Search for fractional charge in tungsten

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A search for fractional charge in tungsten has been carried out using a Millikan-type apparatus. A negative result was obtained, with a 90% confidence limit of less than one fractionally charged particle per 3×10^{-10} g of tungsten. This applies to particles with fractional charges greater than 0.2 in magnitude.

La Rue *et al.*[1] recently reported evidence for fractional charge ($\simeq\pm\frac{1}{3}$) in small niobium balls (diameter 0.26 mm) that had previously been heat treated at 1850 °C on a tungsten substrate. Other niobium balls exposed to the same heat treatment, but on a niobium substrate, were reported as having integral charges. La Rue *et al.* postulated that fractional charges were transferred from the tungsten substrate to the niobium balls in the heat treatment process. To test this possibility we have carried out a search for fractional charge in tungsten "microspheres" of about 1-μm radius supplied by Electronic Space Products Incorporated, U.S.A. We have studied a total mass of about 10^{-9} g of tungsten. We estimate this to be at least 20 times the amount of tungsten that might have adhered to a niobium ball by evaporation during the course of a day for the heat-treatment process described by La Rue *et al.*[2]

The technique used here is a modified version of the Millikan oil-drop experiment using the tungsten balls mentioned above. Examination of these balls with an electron microscope revealed that they were not particularly spherical, and consequently the conventional technique based on a precise application of Stokes's law could not be used. Instead, a simple levitation and charge-changing method was used. A charged tungsten ball was first levitated by an electrostatic field E in the Millikan cell shown in Fig. 1. We then have

$$qE = mg.$$

Next the charge on the ball was changed, by an integral multiple of e using the radioactive α sources[3] shown in Fig. 1, and the ball relevitated. If the charge change is $(\Delta n)e$ we then have

$$[q + (\Delta n)e]E' = mg.$$

These equations may be solved to yield the original charge q,

$$q = \frac{(\Delta n)eE'}{E - E'} = \frac{(\Delta n)eV'}{V - V'}. \quad (1)$$

Here V and V' are the original and final levitation voltages. The only unknown in (1) is the integer Δn. This may be determined in either of two ways. If several charge changes are made on one ball then a sequence of unknown Δn's is obtained. But the product qV is a constant for all levitations ($=mg\times$plate separation) and, by trial and error, one may easily determine the appropriate sequence of Δn's for which this condition is satisfied. Most Δn's are ±1.[3] The second method for determining the Δn's utilizes Stokes's law. The speed of any ball in free fall may be measured and from this the product qV may be calculated assuming the ball is spherical and has a density of 19.3, i.e., that of tungsten. The value of qV so obtained was found to be sufficiently accurate to determine the Δn's.

In Table I the above technique is illustrated for a typical case, ball No. 16. Taking the least and (the average of the) greatest levitation voltages to minimize the error in the denominator of Eq. (1), its fractional charge is found to be $+0.01\pm0.04$. Its mass may be calculated from its qV value and equals 4.3×10^{-11} g. Its free fall velocity was measured at 1.24 ± 0.15 mm sec^{-1}. Assuming it is approximately spherical and has the density of tungsten, Stokes's law yields a predicted value of about 50 keV for qV. This reasonably confirms the Δn assignments listed in Table I.

Before discussing the results for the entire sample of balls studied here we note the following experimental details. The tungsten balls were swept into the cell using a small, dry, dust-free brush. The oil smear on the bottom plate was placed there to retain balls which had dropped to the bottom plate. Illumination was provided by

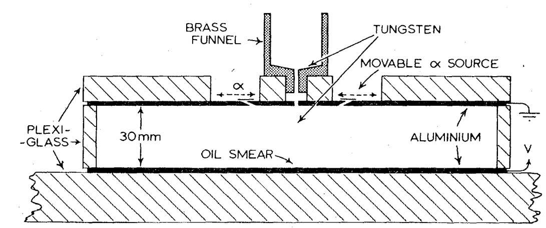

FIG. 1. The Millikan cell used in the present experiment.

TABLE I. Data for one of the tungsten balls (No. 16). The error in the first column denotes the setting error. Possible systematic errors in the levitation voltages were neglected because Eq. (1) involves voltage ratios only.

V (volts)	$\frac{V'}{V-V'}$	Δn	q	qV (keV)
−163 70 ± 20	+4.93	−1	−4.93e	80.7
−136 10 ± 20	−6.00	+1	−6.00e	81.7
−163 30 ± 20	+ 2.50	−2	−5.01e	81.8
−116 70 ± 20				

two small 100-W lamps each at 90° to the viewing telescope. The light beams were passed through 2 cm of Plexiglass and 5 cm of water to eliminate possible convection effects in the cell. The aluminum plates were anodized dull black. The voltage was supplied by a 30 kV regulated Brandenburg power supply, and was monitored by a Fluke digital voltmeter via a temperature stabilized 1:10^4 voltage divider. The experiment was carried out in a darkened, draught-free room at 20 ± 1 °C. All balls reported here were levitated in at least three charge states, and all levitation voltages were measured with the α sources removed. Polarization induced in the balls was neglected because it simulates charges $<10^{-2}e$ in the microspheres used here.[1]

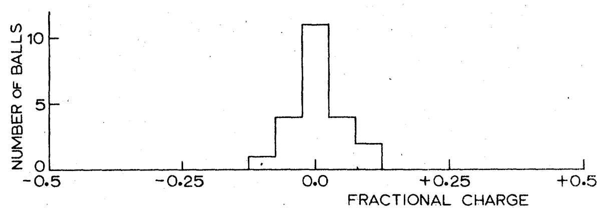

FIG. 2. Measured fractional charges of the 22 tungsten balls studied here.

A total of 22 tungsten balls were examined as above and their measured fractional charges are plotted in Fig. 2. The measured fractional charges are consistent, within experimental errors, with zero in all cases, and there is no evidence for fractional charge in any one of them. We conclude that, with 90% confidence, there is less than one fractionally charged particle per 3×10^{-10} g of tungsten. This applies to particles with fractional charges greater than 0.2 in magnitude.

Note added. After submitting this paper for publication we learned that similar results had been obtained independently by Roger Bland *et al.*, Phys. Rev. Lett. 39, 369 (1977).

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[1]G. S. La Rue *et al.*, Phys. Rev. Lett. 38, 1011 (1977).

[2]The evaporation rate for tungsten is tabulated in *CRC Handbook of Chemistry and Physics*, edited by Robert C. Weast (CRC Press, Cleveland, 1974), p. E-229.

[3]The α sources were ^{241}Am and their strengths (~0.2 μCi) such that charge changes occurred in a typical exposure of 20 s. The ion pair separation along α tracks at the center of the cell was about $\frac{1}{4}$ μm [R. D. Evans, *The Atomic Nucleus* (McGraw-Hill, New York, 1955), p. 655] and consequently most charge changes were ± 1e only. Charge changes could be induced with the electric field off or on, and the signs of changes were partially controllable [R. A. Millikan, *Electrons (+ and −), Protons, Photons, Neutrons, Mesotrons, and Cosmic Rays* (University of Chicago Press, Chicago, Illinois, 1947), p. 77].