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MEASUREMENT OF GRAVITATIONAL ACCELERATION OF ANTIMATTER *

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ABSTRACT

The minute yet effective impact of gravitational potential in the central region of a long tube magnetic container of non–neutral plasmas can be utilized for the measurement of the gravitational acceleration of antimatter particles. The slight change in distribution of plasma particles along the gravitational field affects the internal electric field of the plasma, which in turn affects the frequency of the magnetron motion of its particles. Thus, a rather straightforward relation is established between the gravitational acceleration of the particles and their magnetron frequencies, which is measurable directly, determining the value of the gravitational acceleration.

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Incompatability of gravitational and electromagnetic forces has prevented researchers, thus far, from measuring the acceleration of electrons as well as antimatter particles, such as positrons and antiproton. This problem is even greater when the gravitational acceleration of lighter particles such as electrons and positrons are considered. In the present paper, a relatively easy and feasable method is proposed for the measurement of gravitational acceleration of electrons, positrons and antiprotons, via long tube magnetic plasma containment of the particles under study.

Single–species plasma is successfully contained for a long period of time by magnetic confinement in a long tube [1] (Fig.1). It has been theoretically proven that particle interactions do not destabilize the plasma column formed in such a process and hence, establishes a good agreement with the experiment [2)–5)]. The principle reasoning for stability of equilibrium state (i.e. radial distribution of particles) is based on the conservation of the angular momentum of the system. In other words, the radial distribution of particles in the plasma column is not going to change unless an external torque is exerted upon it. Such torques could be due to radiation effects, finite wall resistance, and asymmetries of magnetic field, and/or asymmetries of a containment vessel [1]. These effects have been minimized to a proper extent by improvement of the vessel, a decrease in pressure, etc. Thus, a reliable apparatus has become available for experimentation on pure plasma of non–neutral particles.

The external electric field within and along the axis of the tube exponentially decreases, since it is governed by a $cosh(kz)$ type function. Thus, for a sufficiently long tube the central region is effectively "free" of external forces other than gravity, which plays an effective role in behaviour of confined plasma. The contrast between the gravitational potential and external electric field is shown in Fig.2.

The above two features, i.e. the stability of the contained non–neutral plasmas, and effectiveness of gravitational potential, provides the basic ground for consideration of the present method.

The effect of gravity in the central region of the tube slightly perturbs the axial distribution of the plasmas, which would be uniform in its absence. This perturbed distribution in the central region behaves

$$n(z) \sim n_0\, e^{-mgz/kT}, \qquad (1)$$

where z is the height, and m is the mass of particles in plasma and n_0 is approximately unperturbed particle density to be determined experimentally at the central region. This is primarily due to the fact that in the region under study the external electric field is far smaller than the gravitational field. The numerical solution to differential equation of plasma distribution, schematically shown in Fig.3, thoroughly agrees with this behaviour.

The new distribution along the graviational field will directly affect the internal radial electric field of the plasma column as follows. Due to axial symmetry [1], we have

$$\vec{E}(\rho, z) = \left[\frac{2e}{\rho^2}\int_0^{\rho} 2\pi\rho'\, n(\rho', z)\, d\rho'\right]\vec{\rho}, \qquad (2)$$

where local density $n(\rho, z) = n(z)$, since radial distribution of particles is uniform and only a dependence on height is present. The internal electric field then is reduced to

$$\vec{E}(\rho, z) = 4\pi e\, n(z)\vec{\rho}. \qquad (3)$$

Using (1), the above equation can be written as

$$\vec{E}(\rho, z) = 4\pi e\, n_0\, e^{-mgz/kT}\vec{\rho}. \qquad (4)$$

This internal electric field will have its effect on radial motion of the plasma particle in the following manner. The radial motion of the particles are determined by

$$m\ddot{\vec{\rho}} = e\,\vec{E}(\rho, z) + \frac{e}{c}\dot{\vec{\rho}} \times \vec{B}. \qquad (5)$$

When (3) is substituted in (5) we have

$$m\ddot{\vec{\rho}} = 4\pi e^2\, n(z)\vec{\rho} + \frac{e}{c}\dot{\vec{\rho}} \times \vec{B}, \qquad (6)$$

which shows the combination of two different motions for the particles; magnetron and cyclotron motion. In other words,

$$\dot{\vec{\rho}} = \dot{\vec{\rho}}_c + \dot{\vec{\rho}}_m. \qquad (7)$$

The magnetron motion ($\dot{\vec{\rho}}_m$) is approximately the drift velocity due to the electrical field of plasma in the presence of the magnetic field [6],

$$\vec{v}_m \equiv \dot{\vec{\rho}}_m = \frac{c\,\vec{E}\times\vec{B}}{B^2} \qquad (8)$$

The magnitude of this velocity is

$$\dot{\rho}_m = v_m = \frac{cE}{B} = \frac{4\pi e\, n(z)c}{B}\rho, \qquad (9)$$

by use of (3). The magnetron frequency is then

$$\omega_m = \frac{v_m}{\rho} = \frac{4\pi c\, e n(z)}{B}. \qquad (10)$$

It is clear from substitution of (4) in (10) that magnetron frequency is dependent on z:

$$\omega_m = \frac{4\pi c e}{B} n_0\, e^{-mgz/kT} \qquad (11)$$

Now, if at two different points in the central region the magnetron motion of plasma is measured [6], we have

$$\Delta\omega_m = \omega(z_1) - \omega(z_2) = \frac{4\pi e c}{B}[n(z_1) - n(z_2)] \qquad (12)$$

Using (4), this can be written as

$$\Delta\omega_m = \frac{4\pi e c}{B} n_0 (e^{-mgz_1/kT} - e^{mgz_2/kT}). \qquad (13)$$

Since the exponential terms are small, (13) reduces to

$$\Delta\omega_m \simeq \frac{4\pi e c n_0}{B}(mg/kT)(z_2 - z_1). \qquad (14)$$

This, in turn, gives the value of gravitational acceleration:

$$g = \frac{kTB}{4\pi e c n_0\, m(z_2 - z_1)}\Delta\omega_m. \qquad (15)$$

For a large range of conditions, $\Delta\omega_m$ is substantial or large enough for measurement [7]. Thus, through a measurable quantity directly the value of gravitational acceleration is determined.

Acknowledgments

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REFERENCES

1) J.H. Malmberg and C.F. Driscoll, Phys. Rev. Lett. **44**, 654 (1980).

2) T.M. O'Neil and C.F. Driscoll, Phys. Fluids **22**, 266 (1979).

3) A.N. Kaufman, Phys. Fluids **22**, 266 (1979).

4) R.C. Davidson, *Theory of Non-neutral Plasmas* (Benjamin, Reading, MA, 1974) Chap.3.2.

5) S.A. Prasad and T.M. O'Neil, Phys. Fluids **22**, 278 (1979).

6) L.S. Brown and G. Gabrieles, Rev. Mod. Phys. **58**, 233 (1986).

7) J.H. Malmberg, C.F. Driscoll and W.D. White, Physica Scripta **T2**, 288 (1982).

FIGURE CAPTIONS

Fig. 1 Non–neutral plasma is radially contained by magnetic field and axially confined by electrical potential difference of the end rings.

Fig.2 Contrast of external electrical potential and gravitational potential within a 2m long tube of radius of 5cm is shown.

Fig.3 Schematic distribution of plasma particle density in the central region of a two meter long tube with external electrical potential of 1v is shown.

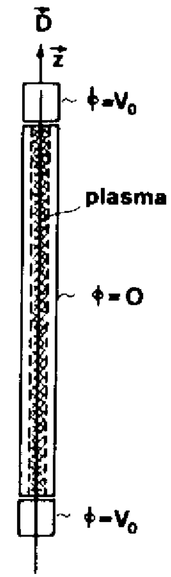
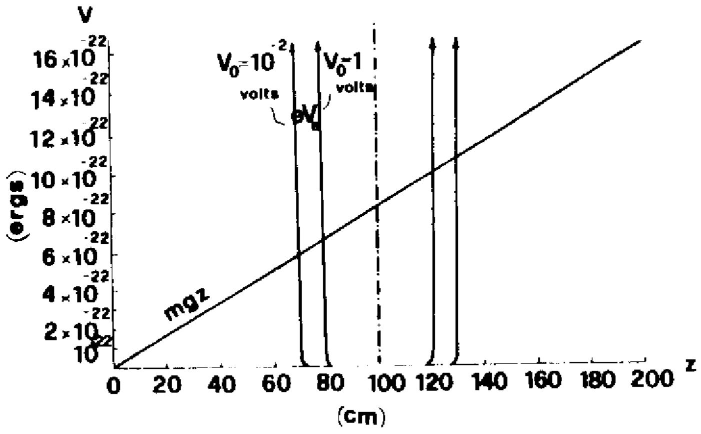
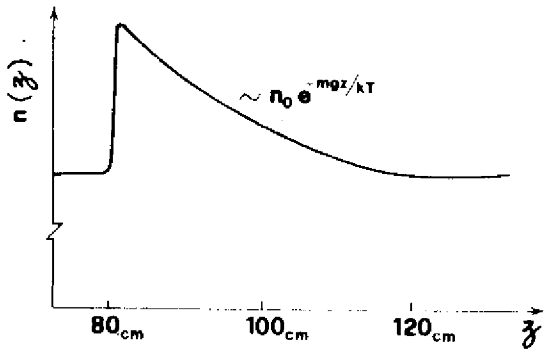


Fig. 1



V
(ergs)
16 × 10^-22
14 × 10^-22
12 × 10^-22
10 × 10^-22
8 × 10^-22
6 × 10^-22
4 × 10^-22
2 × 10^-22
10^-22
V0=10^-2 volts
V0=1 volts
eV0
mgz
0 20 40 60 80 100 120 140 160 180 200
z
(cm)

Fig.2



n(z)
~ n0 e^-mgz/kT
80cm
100cm
120cm
z

Fig.3