Classical Roots of the Unruh and Hawking Effects

M. Pauri\textsuperscript{1, 2} and M. Vallisneri\textsuperscript{1-3}

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Although the Unruh and Hawking phenomena are commonly linked to field quantization in “accelerated” coordinates or in curved space-times, we argue that they are deeply rooted at the classical level. We maintain, in particular, that these effects should be best understood by considering how the special-relativistic notion of “particle” gets blurred when employed in theories including accelerated observers or in general-relativistic theories and that this blurring is an instantiation of a more general behavior arising when the principle of equivalence is used to generalize classical or quantum special-relativistic theories to curved space-times or accelerated observers. A classical analogue of the Unruh effect, stemming from the noninvariance of the notion of “electromagnetic radiation” as seen by inertial and accelerated observers, is illustrated by means of four gedanken-experimente. The issue of energy balance in the various cases is also briefly discussed.

1. INTRODUCTION

The Unruh and Hawking effects sit deservedly among the most widely discussed and popularized subjects in the physics of the last two decades. A strong part of their “folklore” is the conviction that these effects have an eminently quantum mechanical character. For instance, one often hears that black holes would indeed be black by classical physics, were it not for quantum mechanics coming to the rescue of black hole thermodynamics, providing a thermal emission of particles from the black hole’s horizon [\textit{Hawking effect}\textsuperscript{(1)}]. And again, the fact that the Minkowski vacuum

\textsuperscript{1} Dipartimento di Fisica, Università di Parma, 43100 Parma, Italy; e-mail: pauri@parma.infn.it.
\textsuperscript{2} INFN, Sezione di Milano, Gruppo Collegato di Parma, Parma, Italy.
\textsuperscript{3} Theoretical Astrophysics 130-33, Caltech, Pasadena, California 91125; e-mail: vallis@caltech.edu.
should contain particles to be seen by an accelerated detector \[ Unruh effect^{(2)} \] is perceived as a modern quantum marvel on par, say, with quantum tunneling and EPR effects.4 In this paper we claim instead that both the Unruh and the Hawking effect have a clear classical counterpart and that they can be understood as typical examples of the \textit{perspectival semantics} arising within the difficult migration from special-relativistic to curved space-time physics or simply to accelerated observers.\(^{(4)}\)

The assertion of the Poincaré group as the global symmetry group of space-time has been seminal to the great theoretical synthesis of the first half of this century, begun with the full acknowledgment of Maxwell’s electro-magnetism as a special-relativistic theory and beautifully climaxed with quantum field theory. Thus, the concepts and interpretive paradigms of these theories refer naturally to the privileged class of inertial observers. Now, the equivalence principle of general relativity does warrant Lorentz group as a symmetry group, but only locally: this locality becomes crucial when one tries to generalize to curved space-time geometries the concepts and paradigms inherited from special-relativistic theories, when these are based on the global symmetries of Minkowski space-time.

In Section 2 of this article we argue that the gist of the Unruh and Hawking effects can be understood within this frame of reasoning, well beyond their quantum character. Essentially, we discuss how the special-relativistic notion of a quantum “particle” becomes \textit{slippery} when one tries to extend it to curved spacetimes or to noninertial observers.

In Section 3 we show that the \textit{same} ambiguity befalls the entirely classical concept of electromagnetic “radiation.” by examining the especially instructive “paradox” of a charge falling in a constant homogeneous gravitational field: by emitting radiation, such a charge might be distinguishable from a similarly falling uncharged body, pointing to a violation of the equivalence principle of general relativity. We deliberately introduce the issue in a blurred way echoing its initial appreciation in the literature, as a borderline case between special and general relativity; this presentation makes the contradiction most apparent. By fully placing the question within the theoretical framework of general relativity, the “paradox” is seen to fade. The solution lies in the fact that the notion of electromagnetic radiation \textit{is not invariant} with respect to transformations between inertial and accelerated reference frames, so that radiation can be “produced” or “transformed away” by suitably changing the state of motion of the observer.

\(^4\) As insightfully discussed by Sciama,\(^{(3)}\) these phenomena bring together in an intriguing way Einstein’s independent legacies of fluctuation theory and relativity.