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**On the Estimates to Measure Hawking Effect and Unruh Effect in the  
Laboratory**

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**Abstract**

A comparison between the proposals made to measure Hawking-like effects and the Unruh effect in the laboratory is given at the level of their estimates. No satisfactory scheme exists as yet for their detection.

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Two fundamental effects in present-day theoretical physics are Hawking effect [1] and the very similar Unruh effect [2]. They are thermal-like effects involving microscopic (brownian) degrees of freedom of quantum fields which are not causally connected. Thus the whole topic is a fascinating and very challenging one for the physical interpretation.

Apart from the Hawking effect from primordial black holes, [3], a number of experiments have been proposed in the last decade to measure analogs of these effects in terrestrial laboratories even though they are extremely small for any conceivable scheme. Indeed in cgs units the relationship between the temperature parameter of the effects and the proper acceleration parameter is:

$$T = \frac{\hbar}{2\pi ck_b} a = 4 \cdot 10^{-23} a \quad (1)$$

and therefore a thermal effect of only 1 K is produced by an acceleration of  $2.4 \cdot 10^{22} \text{ cm/s}^2$ . Clearly one is dealing with effects which might have some experimental evidence only in very uncommon situations like black-hole physics and/or ultrarelativistic non-linear electrodynamics [4]. Nevertheless the analogies developed over the years showed that other fields of physics could have a contribution to the better understanding of the two effects. Moreover, as a corollary, those fields of physics enriched themselves with some unconventional pictures.

With this in mind we pass to the scope of the note which is a critical analysis of the experimental estimates of the above mentioned fundamental effects.

Unruh, [5], was the first to propose an experimental scheme based on a hydrodynamical analog of the Schwarzschild metric. He showed that for a spherically symmetric, static convergent flow of an irrotational fluid exceeding the speed of sound at some radius, the metric has approximately the form of the Schwarzschild metric. He then quantized the sound field and found an outgoing thermal flux of phonons emitted by the sonic horizon at a temperature:

$$T = \hbar/2\pi k_b \cdot \partial v/\partial r = 10^{-2} K \left( \frac{\partial v}{\partial r} / \frac{100 \text{ m/s}}{1 \text{ \AA}} \right). \quad (2)$$

The estimate (2) is very disappointing. To have 1 K one should produce a velocity gradient of 100 m/s per  $\text{\AA}$  at the sonic horizon. It is by far doubtful that an atomic fluid could allow such huge gradients. The situation may change in the case of superfluids,[6].

In a series of papers written between 1983 and 1987, Bell and Leinaas ,[7], have proposed to interpret the depolarization of electrons in storage rings as a kind of circular Unruh effect. In the case of LEP the centripetal acceleration is  $a_{LEP} = 3 \cdot 10^{22} g_{\oplus}$  implying

a Unruh temperature of 1200 K. This is already a measurable thermal-like effect. However the depolarization of electrons in storage rings has a standard interpretation in terms of the well-known Sokolov-Ternov effect in QED. Besides, the “circular Unruh effect” is not as simple as the linear one. Moreover, the thermal interpretation is questionable in circular motion, [8]. Bell and Leinaas have obtained a more complicated evolution of the depolarization very close to isolated first order vertical betatron resonances for perfectly aligned weak focusing storage rings. This situation is still to be checked, even though it is rather far from the experimental conditions at existing storage rings.

One of the best experimental scheme to measure the “circular Unruh effect” belongs to Rogers, [9]. He proposed a small superconducting Penning trap with only one electron circulating inside, put into a microwave cavity. The ideal Penning trap is the mathematical problem of the electron motion in an external electromagnetic field consisting of a strong, uniform, axial magnetic field, and a quadrupole static electric field. Such a combination of fields is achieved in praxis by means of hyperbola-shaped electrodes. The equation of motion for the ideal fields is linear and could be expressed in terms of three normal modes , the axial, the magnetron, and the trap cyclotron modes. The usual working regime of the Penning trap is:  $\omega_{tc} \gg \omega_z \gg \omega_m$ , where the subscripts mean trap cyclotron, axial, and magnetron modes respectively . In the limit of vanishing electric field the trap cyclotron frequency goes into the free space cyclotron frequency, but otherwise it depends on the axial mode too. A transfer of the cyclotron vacuum noise energy to the lowest transverse magnetic mode of the microwave cavity is made via the axial resonant coupling. The acceleration in Rogers’ experiment is  $a = 6 \cdot 10^{19} g_{\oplus}$  corresponding to  $T = 2.4$  K. The critique of Rogers scheme is similar to that made above for storage rings. The circular noise is not universal and not very adaptable to a pure thermal interpretation, [8]. For further details on the Penning vacuum noise see [10].

Yablonovitch, [11], proposed a plasma front generated on a subpicosecond time scale as an accelerating fast-moving mirror. In this case vacuum fluctuations near the plasma are subjected to the accelerating conversion into real photons, and an Unruh effect of the non-adiabatic Casimir-type is natural. Laser pulses of  $10^{-12}$  sec could produce plasmas moving with  $a = 10^{20} g_{\oplus}$  implying a Unruh temperature  $T = 4$  K. The plasma fronts could be generated by the non-adiabatic photoionization of a gas or a semiconductor crystal.

Very interesting are the proposals of the YERPHY group. They showed that channeling phenomena could be studied in the Unruh perspective too, [12]. The strong fields of crystalline axes and planes are acting with extremely large transverse accelerations reaching  $10^{33} cm/s^2$  in the instantaneous rest frame of the ultrarelativistic channeled particles ( $\gamma = 10^8$ ). The Armenian group provided an analysis of the Unruh radiation of the channeled particles which arises as a result of the Compton scattering on the Planck spec-

trum of vacuum photons. However only at  $\gamma = 10^8$  the intensity per unit pathlength of the Compton scattering on the Planck vacuum spectrum is comparable with the Bethe-Heitler brehmsstrahlung.

In another work, [13], the YERPHY group discussed in the same spirit the radiation of TeV electrons with initial velocity perpendicular to a uniform magnetic field. The centripetal acceleration is  $a = \gamma eH/m\beta$  giving a Unruh temperature  $T = \gamma eH/2\pi k m\beta$ . This time the background which is the synchrotron radiation is surpassed by the Unruh radiation only at  $\gamma = 10^9$  for a magnetic field  $H = 5 \cdot 10^7 G$ , thus making impossible to detect Unruh radiation, say, at CLIC. Supercolliders with bunch structure capable of producing fields of the order  $10^9 G$  are required.

Another case considered in the same work is the propagation of an electron through the electromagnetic field of a circularly polarized plane wave. The proper centripetal acceleration is  $a = 2\omega\gamma\eta\sqrt{1+\eta^2}$ , where  $\omega$  is the angular frequency of the electromagnetic wave, and  $\eta = e\epsilon/m\omega$  ( $\epsilon$  being the amplitude of the field). The Unruh temperature is given by  $T = (\gamma\omega/\pi k)\eta\sqrt{1+\eta^2}$ . The YERPHY group calculated again the dependences of the intensity per unit pathlength for Unruh radiation and for the radiation in the field of an intense laser beam on  $x$  (the fraction of the initial energy taken away by the radiated quanta) and on the parameter  $\eta$ . Under such conditions the Unruh radiation might be observable already at  $\gamma \geq 10^7$ . Anyway, only a collider mode in combination with a powerful laser might make the Unruh signal available in such setups.

The last proposal is that involving the electromagnetic analog of the Mach horizon, i.e., the Cherenkov effect in a GRIN (graded index) dielectric material,[14]. For such a scheme the estimated temperature is given by

$$T = \frac{\hbar c}{2\pi k_b} \frac{dn}{dr}. \quad (3)$$

The present-day optical gradients ( $0.2 \text{ mm}^{-1}$ ) could generate a thermal effect of 0.7K. Again a rather disappointing estimate. Besides, the so-called melting of the Cherenkov cone, [15],that is the structure of the distorted Cherenkov wavefront in GRIN materials must be studied in great detail.

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