Investigation of Muon Interaction with Colloid Suspension

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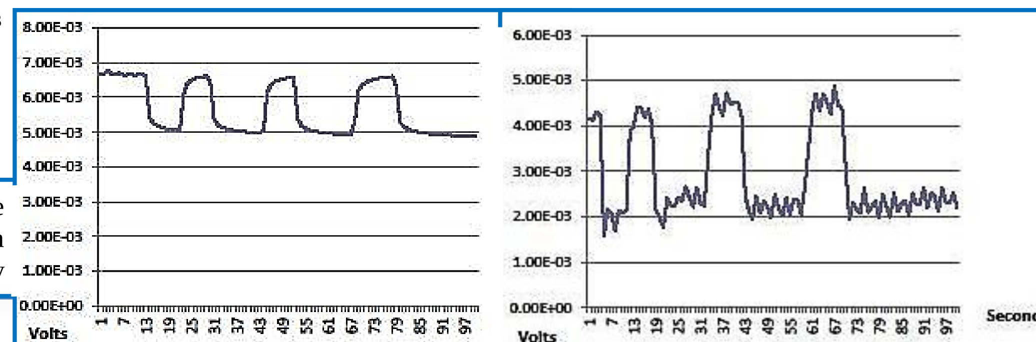
Pilot Scheme Proposal Conventional methods of muon detection such as gas scintillator tubes (GST) or gas wire detectors (GWD) are expensive and bulky; a large detector volume is required. Such detector systems are even larger if it is required to measure momentum as well as tracking position; absorbers or magnets are necessary. A new type of small detecting element is therefore proposed. In the proposed detector, muons interact with nanoparticles suspended in a colloid liquid. Each nanoparticle has the same amount of electric charge, and the same type of charge positive or negative. The nanoparticles are therefore mutually repellant and in an electrostatically stable suspension. When there is coulomb interaction between nanoparticle and muon, movement of the nanoparticle from its equilibrium produces an electric field in the proximity of the interaction. This electric field is detected by insulated electrodes within proximity. The electrodes provide an electrical output that can be amplified and recorded.

Azimuth and altitude angles of the muon track are obtained from two detector arrays in parallel, one on top of the other. Azimuth angle data is also available from two adjacent signaling electrodes. In sample calculations electrode spacing is indicative only. A fully developed detector may be produced using micro-machining techniques in order to minimize electrode spacing i.e. micron or nanometer separation of the detecting elements. The proof of principle device, built as part of this pilot scheme, will have millimeter separation of electrodes. This is still less than the diameters of either a gas scintillator tube or gas wire detectors which are a minimum of approximately 1 cm.

Testing of prototype A prototype has been built as an array of electrodes with a 1mm layer of colloid suspension of nanoparticles. Voltage measurements were taken across two electrodes spaced approximately 1.5 mm apart. The colloid suspension contained 30 nm (average) diameter silica nanoparticles at 30% by volume concentration. The prototype was initially tested with photonic interaction using low power lasers. Photonic/nanoparticle interaction is by the photo-emissive effect and therefore different to the muon/nanoparticle columbic interaction; but the overall effect will be similar to muon interactions i.e. perturbed charge on the nanoparticle causes it to move from its equilibrium position. This movement and subsequent movement of other nanoparticles produce an electric field.

Tests were conducted using lasers<200 mW output. To reduce light intensity the prototype was covered with 0.31mm thick cardboard having 80%-90% obscuration. Figure2 shows the unamplified output from the prototype electrode pair. Maximum signal amplitude was ≈ 1.5 x 10^{-3} volts in response to IR (605 nm) and ≈ 2.5 x 10^{-3} volts with UV (405 nm). The frequency dependence of the signal demonstrates the photo-emissive origin of electrons. There was no output (above noise) from the uncovered prototype when illuminated with daylight only.

Prototype detector response to laser light. Lasers < 200mW were arbitrary-pulsed. The detector was covered with cardboard 0.31mm thick and obscuration 80%-90% to reduce radiation intensity



Detector response when illuminated with Infra Red (650nm) Laser Light | Detector response when illuminated with Ultra Violet (405nm) Laser Light

Simplified Analysis

Simple conservation of energy concepts are used demonstrate feasibility of the device, expected results and how these compare with prototype performance.

In this analysis the cosmic muon is assumed to pass through the center of the cubic lattice, equidistant the cosmic muon is assumed to pass through the center of the cubic lattice, equidistant from the nanoparticles; as shown in Figure 1. only interaction of electric fields between muon and nanoparticle are considered. There are condition for minimum interaction Viscous damping is ignored and velocities are assumed to be in the – Z direction only i.e. no vector components.

Figure 1a Shows an assumed cubic lattice arrangement of charged nanoparticles in electro-static equilibrium. Figure 1b shows dimensions of the lattice used in subsequent calculations.

The table below shows the calculated Surface Charge and Mass for nanoparticles with diameters of 7nm and 30nm. Also shown are the calculated distance parameters r and d for the nanoparticles by assuming a 30% volume concentration in the colloid suspension.

P_0, P_1 and P_2 are illustrations of typical nanoparticles held in electrostatic equilibrium due to their mutually repellant negative surface charge. P_0 is perturbed by a distance Δr due to interaction with the muon electrical field.

Subsequent calculations were based on parameters in the table and the following conservation equation: $\Delta K + \Delta Ue = \Delta k + q\Delta V = 0$

Where: K is kinetic energy (J), Ue is electrical potential energy(J), q is electric charge(C) and V is electrical potential (J/C)

Nanoparticle Diameter (nm)	Inter-particle distance(nm) r	Diagonal distance from muon to nanoparticle(nm) d	Charge on the nanoparticle surface(C)	Mass of the nanoparticle(kg)
30	39	27.5	2.26 x 10^{-19}	2.18 x 10^{-20}
7	9.4	6.66	12.3 x 10^{-18}	2.76 x 10^{-22}

Calculation of velocity is as follows:

$$\left(\frac{1}{2}mv_i^2-\frac{1}{2}mv_f^2\right)+\frac{k\,qmqp}{d}-\frac{k\,qpqp}{\left(\frac{1}{r}-\Delta r\right)-\left(\frac{1}{r}+\Delta r\right)}=0$$

Calculation of electrical potential is as follows:

$$\left(\frac{1}{2}mv_i^2-\frac{1}{2}mv_f^2\right)+qp\Delta V=0$$

Where: v_i and v_f are initial and final velocities of the nanoparticle (m/s). m is the mass of the nanoparticle (kg), k is the electrostatic constant for which the relative permittivity ε of the fluid suspension is assumed to be 80. Other symbols are as indicated in figure1.

A numerical approach was used in calculations: Limiting values of Δr, when velocity was zero, were calculated. Then Δr was divided into incremental amounts and other values of velocity, hence electrical potential were calculated. The results of voltage versus (calculated) times are shown in Figure 2. These values may explain the leading edge of the (detector) output voltage spike shown in Figure3.

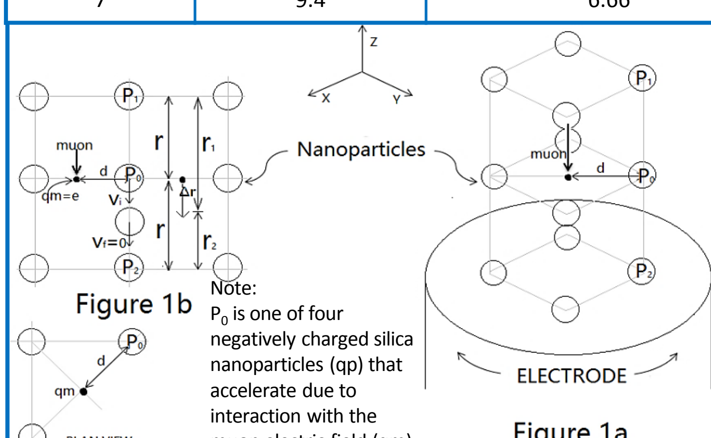


Figure 1a

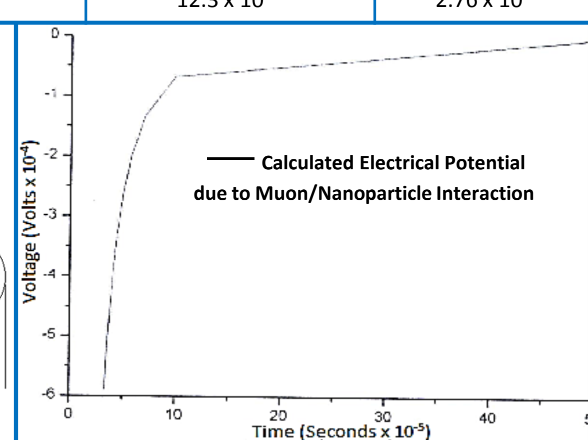


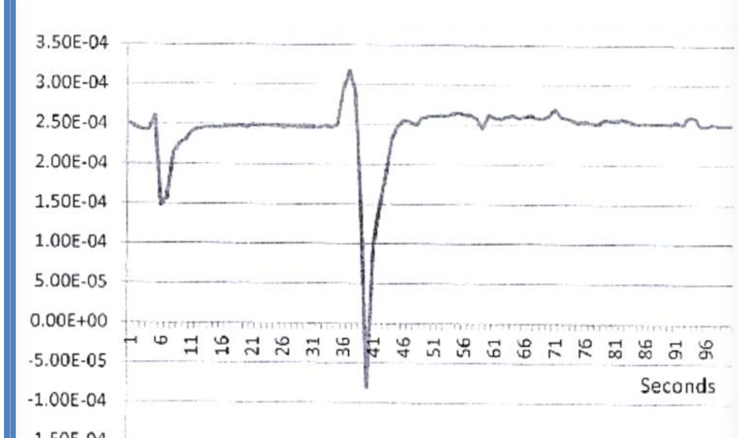
Figure 2

Summary

A mechanism for interaction between charged sub-atomic particles such as muons and a colloid suspension of charged nanoparticles is proposed: The colloid suspension consisting of equally charged nanoparticles are in a mutually repellent electrostatic equilibrium. Columbic interaction with a charged muon causes perturbation of the nanoparticles from there equilibrium positions. This movement of charge produces an electric field which can be detected by electrodes in contact with the colloid suspension.

To test this hypothesis an apparatus was constructed which consisted of an array of electrodes immersed in a colloid suspension of (negatively) charged nanoparticles. Voltage between pairs of electrodes was measured using a six digit precision multimeter (x10^{-5} volts). Initial testing was carried out using laser illumination. Although the photoemission of electrons from the surface of the nanoparticle is a different source of columbic interaction the effect is the same i.e. perturbation of nanoparticle position resulting in an electric field. Pulsed laser illumination produced a corresponding pulsed electrical output, with an amplitude dependant on laser frequency.

A simplified theoretical analysis showed that electrical spikes measured when the device was exposed to background radiation may be a result of the columbic interaction described above. Such interactions with colloid suspension may be the basis of a radiation detector.



Detector Output Voltage

Figure 3