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A Space Apparatus To Search of Fractional Charge on Ordinary Matter

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ABSTRACT

This work shows the structure of a Cubesat-like nanosatellite carrying an apparatus whose aim is the detection of fractional charges (free quarks)on ordinary matter . This search will be at first in an object inside satellite and later in primary cosmic rays supposing that such charges can be absorbed by object . The apparatus realizes not only a space experiment of fundamental physics but also a tool to teach " real science " because it can be operated also by students (including high school students) In this paper several aspect of mission are analyzed with considerations about orbital parameters , dimensions and power consumption of components , software , lying signals and other . Finally aspects related to put into orbit satellite are considered too

INTRODUCTION

It's well known that there are three kinds of fundamental physics experiments : accelerator experiments , " passive " experiments as proton decay searches , and high precision measures .
Among these there are searches of fractional charges on ordinary matter .
In the past years [1]; [2]; [3]; and also recently [4],[5] such experiments have been realizes or proposed . No fractional charge has been found and the best limit is still the Morpurgo limit

$$(quark / nucleon) < 4.5 * 10^{-22} .$$

In the last years it has become possible to make experiments in the space both in ISS and in Space Shuttle or in satellites so that many fundamental physics experiments have been proposed to be done in space or are operated in orbit (AMS-02 , PAMELA , GLAST and so on) .
And it's very probably that it will be possible to make space experiments in private built orbital spacecrafts
In the last years there was a change in satellites too because the technique of little satellites (from minisatellite to nanosatellites) was improved and at today it's possible to make experiments in space that are cheap and so simple that both amateurs scientists and university or high school students can be involved in them
This paper shows the outline of a simple experiment to obtain and to improve Morpurgo limit by a fully automatized apparatus to be installed in a nanosatellite The author had already introduced [6] a plan of a similar apparatus but this needed to be handled by a man and then it had to be made in ISS or inside the space Shuttle .
The introduced experiment gives the possibility to detect , at least theoretically , fractional charges not only in examined object but also in primary cosmic rays if such charges would absorbed by object . The plan of satellite is Cubesat-like [7] such a way students can be involved in its detailed planning and they can handle it . By this way they can learn how a " real science " experiment is made However , because this is only an outlet it isn't clear yet if the requirements of Cubesat project are fully observed

THE EXPERIMENT

Let's imagine a body , freely floating in the air and immobile To put idea in words this body is a cube of lead 1 centimetre side . It contains $7*10^{24}$ nucleons , we can verify this by simple calculus , Let's suppose it has an electrical charge 1/3 electron charge , by presence of a quark . Let it is subjected to an electrical field *E* perpendicular to one of its faces and this field is generated by a plane capacitor whose length is *d* The motion of cube is described by following differential equation ,taking account of the friction of air too

$$m * dv / dt + 6K\pi R\eta v - eE = 0 \qquad (1)$$

where m = mass of cube v = its speed E = applied electrical field ed e = present electrical charge .To describe friction force Stokes' formula has been used where R = length of side of cube , η = air viscosity and K = numerical coefficient taking account that Stokes' law is for sphere and we have a cube The (1) is exactly resolvable and the displacement of cube results

$$s(t) = (B/-A)t + (B/A^2)e^{At} + C$$

Where A = -6RKηπ/m , B = eE/m and C = -B/A^2 In the table 1 the displacement of cube after a certain time is reported . The numerical values used have been . R = 1 cm. , K = 21 , E = 50000 MKS unit, η = 1.4*10^{-5} Mks unit, e = 1/3 electron charge , m = 11.6 g. It can be observed that , after only an hour there is a displacement from original position detectable by a laser system and then it can be measured as variation of distance between laser and the face of cube reflecting laser ray ., .

Table 1: Cube Displacement (μm)

Time	Displacement
10 min.	0.1
1 h	2
1 day	61,76
1 month	1100
1 year	22400 (2.24) cm.

It's to note that a possible absorption of a fractional charge , coming from primary cosmic rays , by cube would produce the same displacement . Then the working life of satellite isn't restricted to an hour but it can be estimated at least one year , similar to the average working life of other satellites

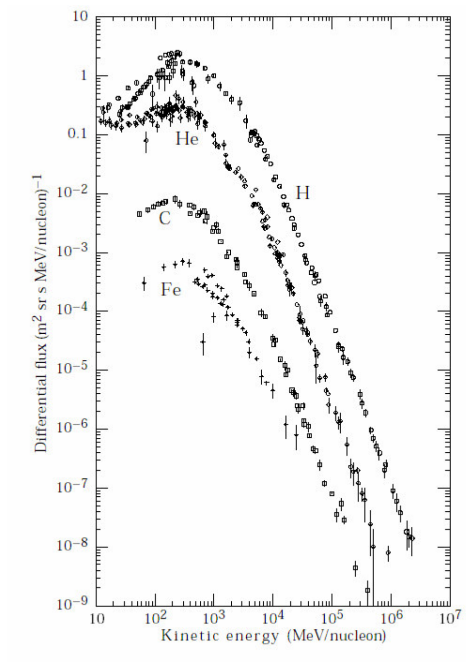
Lying signals

In every experiment it's important to value the possible cause of lying signals . In this case mechanical vibrations generated or by putting satellite into orbit or by its rotation can be , and these can shift the cube ,but these vibrations are unrelated from presence of electrical field .. Besides , working by a cube only the displacements parallel to cube-laser axis will disturb our measurements . Then , to resolve this problem , it needs only to make some measurements of position of cube as to laser before to apply electrical field , and to take account of this " residual displacement " in analysis of data .

It's to note this " residual displacement " hasn't to be so large that cube knocks against the plate of capacitor . This aspect will have to be considered during detailed planning of satellite .

. Another problem could be this : cosmic rays could hit the cube and release ionization electrons that could leave cube . By this way cube would gain an electrical charge .. A rigorous calculus of this effect needs to be performed by a computer simulation made by a specific software as GEANT4 but some calculations by author indicate this effect is negligible .

Let's consider plot 1 [8] showing the differential flux of primary cosmic rays . It's to note that :



Graph 1: Flux of Incoming Primary Cosmic Radiation (m^2 sr s Mev/nucleons)-^{1} vs Energy (Mev)

it's possible to consider cosmic radiation composed only by protons (their flux is larger of at least one order of magnitude than others)

it's possible to neglect protons whose energy is larger than 1 GEV (their flux is very small and it is negligible in an interval of time of an hour)

it's possible to suppose some protons (4 -5) arrive in an hour (one every 10 – 20 minutes) and that their energy is some dozen MEV

Under these assumptions let's consider [9] formula giving energy loss by ionization in the case of a particles whose mass is much larger than electron one

$$-dE/dx = (4\pi Z^2 e^4 / m_e v^2) N_e \log((m_e v^2 / b$$
$$(1-\beta^2))$$

Where Z = atomic number of crossed material , e = electron charge , m_e = electron mass , v = speed of ionizing particle , N_e = number of electrons in one unit of volume , β = v/c where c = speed of light, b = statistical average of ionization energies that we can set , by Thomas – Fermi model , equal to

$$Z(9.1(1+1.9Z^{-2/3}))ev.$$

By this formula let's estimate ionization energy loss of cosmic ray in 50 Mev every centimetre and then number of electrons produced in 2.5 millions every centimetre because the primary ionization energy of lead is 12 ev and supposing every electron has an kinetic energy 8 ev .. Then there will be one electron produced every $0.4*10^{-6}$ centimeter .

These electrons will move towards the positive pole of capacitor but in this movement they have to cross cube of lead and they lose energy too .The energy loss of an electron is complex affair by several reasons as relativistic effects , bremsstrahlung and so on but , when energies are so low .these effects are negligible and it's possible to utilise a formula similar to (1) [10] that is

$$-dE/dx = (4\pi e^4 N_e / m_e v^2)(\log((Zm_e v^2 / 2b) - 1/2(\log 2) + 1/2) \quad (2)$$

.

And this formula produces numerical values practically equal to (1) Applying (2) it's possible verify that electrons loss their energy in only $0.5*10^{-12}$ centimetres . We can think electrons produced by ionization don't succeed in going out the cube . The only exception could be those electrons (so called δ rays) that succeed in receiving from ionizing particle an energy much bigger than 10 ev supposed .

But also in this case they go back inside the cube through the external circuit of capacitor and in a time much shorter than 10 – 20 minutes above citied .

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Another problem could be created by airstreams shifting the cube . These streams could derive by differences of temperature between the side of satellite exposed to Sun and opposite side . It's sufficient let satellite rotate , or at least permit it rotate only around an axis perpendicular to its orbit , to avoid this problem .It's obvious rotation of satellite makes things difficult for communications between satellite and earth radio station . In the following we will show as this problem can be resolved On the other hand this problem becomes important when or the speed of rotation or transmission times become large and this isn't our case

THE SATELLITE STRUCTURE AND ORBIT

Hardware

The structure of satellite is Cubesat-like . Let thinks to a metallic frame that is a cube (let see Figure 1) 10 centimetres side and let think solar cells on four lateral side . Solar cells will provide power supply together to some recharged batteries Cells are in every lateral side to ensure power supply also if satellite rotates (there will be one side exposed to Sun)

Figure 1: Outer Wrapping of a Cubesat

Inside frame there will be

a) experiment board with the components of experiment

b) microcontroller board

c) communication board

d) stability board

Let consider figure 2 .It shows the position of components of the experiment board . It's to note figure is not to scale and , by simplicity , there aren't both the power supply lines and the buses connecting it to microcontroller board . Battery A are for power supply and we have to think them connected in parallel each other and serially to solar cells .In the following it will be showed the simple calculus needed to determinate the type of batteries .

The object C is the cube of lead that is inside capacitor B . Also capacitor has cubic form and its side is 2 centimetres . Position of B is monitored by laser system L . Screws indicated by black larger lines stop B until satellite enters into orbit . They are shifted by two micromotors M .

It's to note cube C is stopped in a position that is central as to satellite . By this way the centrifugal force produced by satellite rotation keeps cube near to the centre of capacitor and doesn't send it to hit sides of capacitor

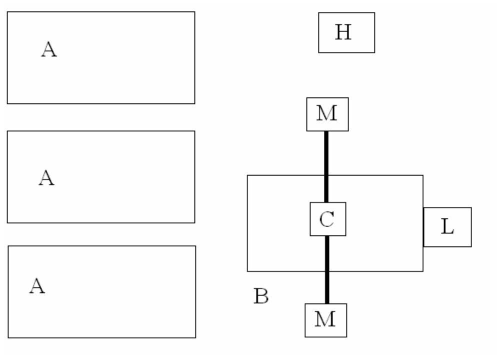


Figure 2: Experiment Board

Other boards are practically equal to commercial components or to boards of Cubesat kit [11]. and then isn't useful to describe them

Only a clarification about stability board , it contains only a permanent magnet to stabilize satellite that will rotate only around an axis parallel to earth magnetic field lines . This represents the simplex way[12] to stabilize satellite , it's the cheaper and doesn't need power supply .

In this satellite there isn't GPS or other system to detect its position . It's clear presence of fractional charge or absorption of one of these by cube of lead is independent of satellite position ..

Table 2 summarizes data about dimensions , prices , and consumptions of components . Prices are considered negligible if they are less then 10 $ and are taken from Internet sites of specialized firms .

Table 1: Components Specifications

Name	Size (cm)	Price ($)	Power (mW)	Weight (g.)
Capacitors	2×2×2	negligible	negligi ble	20-30
Micro motors and screws	3.5×4.5	<50	40-50	10
Laser system	1×1	100	10	50
HV supply	2×2×2	2000	500	25
batteries	4.3×4.3×1.3	20		70×N
Frame and microcontro ller	10×10×10	13000	200	200
transceiver	10×10×1	1500	1000	200t
Permanent magnet	10×2	negligible	0	2

It's to remind that we are in outlet stage . Probably , in the stage of detailed planning , problems could emerge such as several characteristics of satellites would have to be modified . For example active stability systems , similar to those used in other Cubesat or microsatellites , could be needed .
In any case no new , as to actually available , technical solution needs .

Orbital parameters

It's well known satellites orbit are characterized by several orbital parameters (let see figure 3) . They are

• Greater semiaxis α. It describes the dimension of elliptical orbit . In the case of circular orbit coincides with the diameter

• Eccentricity ε. It describes the form of elliptical orbit ant is 0 if orbit is circular

• Inclination i. It's the angle between equatorial plane and the orbit plane .Its importance is connected with the latitude of launch station . This cannot be greater then inclination

• Right ascension of ascendant node Ω. It's the angle between Ares point and ascendant node ,measured along the celestial equator . This angle is measured in a anticlockwise. direction starting from Ares point

Argument of perigee ϖ. It's the angle between ascendant node and perigee measured along the plane of orbit in a anticlockwise. direction .. It isn't defined in the case of circular orbits

• anomaly ν. It's the angle between satellite position and the perigee , measured in a anticlockwise. direction It represents the explicitly time dependent parameter and , as initial time , is considered the time of passage to perigee .

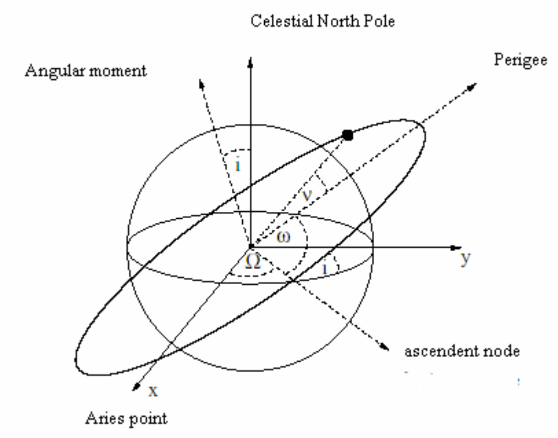


Figure 3: Orbital Elements

In our case the nature of experiment requests only that orbit is both so high that satellite is hit only by primary cosmic rays and so high that friction of the atmosphere permits a working life of at least one year .. The exact numerical values of parameters aren't crucial .

Now the important thing is the fact orbital parameters are subjected to changes in time . These changes are both periodical (not very important) and secular (more important because rise in time) .
Reasons of these changes are :

earth isn't a perfect sphere and then its gravitational potential doesn't vary according to a 1/r law but has to be expressed in a more complex form

the gravitational attractions of Sun and Moon on the satellite

the friction with the air . It causes lowering of the orbit until satellite drops in the lower and denser part of atmosphere where satellites is destroyed

the radiation pressure by solar light . However it causes only periodic variations and then this effect can be neglected

It's to remark absolute value of orbital parameters affects two very important aspects of mission and precisely : the visibility of satellite from earth radio station (or stations) and the length of interval of time in which satellite is lighted by Sun and then solar cells can operate .
Let consider these aspects

For a rigorous study we would have to utilize a specialized software as SSK but , for simplicity , author has decided , at least in this stage of outlet , to fit some results [13] obtained in the case of another satellite : the Cubesat Atmocube satellite , never operated in orbit because of failed launch by problems to carrier rocket .
Atmocube satellite would had to operate in a circular orbit of 600 kilometres height , radius of orbit 6978.14 kilometres and an inclination of 70 degree .

Starting from these orbital element it's possible to deduce immediately orbital period P and radial speed by formulas :

$$P = 2\pi\sqrt{\frac{\alpha^3}{\mu}}$$

$$v = \sqrt{\mu / \alpha}$$

Where μ = constant describing earth gravitational field whose value is universal constant G multiplied by mass of earth. It results by calculus

$\mu = 5801.231\ km^3/s^2$

P = 1.61146 h

v = 7.55786 km/s

As for perturbations of orbital elements , these was studied both by SSK and by rough formulas . Secular variations both by not roundness of earth and effects of Sun and Moon , were obtained of some thousandth of degree every day namely less than one degree every year .(let see figure 4) . Let's remind that our experiment needs only a sufficient height of orbit , angles defining orbit and its nature (circular or elliptical) aren't important . It will be clear such perturbative effects can be neglected .

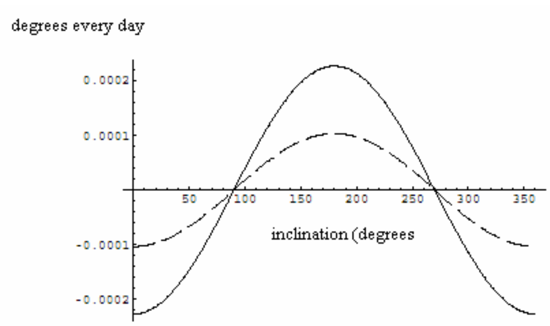


Figure 4: Variation of Right Ascension vs Inclination of Orbit

That of friction is a very different case because working life of satellite is involved . The friction force , in the range of speed of our interest ,can be expressed as

$$-(1/2)\rho(CA/m)v^2 m/s^2$$

Where ρ = density of atmosphere , A = the section of satellite , m = its mass , v = its sped , C = drug coefficient ,generally independent from type of satellite except for very particular form .
The perturbations of orbital parameters by friction are generally expressed as variation of orbital period and , in the case of almost circular orbits are given by simple equations as following , that gives variation of revolution velocity

$$\Delta v_{rev} = \pi(CA/m)hv\rho$$

Where h = orbit radius
.Atmospheric friction lowers revolution speed so that orbit diminishes and the working life of satellite is limited .A useful formula to calculate working life , expressed in number of orbit is

$$L = H/\Delta v_{rev}$$

Where H = height scale for density of atmosphere .
Let's remind that height scale is the distance in which a quantity varies of a value equal to natural logarithm base . In the our case H can be estimated as

KT/Mg

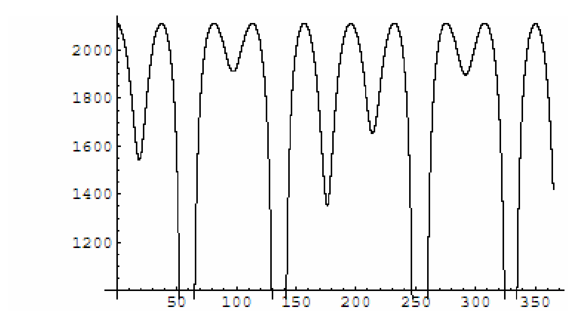
Where K = Bolzman constant T = absolute temperature g = gravity acceleration M = mass of a molecule of air

By these formulas it's possible to calculate working life of satellite but there is a difficulty , This difficulty arises because of density of atmosphere at great altitude is much variable in time for several reasons . . In the case of Atmocube values of density varying from 1.68×10^{-14} Kg/m^3 to 4.89×10^{-13} were considered and values of working life from 121 years to 4.7 years were obtained . Both these values are perfectly compatible with our goal . .

Let's conclude this part with two considerations about visibility between satellite and earth radio station .It's a complex topic and an exact study of it it's possible only by a specialized software and having clear ideas about radio station is (or radio stations are) The topic is complex also because of , while satellite rotates around earth , radio station rotate around axis of earth and then the time between a passage of satellite over a station and the following (transit time) one isn't equal to satellite period Then this question hasn't been studied in this stage of planning also because this question has arise , and has been resolved ,in other satellites too

Power consumption

Starting with data of Table 2 let's deduce a needed power of 2 W .. Let's consider every side of cube there are solar cells of 81 cm^2 area (9 centimetres side) and let's suppose a power of 37 mW every square centimetre we have an available power of 2.997 W that is more than sufficient for our aims .Let's consider only the cells of one side because satellite rotates and there will be only one side illuminated . There is till to evaluate when and how much time, satellite is shielded by Earth and then isn't illuminated by Sun . . Making always reference to Atmocube satellite let's has situation summarized in this plot showing the duration of eclipse periods in the days of a year



It can be seen a complex situation in which there are both days without eclipse and days with an eclipse time very long (more than half of orbital period . . But we can estimate a period of eclipse of 2000 seconds (the worst of the hypotheses) . Let's suppose a consumption of 2 W we have a necessity of power of 1.12 Wh that is more than satisfied by three rechargeable Ni-MH batteries generating 1.26 V and 2025 mA every hour giving 2.56 Wh .

Software

Satellite software installed in microcontroller board , just satellite enters into orbit will have to put into execution a sequence of operations or rather

1) to active micromotors M to unlock cube

2) To switch on laser

3) To measure the position of cube as regards laser every 10 minutes (numbers are purely indicative) . This operation has to be made for one hours with capacitor off and in this stage displacement by mechanical vibrations is measured . The results of measures are stored . Measuring a distance of centimetres size with a precision of tenth of micron size we have a precision of 1 part out of 10^5 and then the result of measure will be a number of at least 17 bit (3 byte)

4) To switch on HV power supply giving tension to capacitor

5) repeat the stage 3) for another hour

6) to switch on transceiver waiting for signal START coming from earth station

7) to transmit to earth the signal of ROGER and data . The data will be only 36 byte .Time of transmission will be very short both respect to the time of transit and respect the time in which antenna will remain pointed towards earth station (don't forget satellite is free to rotate)also considering transmission mistakes , need to transmit control characters and so on . .

8) to switch off HV power supply and laser

At this point satellite comes into a stand by stage in which it limits itself to control if START signal arrives from earth . If a group of students want to utilise it as an example of " real science experiment " they send to it START signal , when satellite is seen from earth station which students are in .. Satellite repeats above citied operations from point 2 to point 7

HYPOTHESIS ABOUT CONSTRUCTION AND LAUNCH

Starting from satellite features it's possibile to deduce several conditions about its launch . First of all the very small weight and the reduced dimensions do it very similar to a typical Cubesat satellite and then it is possible to think to a launch together other satellites of the same kind . It's possible to think to a carrier racket whose capacity isn't too big and to a LEO orbit . A launch similar to Cubesat Dnepr 2 launch being been in April of this year . The latitude of launch base isn't important because of the execution of experiment doesn't depend by inclination of orbit .

In author's opinion any firm that has built satellites or parts of them can to make this satellite both because the simplicity of structure and because not much money needed and because of it's possible to utilise many commercially available parts

It's essential , however that detailed planning and the construction are made by a team ,refering to a university being experienced in satellites construction. Then it is will of the author to contact such institutions .

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