Search for fractionally charged particles in large samples of matter

D. D. Ogorodnikov, I. M. Samoĭlov, and A. M. Solntsev

I. V. Kurchatov Institute of Atomic Energy
(Submitted 22 July 1978; resubmitted 19 February 1979)
Zh. Eksp. Teor. Fiz. **76**, 1881–1883 (June 1979)

A search for quarks has been carried out in sea water and in the principal bottom deposits of the ocean: finely divided deep-sea clays, silts, and concretions. Estimates of the upper limits of concentrations of the desired particles made on the basis of the measurements lie in the range 8×10^{-29}–4×10^{-27} particles per nucleon for the various materials studied.

PACS numbers: 14.80.Dq, 92.20. – h, 91.50.Ey

The technique of searching for fractionally charged quark ions, which should be formed on contact of free quarks with ordinary matter, was similar to that described in our previous article[1] and consisted schematically of the following. The desired particles were extracted by desorption on heating of the materials under study to 600–800°C in a special crucible for accumulation of quark ions. The flux of the volatile fractions and vapor of material from the crucible were passed through a vapor duct which served as an electrical filter. At all times quark ions carrying charge were collected from the vapor flow onto the filter electrodes, which were maintained at a constant potential difference $V_f=\pm(100-120\text{ V})$; the quark ions were retained on the electrodes and were thus accumulated in the filter with the passage of time. At the end of the accumulation stage they were transported from the filter (on removal of V_f after heating of the filter) to a special collector with appropriate sign of potential, which then served as an emitter of quark ions in the source of an apparatus intended for identification of the particles. Charged particles leaving the source were accelerated by a voltage of 20–25 kV and focused onto a detector consisting of an open electron multiplier. Particles were identified by the technique of recording particle-desorption curves from the heated source with use of an electric-field gate which permitted retention in the source of quark ions with uncompensated charge, whereas ordinary particles in this situation are evaporated continuously in the form of neutral particles. It is obvious that if the source is successfully cleansed of ordinary particles capable of providing background ions, then on opening the gate for a detection time t_d only the desired quark ions will be detected. (We note that the lifetime τ of particles on emitting surfaces decreases exponentially with increase of the temperature and the number of such particles falls off with time as $\exp(-t/\tau)$.)

In the specific measurement scheme the source temperature T_s was raised in steps of ~100°C with an aging period before detection in each step of $t_a\approx 5-10$ minutes, where $t_a\gg t_d$. This permitted the effective exclusion of most background particles with lifetimes in the source $\tau_b<\tau_a$ without greatly decreasing the lifetime τ of the desired particles with low activation energy for evaporation, which otherwise could lead to their leaving the source during the heating time τ_a. In this measurement scheme a clear indication of the presence in the source of quark ions would be the detection of an appreciable number of desorbed particles with intensity falling off rapidly in a time $\Delta t\sim\tau\lesssim\tau_d$ and with an appreciable excess over the background of ordinary ions. In the general case, to bring out an excess over the background (during detection at each temperature state) the gate was opened twice for time intervals t_1 and t_3 separated by an interval t_2 when the gate was closed; here the changes of intensity of desorbed charged particles and the total numbers of such particles N_1 and N_3 were measured, (usually $t_{1,2,3}=t_d=0.1$ sec). For the desired particles with $\tau\leqslant\tau_d$ the number of particles can be characterized by the difference $\Delta N=N_1-N_3$, since with high accuracy $N_3=N_{3b}-N_{1b}$, where N_{3b} and N_{1b} are respectively the numbers of background ions in the intervals t_3 and t_1. (We note that after heating the source only background particles with $\tau_b\sim\tau_a$ can remain in it, and the change of intensity of these particles during the measurement time $t_d\ll t_a$ is small: $\Delta N_b=N_{1b}-N_{3b}\sim N_{1b}\times 2t_d/\tau_b$.) The minimum values of ΔN which can be observed in this manner are determined mainly by the fluctuations of the numbers N_1 and N_3.

The procedure described above for observing the desired particles has a limited nature in the sense that detection of the effect, i.e., of ΔN values appreciable exceeding the flucutations of (N_1-N_3), is a necessary but strictly speaking not a sufficient condition for the unique identification of these particles as fractionally charged. It was proposed to use for the further analysis a magnetic mass spectrometer available at our laboratory for the purpose of establishing the presence of particles with a ratio e/M differing from known ratios. However, in the present series of tests, as in our previous work, the total numbers of particles recorded in the segments of the desorption curves were below the detection sensitivity of the mass spectrometer.

In the tests of the present series, both in the quark-ion accumulation stage and in the subsequent stages, all details of the technique and the searching procedure, and also the temperature and time intervals, etc., were the same as those described previously.[1] Some changes were made only in study of water samples in the accumulation stage, as a result of the limited volume of the storage crucible. In the three-stage transfer of the desired particles from the filter to the

 0038-5646/79/060953-02$02.40

collectors (see Ref. 1) the first transfers were carried out after evaporation of each eight-liter portion of water at a filter temperature 50°C (each portion to a new collector). The second transfers were made with accumulation of the residual salts after evaporation of ~40 liters of water (filter and crucible temperature 200°C). Then the salt was removed from the crucible, powdered, and studied as a new material with the complete scheme. In order to reduce the contamination of the collectors by vapors of the salts, during the last stage the crucible was heated only to 600°C.

EXPERIMENTAL RESULTS

In the measurements with the technique described above, which as previously[1] were designed for quark ions of both signs of charge, in none of the tests did we observe effects which would be explained by the existence of the desired particles, and as a rule the intensity of light did not exceed the intrinsic background of the heated source. For this reason in estimates of the upper limits of the concentration of fractionally charged particles (quarks) in the materials studied, we considered all particles recorded in the measurements to be quarks. The results of the estimates are given in the table. In comparison with the results of Ref. 1 the values of the lower limits for quark concentration for water and the clay-silts are lower, roughly in accordance with the increase in sample size, and for the concretions they are lower by almost two orders of magnitude—the latter being due to the unfavorable background situation in the previous experiments with concretions.[1] Unfortunately, as a result of the lack of material, we were unable to study large samples of volcanic lava, for which in the previous work[1] we observed weakly expressed effects similar to those sought.

TABLE I.

Material studied	Upper limits of concentration, (quarks/nucleon)			
	In detection of negative particles		In detection of positive particles	
	$T_s = 25°$ C	$T_s = 25-470°$ C	$T_s = 25°$ C	$T_s = 25-280°$ C
Sea water (84 liters)	$8 \cdot 10^{-29}$	$6 \cdot 10^{-28}$	$1 \cdot 10^{-28}$	$5 \cdot 10^{-28}$
Finely divided clays and silts (23 kg)	$4 \cdot 10^{-28}$	$2 \cdot 10^{-27}$	$3 \cdot 10^{-28}$	$4 \cdot 10^{-27}$
Concretions (16 kg)	$4 \cdot 10^{-28}$	$4 \cdot 10^{-27}$	$5 \cdot 10^{-28}$	$3 \cdot 10^{-27}$

Thus, the result of the search is negative also in this series of measurements. However, taking into account the success of the quark model (which has again brought to life the question of the reality of quarks), one can with a certain amount of optimism consider our results as a further proof of the unobservability of free quarks.[2]

The authors express their gratitude to É.N. Braverman for designing the instruments and equipment used in this work.

[1]D. D. Ogorodnikov, I. M. Samoĭlov, and A. M. Solntsev, Zh. Eksp. Teor. Fiz. **72**, 1633 (1977) [Sov. Phys. JETP **45**, 857 (1977)].

[2]Y. Nambu, The Confinement of Quarks, Scientific American **235** (5), 48–60 (November 1976). Russ. transl., Usp. Fiz. Nauk **124**, 147 (1978).

Translated by Clark S. Robinson

Wave function with spin on a light front

V. A. Karmanov

Institute of Theoretical and Experimental Physics
(Submitted 6 February 1979)
Zh. Eksp. Teor. Fiz. **76**, 1884–1897 (June 1979)

A method is developed for constructing relativistic wave functions with spin on a light front. The spin structure of the wave function of a deuteron in the relativistic region is obtained. The calculation procedures are illustrated by a determination of the *pd*-scattering cross section. The described construction is equivalent to solving the problem of allowance for the spins and angular momenta in the parton wave functions in a system with infinite momentum.

PACS numbers: 11.90. + t, 13.85.Kf

1. INTRODUCTION

The author has previously[1] developed a formalism of wave functions (WF) on a light front, which describe relativistic systems consisting of zero-spin particles and having zero total angular momentum. The need for developing a covariant formalism, convenient for use in practice, for the description of nuclei when the relative momenta of the nucleons are of the order of their masses and of elementary particles within the framework of the composite models, is brought about by modern experimental data. Wave functions in relativistic coordinate space were discussed in the papers by Shapiro.[2] A review of the experimental situation in relativistic nuclear physics, of the theoretical problems that are raised, and of the existing approaches is presented in Ref. 3.

The wave fronts on the light front are the components of a Fock column of the wave vector of state in the

