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Relativistic Aspects of the Centripetal Force

M. Conte

Dipartimento di Fisica dell'Università di Genova
and INFN-Sezione di Genova, Via Dodecaneso 33, 16146 Genova, Italy

Abstract

The use of partially ionized atoms revolving in a storage ring is here proposed.
Easy and low cost experiments, regarding the radiation emitted by these ions duly excited, can be performed. Particularly, the e_ects of the centripetal force on the light spectrum can be analyzed.

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1 Introduction

In a former paper [1] we proposed to use partially ionized helium atoms as probes for relativity experiments. In this note we intend to consider only the effects (if any...) of the centripetal force on the electromagnetic spectrum of the light emitted by ions, revolving in a storage ring, excited by either a laser or some other kind of procedure which will be considered suitable. Moreover, we intend to leave momentarily aside what proposed in the second part of the former paper, where the effect studied was the growth of the velocity modulus. The consequence is a continuos Doppler displacement of the spectral lines. Notice that the role of centripetal force is usually played be the magnetic field through the Lorentz force, but in some circumstance [2] an electrostatic field can be used as well. Considering that the Universe is full of “objects” of any size that are rotating around other “object” and that the centripetal force is the Newton force, it is natural to search for any eventual similarity.

The first test to be performed consists in comparing (see Fig. 1) the optical spectra of the light coming from the straight sections with the light coming from the bending magnets, where the ions undergo the action of the centripetal acceleration.

$$a_{\mathrm{c}} = \frac{(\beta c)^2}{\rho} \tag{1}$$

Note that the particles velocity, and consequently the Doppler shift, remain constant.

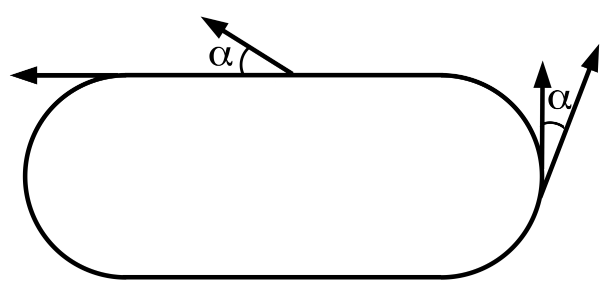

Figure 1: Sketchy illustration of light beams leaving the orbit either coaxial or with an angle α.

Another test could consists in comparing (see Fig. 2) the two light-beams which leave perpendicularly the orbit when they are traveling inside the bending magnets. The main interest of this experiment is given by the possibility of unveil some difference between the spectral lines of the light-beam pointing outward and the spectral lines of the light-beam pointing inward. A mirror has to be settled for inverting the direction of the inward going light-beam since in this side of ring donut there is usually the yoke of the magnet.

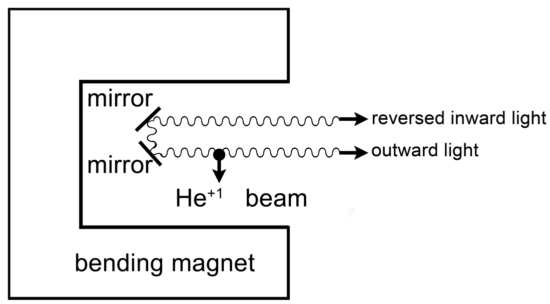

Figure 2: Device aimed at comparing light beams which leave perpendicularly to the orbit in opposite directions.

Due to the complete isotropy of the light emission in the ion rest frame, we have to create and address the light beams by using dark tubes, closed at the ends, but with two small holes which will define a straight line, according to the first Euclid's postulate. Indeed, in the third example hinted before, the two holes must be also aligned with a third point: the center of curvature of the bent orbit! In Fig. 3 we sketchly illustrate how a beam can be created and addressed. Defining as σ the small area of the two holes and ℓ the distance run by the light from the ion beam and the exit from the Euclid tube, we obtain a light beam enclosed within a very small solid angle, namely

$$\delta\Omega = \frac{\sigma}{\ell^2} \simeq \frac{1\ \mathrm{mm}^2}{1\ \mathrm{m}^2} = 10^{-6}\ \mathrm{sr} \tag{2}$$

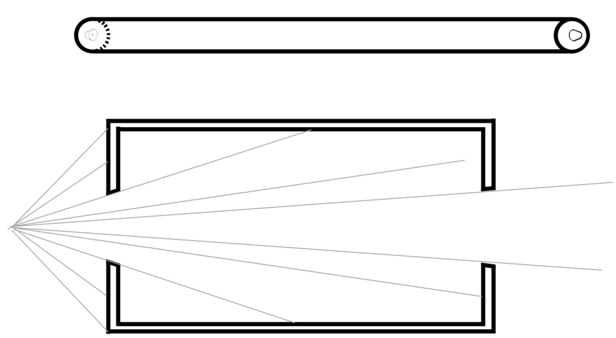

Figure 3: How to make a very thin light beam.

Next, we can evalute the portion n_{ph} of emitted photons that can be measured:

$$n_{\rm ph} = \frac{\delta\Omega}{\Omega} N_{\rm ph} \simeq 8 \times 10^{-8} N_{\rm ph} \tag{3}$$

where $\Omega = 4\pi$ sr is the solid angle containing the total number $N_{\rm ph}$ of photons which enter inside the Euclid tube.

2 A few practical examples

The COSY ring [3] could be very, appropriate indeed. Setting the ring for 3 GeV/c protons, a Helium ion with the same momentum will be characterized by

$$\beta\gamma = \frac{p}{M_{\rm He}c} = \frac{3}{3.725} = 0.805 \quad \Longrightarrow \quad \beta = 0.627\, \gamma = 1.283 \tag{4}$$

with

$$M_{\rm He} = 6.64 \times 10^{-27}\ \text{kg} = 3.725\ \text{GeV/c}^2 \tag{5}$$

Being the COSY bending radius $\rho = 7$ m, the centripetal acceleration (1) will be

$$a_{\rm c} = \frac{(\beta c)^2}{\rho} = 5.05 \times 10^{15}\ ms^{-2} = 6.15 \times 10^{14}\ g \tag{6}$$

where $g \simeq 9.81$ ms^{-2} is the average Earth gravity acceleration.

Another solution could consists in "resurrecting" the CERN Low Energy Antiproton Ring LEAR [4] which is temporarily dismantled. Recalling that the highest momentum accepted by such a ring is $p = 2$ GeV/c with a field $B = 1.60$ Tesla and a bending radius $\rho = 4.17$ m. Hence we shall obtain for a helium ion with the same momentum

$$\beta\gamma = \frac{p}{M_{\rm He}c} = \frac{2}{3.725} = 0.537 \quad \Longrightarrow \quad \begin{cases} \beta = 0.473 \\ \gamma = 1.135 \end{cases} \tag{7}$$

and, reiterating what done above, we have

$$a_{\rm c} = 4.87 \times 10^{15}\ \text{m}\,\text{s}^{-2} = 4.92 \times 10^{14}\ g \tag{8}$$

For comparison sake, we recall that a neutron star with a radius of about 1000 meters and a mass of the order 1.4 times the solar mass, i.e. $M_{\rm ns} \simeq 2.8 \times 10^{30}$ kg, has on its surface a gravitational acceleration

$$g_{\rm ns} = 1.87 \times 10^{14}\ \text{m}\,\text{s}^{-2} = 1.90 \times 10^{13}\ g \tag{9}$$

being quite close to the Lorentz accelerations (6) and (8).

For the sake of giving an example, we take into consideration the experiment hinted before of the two beams perpendicular to the ions orbit. The transversal Doppler shift is

$$h\nu = \frac{h\nu_0}{\gamma} \qquad \text{or} \qquad \lambda = \gamma\lambda_0 \tag{10}$$

where the label "0" pertains to the rest frame of the emitting ions. Hence we look for that Lorentz factor which can displace e.g. the red spectral line over the yellow one. Picking up their values from the following table,

Colour	λ (nm)	$h\nu$ (eV)
Red	667.8	1.857
Yellow	587.5	2.110
Green	492.2	2.519
Violet	117.1	2.773

we obtain:

$$\gamma_{\text{shift}} = \frac{\lambda_{\text{red}}}{\lambda_{\text{yellow}}} = 1.126 \tag{11}$$

finding a Lorentz factor quite close to the ones of COSY and LEAR. The smallness of the Lorentz factor is appropriate for obtaining an e.m. radiation which can be manipulated with mirrors. Since the excited states of the lonely electron lasts about 0.8 μs in the particle rest frame, with such small Lorentz factors there will not be a too big time dilation.

3 A shy proposal

Last but not least, a further possibility does exist: to use a helium beam which travels from the source to the dump crossing a bending magnet. For instance, the comparison between light-from-bend and light-from-straight could be accomplished.

This test could be implemented by picking up materials in INFN sections and/or INFN laboratories. The most important item is the High Voltage Generator, which we doN't despear to find in some repository. A very good optical spectrometer is stored somewhere in the LNF. The ion source could be found either in the LNL or in the LNS. No problem should subsist in providing a suitable magnet, since any workshop of the INFN Sections has the requirements for attaining such a result.

For example sake, let us carry out a few data obtainable with a High Voltage Generator with $V_{max} = 100$ kV and a small magnet with $B_{max} = 1$ Tesla. The yield is as follows:

- $v = 4.91 \times 10^6$ m s^{-1} ion velocity,
- $\rho = 0.203$ m bending radius,

- $a_{\mathrm{c}} = 2.38 \times 10^{13}\ \mathrm{m\,s^{-2}}$

Notice how this centripetal acceleration is not much smaller than the other accelerations shown above.

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