SEARCHES FOR FRACTIONAL ELECTRIC CHARGE IN TERRESTRIAL MATERIALS

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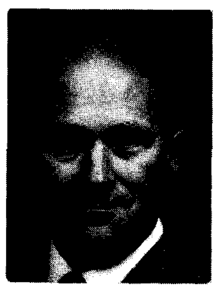

A brief review is given of the results of searches for free fractional charge in terrestrial materials during the past 20 years, and the latest results from the RAL/IC/Oxford programme of levitation searches are summarised. Techniques for reaching very low cosmic ray produced concentrations are discussed.

In his original paper proposing the quark model Gell-Mann [1] recognised that quarks could either be physical particles bound within the proton or more probably simply mathematical entities or quasi-particles. He thus advocated experimental searches for fractionally-charged particles "to reassure us of the non-existence of real quarks". Subsequently, quarks were "seen" as fractionally-charged point-like particles within the nucleon by electron and neutrino scattering experiments, but never produced singly in collisions. Nevertheless two possibilities are still open:

(1) fractional charge is a quasi-particle effect, with no independent existence in the free state (analogous to soliton discontinuities in a molecular chain, which can also have local fractional charges while the total charge on the molecule remains integral [2-4]).

(2) the charge unit for elementary particles really is e/3, and even if quarks are fully confined other types of particle may exist with fractional charge at higher mass levels.

Fig 1 summarises the results of searches for free fractional charge in terrestrial materials over the period 1965-86 (this diagram is from a review article in preparation and the full list of references to these results will not be given here). There are two classes of experiment: (a) those based on detection of anomalous particles in ion beams, and which are limited typically to anomalous particle masses $< 10^{2}-10^{3}$ GeV, and (b) those based on levitation, which are mass-independent.

In assessing possible experiments it is important to note that the 'natural' upper limit in common materials such as water and rock from cosmic ray production (based on typical observed flux limits $\approx 10^{-11}cm^{-2}s^{-1}$) would be in the region $1-10^{-4}$ quark g^{-1}, whereas essentially all the mass-independent experiments have been limited to rather higher concentration levels > 10 quark g^{-1}, which would correspond to a possible primordial or geochemically enriched concentration. By the early 1980's, the results of these experiments posed two important experimental questions:

(1) Could techniques be developed to probe the possible 'natural' concentration levels down to say 10^{-4} quark g^{-1} or below?

(2) Was the positive fractional charge effect reported several times by the Stanford Group for levitated niobium samples [5] a genuine effect or the result of a systematic error?

A programme (RAL/IC/Oxford collaboration) has been in progress since 1982 to investigate the second of these questions, and is also now contributing to the first. It is based on a levitation apparatus designed to reduce all systematic errors to < 0.1e and to achieve a high sample testing rate. Ferromagnetic levitation is used for all samples, non-magnetic materials being first coated with a thin layer of iron. Details of the apparatus and charge measurement procedure have been already published, together with several sets of results [6-8]. The important points are

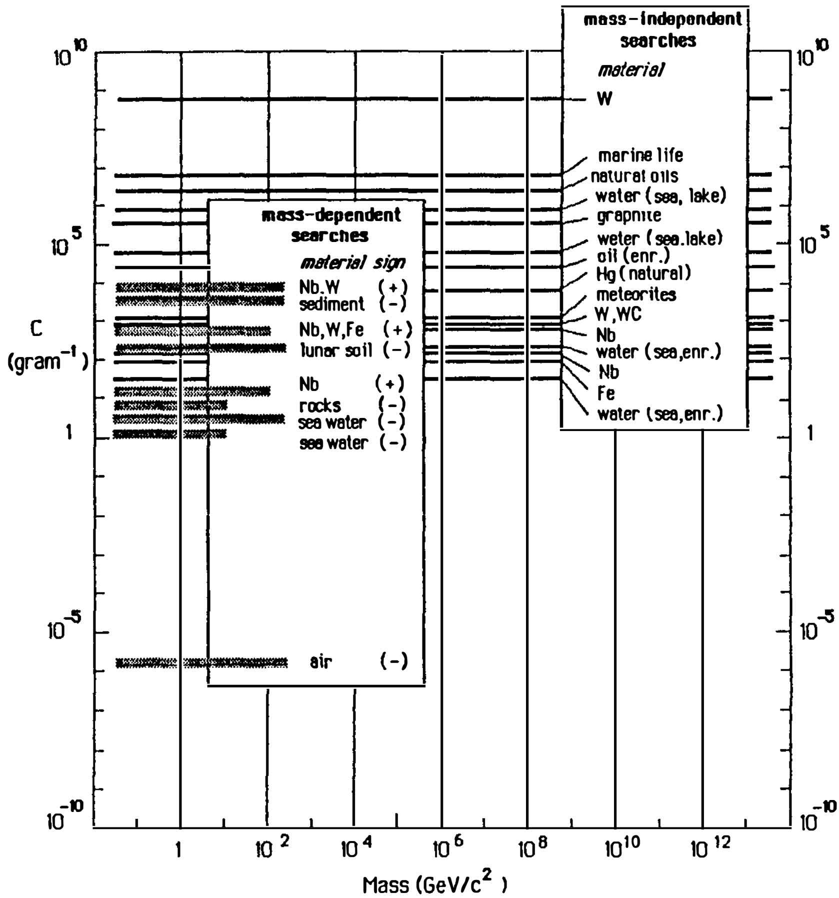

Fig 1. Summary of concentration levels achieved in free fractional charge searches in various materials. Searches based on ion beams are for a specific charge sign and are restricted in mass range (indicated by the bar lengths) and in some cases involve an extraction or enrichment procedure of uncertain efficiency. The mass-independent searches labelled "enr" also utilise pre-enrichment, but with a high confidence level.

(a) that the zero shift arising from the 'patch effect' on the field plates is reduced (by choice of a large plate separation) to a slow drift of < 0.1e over periods of many months, so that it cannot simulate a fractional charge change, and (b) that systematic errors arising from physical or magnetic irregularities in the samples (usually 0.3mm diameter spheres) are eliminated by using a configuration with magnetic, electric, and ball spin axes parallel. A further consequence of the latter is that non-spherical (and even irregular) samples can be tested, including short plated lengths of wire and diced meteorite samples. Each test runs overnight under computer control, and an average of 15 tests/month has been maintained over a period of 2 years. The following numbers and types of sample have been tested (all consistent with zero residual charge):

1. Plated niobium balls. 84 tests on 65 samples.
2. Plated niobium balls with portion of niobium surface exposed to liquid helium. 21 tested.
3. Steel balls. 100 tested, 20 exposed to liquid He, 60 exposed inside SPS UA2 vacuum chamber.
4. Plated tungsten carbide balls. 14 tested.
5. Tungsten-coated steel balls. 13 tested.
6. Plated cylinders of tungsten wire. 8 tested.
7. Diced iron meteorite samples. Hoba, 20 tested. Forsythe, 20 tested.
8. Plated diced Murchison (stony) meteorite samples. 10 tested.

Since Stanford reported 14 fractional charges in 40 tests on 13 samples, the results of set 1 above are clearly in statistical disagreement with their results. Test sets 2 and 4-6 were designed to investigate the possibility that this difference resulted from a different sample history, for example exposure to low temperature or contact with tungsten during heat treatment. Samples have also been sent to Stanford for comparative tests and, after a long period in which their low temperature apparatus has been out of commission, we understand that they may be in a position to restart tests in the near future [9]. We believe that our results suggest that the possibility of the original Stanford observations being confirmed must now be regarded as unlikely, and, with the number of different materials now tested at the $10-10^2$ quark g^{-1} level, the chances of any free fractional charge being found at this concentration also appear remote. If interest in free fractional charge can be maintained, therefore, it remains to investigate the possibility of much lower concentration levels in natural materials. Since levitation techniques are only capable of a testing rate of order 10^{-4} g day^{-1} several alternative approaches have been studied:

(1) The development of a 'rotor electrometer' [10] in which about 10 mg material is contained in a suspended Faraday cup capacitatively coupled to a rotating array of pick-up electrodes, giving an ac signal proportional to the charge. Noise levels have been reduced to the e/3 charge level, but the problem of large systematic charge fluctuations makes it unlikely that this technique will be pursued further.

(2) The use of a high speed stream of uniform liquid droplets deflected by an electric field, allowing in principle several grams of material to be tested per day [11]. Two experiments based on this idea have been under development. One of these [12] was found to be limited by systematic errors and was unable to improve on the sensitivity of levitation experiments. The other [13] is still under development.

(3) The use of enrichment by evaporation in conjunction with levitation. For example if sea water is repeatedly allowed to evaporate on the surface of a steel ball, any fractionally charged ions would remain in the resulting salt coating, and we have found that such salt-coated balls can be tested without difficulty (despite their irregular non-conducting surface). Because sea water contains 3% impurities, the direct gain by this procedure is limited to a factor 30 and we have already achieved this [14]. However if a large proportion (>99%) of the integer charge impurities is first removed by ion exchange [15] then many orders of magnitude gain in concentration could be achieved in this way, with high confidence of retaining any fracitonal charge, so that very low concentrations in sea water could be investigated for the first time.

Acknowledgements

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