quantum chromodynamics — are forced contrivances with none of the elegance that comes from understanding at the very deepest levels.

It is no exaggeration to say that since the discovery of the renormalization procedures in the late 1940s theoretical particle physics has been a succession of gimmicks with which we have tried to outwit rather than understand nature. Shortly before his suicide in 1933, Ehrenfest[4], in his paper 'A few queries related to quantum mechanics', foresaw the present trend: "These questions might well be cast aside as 'meaningless' for the sake of convenience. It is even considered proper to do so. But for this reason particularly, someone has to take upon himself the odium of asking these questions." So it is today.

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1. Kennedy, D. C. *Nature* **357**, 449 (1992).
2. Maddox, J. *Nature* **353**, 497 (1991).
3. Bjorken, J. D. & Drell, S. D. *Relativistic Quantum Mechanics*, 158 (McGraw-Hill, New York, 1964).
4. Ehrenfest, P. *Z. Physik.* **78**, 555 (1932).