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Search for $+\frac{1}{3}e$ fractional charges in Nb, W, and Fe metal

J. P. Schiffer and T. R. Renner
Argonne National Laboratory, Argonne, Illinois 60439
and University of Chicago, Chicago, Illinois 60637

D. S. Gemmell and F. P. Mooring
Argonne National Laboratory, Argonne, Illinois 60439

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The possibility is explored that the recent result of LaRue *et al.* on fractional charges in Nb spheres, and earlier negative results from quark searches would be reconciled if a $+(1/3)e$ quark were stable. Such particles would be loosely bound in most metals and would diffuse readily. Nb, W, and Fe filaments were heated in a 1-MV terminal and positively charged particles accelerated into a Si detector. From each filament fewer than ~ 10 particles of such charge seem to be emitted below 600°C, giving an upper limit of $\sim 10^{-22}$ per nucleon, an order of magnitude below the value implied by the result of LaRue *et al.*

INTRODUCTION

In a recent Letter, LaRue, Fairbank, and Hebard[1] reported the possible observation of fractional charges in superconducting Nb spheres levitated in a magnetic field. The mass of these spheres was about 90 μg and, of a total of eight, one was found to have a charge of $+(0.337 \pm 0.009)e$ and another *a* charge $(-0.331 \pm 0.070)e$. This result is in apparent contradiction with earlier work[2] in which fractional charges were sought by mass spectroscopic techniques in materials that had undergone little geochemical aging (lunar dust and meteorites), or in materials in which fractionally charged atoms may have been accumulating (sea water). The results of these searches were negative, with upper limits of concentration of 2×10^{-22} per nucleon for lunar soil and 3×10^{-24} for sea water for either atoms with a $-\frac{1}{3}e$ quark attached or $+\frac{2}{3}e$ quarks. One would therefore be surprised to find such particles in chemically refined and purified materials such as the Nb used in Ref. 1 or even the W boat in which the Nb spheres were annealed. Indeed it would seem likely that the $+\frac{2}{3}e$ quarks would have diffused out of the Nb under the 1850°K annealing to which they were subjected. The Nb spheres contained roughly 5×10^{19} nucleons.

This apparent conflict might be resolved if one were to suppose that the $+\frac{1}{3}e$ $\overline{\mathfrak{N}}$ antiquark is stable. Such particles were not searched for in Ref. 2 nor in most of the other stable-quark searches summarized in the recent review article by Jones.[3] They would have rather peculiar chemical properties since they could bind an electron by at most 1.4 eV. Thus such particles are not likely to be bound very strongly to anything and might, in fact, diffuse rather easily through metals. It is, however, difficult to make reliable qualitative estimates of the exact properties of such particles in solids,[4] and particularly so in transition metals. One may then postulate that these particles would have diffused out of the Nb spheres during heating, and then were reabsorbed from an ambient concentration during the subsequent exposure to air and an alcohol-dipped paint brush. They then may have been the charges seen in Ref. 1, and possibly also the source of the apparent, but more tentative, observation of fractional charges in Fe spheres in a room-temperature levitation experiment.[5] The $-\frac{1}{3}e$ results could be the consequence of one of the spheres having two quarks (or more generally $2+3n$). A total of three quarks on eight Nb balls implies a concentration of $\sim 10^{-20}$ per nucleon. The results of Ref. 5, where ten of the eleven steel balls behaved as if they had $+\frac{1}{3}e$ or $-\frac{1}{3}e$ charges, imply $\gtrsim 10^{-19}$ per nucleon.

EXPERIMENTAL METHOD

The basic plan of the experiment was to place a metal filament in the terminal of the Argonne 4 MV Dynamitron accelerator and to heat it while applying +1 MV to the terminal of the machine. Any charged particles originating from the filament, independent of their mass, were guided by a purely electrostatic system (no magnetic fields) into a Si surface barrier detector, which measured their energy. Any particles with integral charge would in principle, give a pulse from the detector corresponding to an integral multiple of 1 MeV. A particle with $+\frac{1}{3}e$ would produce a pulse corresponding to $\frac{1}{3}$ MeV.

Provisions were made to reduce two possible sources of background. One of these is the possible production of charged particles part way down the accelerator tube (by cosmic rays, or a variety of breakdown phenomena). To discriminate against such particles we used an electrostatic deflector after the Dynamitron to deflect the 3-mm beam spot by ~6 cm. Any particle originating at a lower potential in the accelerator tube would undergo a bigger deflection and miss the detector. The second possible source of a false signal is large organic molecules that desorb in a singly charged state from heated filaments. They would follow the correct path but produce an anomalously low pulse height in the detector because of their low velocity. To guard against this possibility a 5-μg/cm^2 carbon foil was placed before the above-mentioned electrostatic analyzer. This foil would break up large molecules, and the fragments would not be deflected into the detector.

The temperature calibration for the filaments was obtained by calculations using the known resistivity of metals, and this was checked against a pyrometer at temperatures above 800 °C.

The experiment was carried out by first heating a filament to a temperature (~ 700 °C) where it emitted a sufficient current of positive ions (presumably alkali metals and most likely potassium ions) to be visible on a ZnS(Ag)-coated quartz plate. The beam was then focused to a spot about 3 mm across. When the electrostatic deflector plates were turned on, the spot moved by ~6 cm on the screen, which was 6.3 m downstream from the deflector. The ZnS(Ag) screen was accurately centered on this spot. The filament was then replaced by a fresh one, with great care taken to reproduce its position and all the voltage settings. The ZnS(Ag) screen was replaced by a 100-mm^2 detector, accurately placed at the final position of the beam spot, and the 5-μg/cm^2 carbon foil was introduced.

The detector was calibrated with an ^{241}Am α-particle source and a linear pulser. The background was monitored for ~one h with all voltages set as before but with the filament cold. Pulse-height data were recorded in 256 channels, starting a new spectrum every 5 sec without loss of counting time. After the background runs the filament current was increased in several steps at ~one minute intervals until the counter was flooded with ~1000 counts/sec. Then the filament was cooled and another background run taken. The procedure was then repeated with a new filament.

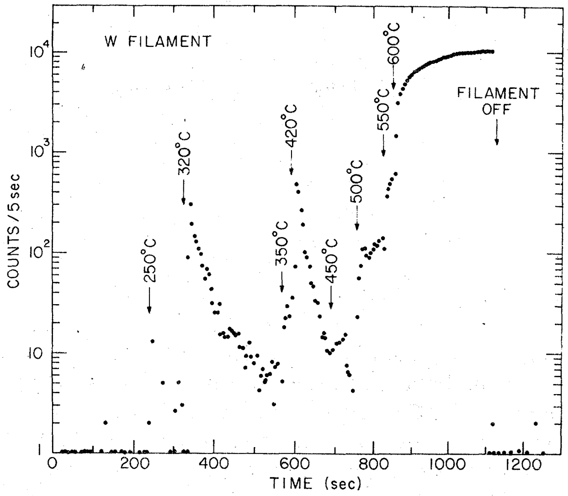

FIG. 1. Time dependence of all counts (including pulses from 100 to 1200 keV) from a W filament. The arrows and approximate temperatures indicate changes in the filament heating current.

Changing filaments had to be done by pumping out the insulating gas in the pressure tank of the Dynamitron and allowing the accelerator tube to come up to atmospheric pressure. This required approximately 10 h for each filament.

RESULTS

The background was quite low ($\le$0.1 count/min) in the region where the $\frac{1}{3}$-MeV peak is expected. The time distribution of all counts during the heating of a W filament is shown in Fig. 1, with the approximate temperatures. Several spikes in counting rate may be seen when the filament temperature is raised, first at 250 °C, then at 320 °C

TABLE I. Summary of results.

Run	Filament	$T_{\max}$ (°C)	Counts in energy interval 0.30–0.36 MeV	0.24–0.30 MeV	0.36–0.42 MeV	Differential rate[a]
127	W	500	59	109	69	− 30 ± 5
133	Fe	350	17	13	39	− 9 ± 5
136	W	500	46	86	70	− 32 ± 9
137	Nb	650	295	255	556	−100 ± 22
140	Nb	500	9	18	35	− 17 ± 5

[a] Number of counts in 0.30–0.36-MeV bin with the average of counts in the adjacent bins subtracted. The errors are statistical.

TABLE II. Accumulated counts from a W filament (run 127) in various temperature ranges.

Temperature range (°C)	Time interval (min)	Counts in energy interval 0.30–0.36 MeV	0.24–0.30 MeV	0.36–0.42 MeV
20°	5	1	4	0
250–320°	3	23	55	30
350–420°	3	27	48	33
450–500°	2	6	9	9

and higher, these rates decay rapidly as the material is driven off the filament. Then, starting above ~500 °C a large counting rate of positive ions sets in presumably from K^+ ions, and the temperature range in which this measurement may be usefully performed has clearly been exceeded.

The total spectrum obtained during the heating of a Nb filament is shown in Fig. 2. It is clear that neither the spikes nor the occasional counts in between show a tendency for clustering around 0.33 MeV and that at most ~10 counts could be assigned in this region of pulse height. The results from all filaments are summarized in Table I. The number of counts observed during the heating of the filament to a maximum temperature is given in the relevant region of pulse height, and also in the adjacent regions just above and below the expected interval. The 0.33-MeV region seems to be at a minimum in the counting rate. Subtracting the average of adjacent counting rates, as is done in Table I is not really a valid procedure, but it serves as a rough indication of the magnitude of a possible effect. The results from runs 133 and 140 with Fe and Nb filaments clearly show fewer than ten counts, the results of runs 127 and 136 with W filaments give a slightly higher limit.

The increase in counts as the temperature is raised shows no pattern between the 0.33-MeV region and the adjacent ones, Table II gives the results of run 127 as an example, the same run as is shown in Fig. 1.

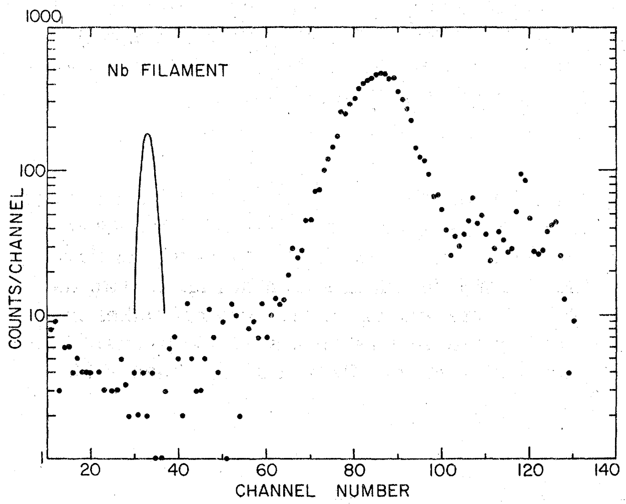

FIG. 2. Spectrum of pulses from a Nb filament during the time it was heated from room temperature to ~500° C, a total of ~8 minutes. The broad peak at ~channel 88 is most likely from alkali ions (K^+); these are broadened and degraded in energy because of the carbon foil, the Au surface layer on the Si detector, and the poor response ("pulse-height defect") of such detectors to slow heavy ions. The peak drawn at ~channel 30 represents the expected position and shape for pulses produced by a lightly ionizing particle with $E = \frac{1}{3}$ MeV, as determined from a calibrated pulser.

CONCLUSIONS

Two W filaments (0.1 × 1.6 mm in cross section), one Fe filament (0.46 mm in diameter) and two Nb filaments (0.53 mm in diameter) were used with limits all about the same. The heated volume in these filaments was ~6 mm long so that the concentration limits per nucleon would be $< 10^{-22}$, lower by about an order of magnitude than the concentration we would deduce from Ref. 1, and two orders of magnitude compared to Ref. 5.

The hypothesis outlined in the Introduction therefore appears to be wrong and the apparent inconsistency between the results of LaRue, Fairbank, and Hebard and those of Ref. 3 remains. The uncertainties in assumptions regarding diffusion rates of $+\frac{1}{3}e$ charges in solids are large. Negative results are never conclusive and one has to await a clearer confirmation or explanation of the positive results of Ref. 1.

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[3] L. W. Jones, Rev. Mod. Phys. 49, 717 (1977).

[4] We are indebted to Dr. John E. Robinson of the Solid State Science Division, Argonne National Laboratory, for helpful discussions on this subject.

[5] E. D. Garrick and K. O. H. Ziock, Nucl. Instrum. Methods 117, 467 (1974).