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An Improved Search for Elementary Particles with Fractional Electric Charge*

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Abstract

The SLAC Quark Search Group has demonstrated successful operation of a low cost, high mass throughput Millikan apparatus designed to search for fractionally charged particles. About six million silicone oil drops were measured with no evidence of fractional charges. A second experiment is under construction with 100 times greater throughput which will utilize optimized search fluids.

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AN IMPROVED SEARCH FOR ELEMENTARY PARTICLES WITH FRACTIONAL ELECTRIC CHARGE

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The SLAC Quark Search Group has demonstrated successful operation of a low cost, high mass throughput Millikan apparatus designed to search for fractionally charged particles. About 6 million silicone oil drops were measured with no evidence of fractional charges. A second experiment is under construction with 100 times greater throughput which will utilize optimized search fluids.

1 Introduction

Searches for evidence of the existence of fractional electric charge date back to Robert Millikan and his contemporaries[1] with one measurement of 2/3 e taken by Millikan himself which he attributed retrospectively to an evaporative measurement artifact[2]. Later experiments conducted by Fairbank, Phillips and LaRue[3] made in the 1970s at Stanford gave tantalizing evidence of the possible existence of fractionally electrically charged particles but were not replicable by others[4,5,6]. The failure over many decades to implement a reproducible experiment capable of detecting fractionally charged particles have led most groups to abandon this line of research as unproductive. Current theory also gives reasons why the quark fractional electric charges of $\pm 1/3$ e and $\pm 2/3$ e may be intrinsically unobservable.

The final arbiter of any hypothesis, in this case the hypothesis of total quark confinement, is experimental confirmation. There is always the possibility that the quantities of matter measured in the past were insufficient to have a high enough probability of consistently finding these rare particles or that the test material selected was by natural or intentional chemical refinement depleted of its natural quark mass fraction [7].

The computer multimedia revolution of the last decade has opened up the possibility of performing searches for free quarks in normal matter with a higher mass throughput than any previous experiment at a hardware cost of one to two orders of magnitude lower than these prior searches [8]. Commercial consumer grade high speed real time image processing hardware can be used to act as the enabling technology for a very high throughput Millikan oil drop based fractional charge searches. The scientific and practical engineering payoffs if free fractionally charged particles are found are so high that if a low cost experiment that can extend these search limits is possible it would almost be scientifically negligent not to perform it.

This paper will summarize the results of a preliminary feasibility experiment of a CCD camera based Millikan experiment as well the in progress construction of its successor.

2 Apparatus

The Millikan apparatus was designed in 1993 using IBM PC compatible data acquisition and control hardware. The original system was run with a 66 MHz 486 and an ISA bus image capture card. A high end commercial RS 170 compatible monochrome CCD camera was used to image the falling drops. Backlighting of the falling drops was done with an externally triggered strobe diffused with a ground glass screen. The optical components and test chamber were mounted on an aluminum I-beam stiffened wooden table for vibration suppression. Limitations in the real time image analysis speed of this computer restricted the drop generation rate such that there could be only one drop in the camera field of view at a time. The requirement to have at least three charge measurements performed on each drop as a guard against artifacts that can produce pseudo fractional charge measurements limited the size of the drop to between 7 – 8 microns. These two factors defined the maximum throughput for this first experimental setup. The drop generator was an in-house designed piezo electrically actuated cylindrically configured drop on demand fluid drop ejector. The Millikan electric field plates were contained within two levels of transparent convection shielding as well as having the experiment located within a temperature controlled room. Dow-Corning 200 5 centistoke viscosity silicone oil was used as the test fluid. Since this is a chemically refined synthetically manufactured test liquid it was not expected to contain any atoms with bound quarks. This experiment was intended primarily as a test of the feasibility of a CCD camera based Millikan experiment.

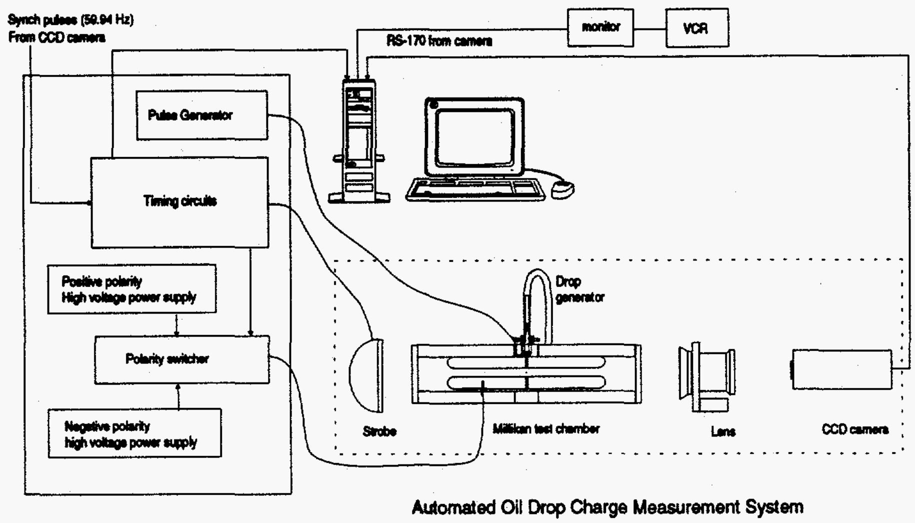

Figure 1: Schematic block diagram of the SLAC automated Millikan fluid drop charge measurement system.

3 Results

A measurement of the charge of a falling drop was considered valid if it met the two criteria of (1) having at least 3 separate determinations of its charge as it fell between the electric field plates and (2) if these 3 or more charge determinations agreed to within 0.15 e. This criteria was implemented as a precaution against pseudo fractional charge measurements caused by the absorption of an ion or emission of an electron from a drop during the course of a measurement. Approximately 97% of the measured drops satisfied these two criteria which resulted in successful measurement of 5,974,941 drops over the nine month experimental run with a total mass of 1.07 mg (6.41×10^{20} nucleons) of silicone oil being tested. The standard deviation for these electric charge measurements was 1/40 e. The square of the error due to Brownian motion accounted for 70% of the square of the total error in charge measurement. No electric charges were measured in the range of an integer charge $\pm 1/3$ e or $\pm 2/3$ e.

The experimental apparatus ran continuously for these 9 months with the exception of a brief period when the experiment had to be relocated due to building construction. Operator intervention was limited to stopping and restarting the data acquisition computer to periodically download the charge measurement data to UNIX mainframes for analysis.

While no evidence of fractional electric charges were found, this experiment was a success in that it demonstrated that a low cost implementation of the Millikan method using commercial grade computer imaging hardware is possible. The standard deviation of the charge measurements makes this experiment in fact the most accurate in the literature[9].

4 Discussion - plans for the next experiment

The use of a chemically purified synthetic test fluid made it highly unlikely that any atoms with bound free quarks would be found in this initial test run. The next experiment will utilize the silicone oil as a carrier for finely powdered solid materials that by their history and chemical composition make them more likely at least to have not lost any primordially formed quark containing atoms[2,7]. A test colloidal suspension that contained approximately 11 percent powdered test material by mass using on Dow Corning 200 silicone oil as a base fluid has been recently synthesized at SLAC.

An increase in the mass throughput for a CCD based Millikan apparatus can in principle be achieved by injecting multiple drops to be measured simultaneously between the electric field plates. Because of the need to avoid collisions between drops of different electric charge as well as minimize interdrop induced dipole interactions, the maximal measurement rate will be achieved with an ejected two dimensional uniformly spaced grid of drops. A prototype ejector capable of generating such arrays has been developed at SLAC using the technique of sequentially modulating the drive pulses of a single horizontally ejecting drop generator.

Utilizing a 133 MHz Pentium computer with a PCI bus image capture card increased the image processing speed such that measuring the velocities of up to 10 drops falling in a vertical column has been achieved. A two dimensional grid can be measured by paralleling additional computers, having each computer analyze one out of several simultaneously falling columns of drops. As low cost computer power increases, a single personal computer will be able by itself to analyze increasingly large fractions of these multidrop images. This steady increase in the price performance ratio of computers combined with the falling cost of high performance digital cameras will allow multiple Millikan apparatus to be constructed at low cost and operated simultaneously in the same temperature controlled room, tended by the same operator. An increase in mass through put of a factor of a thousand from the best past experiments should be achievable for an apparatus costing well less than $100,000 relying on incremental construction and the falling costs of sophisticated digital image processing computing systems. This economic advantage of designing an experiment to be rate limited by its ability to perform automated analysis of raw data in real time is important in performing what is considered to be long odds, high pay off experiments such as the search for free quarks in bulk matter. This high speed computer interfaced Millikan chamber experimental architecture both allows the experiment to be performed with realistically available resources and insures that the experimental apparatus can be readily replicated at low cost by other institutions if fractional charge events are found.

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