An Alternative Interpretation for Unruh Effect

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Abstract: This paper going to represent a new theoretical explanation of the Unruh effect. According to the current status of the Unruh effect, an accelerating observer will perceive an apparent event horizon forming and the existence of Unruh radiation could be linked to this apparent event horizon. In this paper, I review the work of the Unruh and give a slightly different theoretical interpretation of it. According to this interpretation when an observer accelerates, it transforms its energy and momentum (Just like Gravitational frame dragging effect in General Relativity) into the continuously popping in and out virtual particles. And just like in the case of Black Hole where virtual particles pop out and accelerate with the help of Black Hole Gravitational field and become real, the longer the virtual particle exists, the closer its characteristics come to those of ordinary particles, same in here first the virtual particles absorb the energy and momentum then excites (increase the time lag between popping in and out) and then again annihilates each other with the increment of temperature in the accelerated observer surrounding, so the background appears to be warm for an accelerating reference frame. More the acceleration, more the transformation of momentum and energy, more the radiation, and more the increment in temperature or in other words temperature is directly proportional to the acceleration of the observer (as predicted earlier by Unruh). But inertial observer observes no radiation at all because it's not accelerating (means no applications of General Relativity can be applied here).

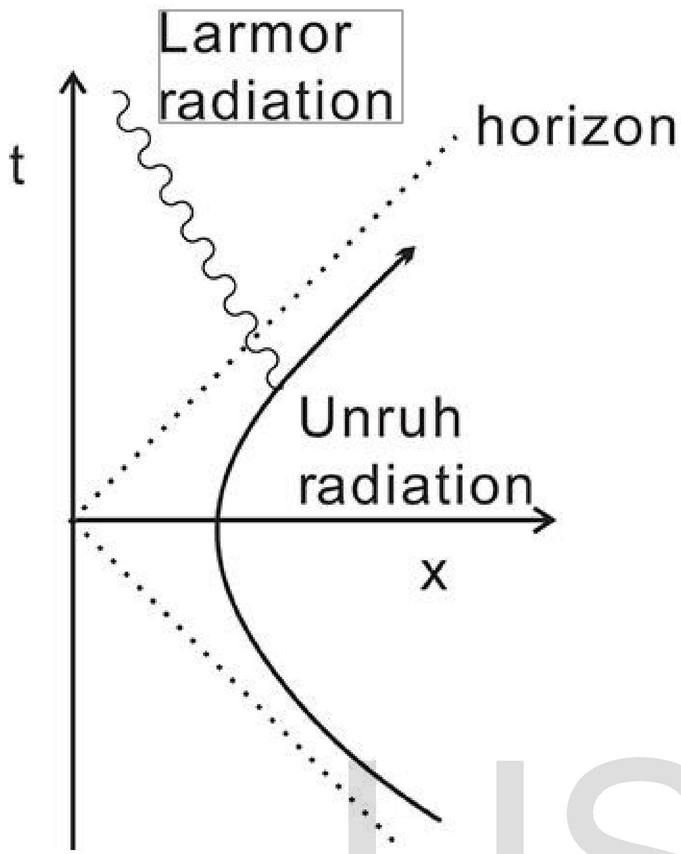
Introduction:

The Unruh effect (or sometimes Fulling–Davies–Unruh effect) is the prediction that an accelerating observer will observe blackbody radiation where an inertial observer would observe none. In other words, the background appears to be warm from an accelerating reference frame; in layman's terms, a thermometer waved around in empty space, subtracting any other contribution to its temperature, will record a non-zero temperature. For a uniformly accelerating observer, the ground state of an inertial observer is seen as in thermodynamic equilibrium with a non-zero temperature.

The Unruh effect shows that the vacuum in quantum field theory is essentially thermal. It should also make you think about what do we really mean by the vacuum. If we interpret the vacuum as "the nothing state", then the Unruh effect seems very odd indeed, and there seems to be no physical explanation for it. The proper explanation for the vacuum state is thus "the state of lowest energy" – from this angle, the Unruh effect does not seem so strange anymore since, accelerating observes feel "forces" which will make them interpret the state of lowest energy differently. Unruh demonstrated theoretically that the notion of vacuum depends on the path of the observer through spacetime. In modern terms, the concept of "vacuum" is not the same as "empty space": Space is filled with the quantized fields that make up the universe. Vacuum is simply the lowest *possible* energy state of these fields.

The energy states of any quantized field are defined by the Hamiltonian, based on local conditions, including the time coordinate. According to special relativity, two observers moving relative to each other must use different time coordinates. If those observers are accelerating, there may be no shared coordinate system. Hence, the observers will see different quantum states and thus different vacua. That's the reason why vacuum appears different in the perspective of an accelerated observer and for the inertial observer.

According to current theoretical status of the Unruh effect, an accelerating observer will perceive an apparent event horizon forming (Rindler spacetime).
The existence of Unruh radiation could be linked to this apparent event horizon. But an inertial observer observes nothing (Minkowski Spacetime).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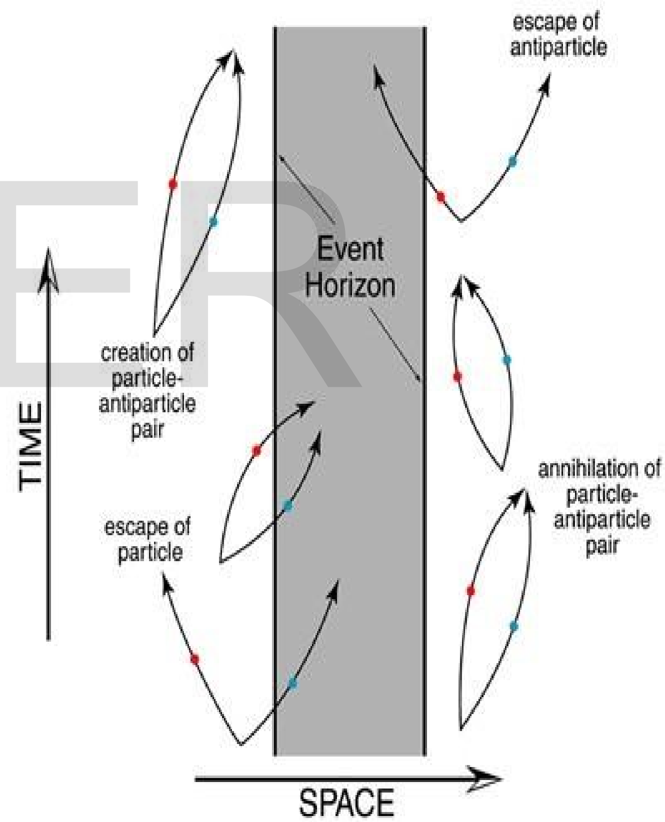
In section first which is "New Theoretical Interpretation", I'm going to discuss how Light frame dragging, Gravitational frame dragging, and General Relativity help me to find a new intuitive interpretation of Unruh effect. And in section second I'm going to present the same mathematical formulae to calculate Unruh temperature for the accelerated observer. The mathematical formula to calculate the Unruh temperature is going to be the same as Unruh derived in 1976.

New Theoretical Interpretation:

Previously in the introduction, I discuss the Unruh interpretation of the Unruh effect, which he developed in 1976. Now, I'm going to represent my interpretation of the Unruh effect.

In General Relativity, Gravity is just the manifestation of the curvature of spacetime. And when Einstein realized that Acceleration leads to the same effect as Gravity, he developed a principle which is called the Equivalence principle. According to the Equivalence principle in General Relativity, Gravity is equal to Acceleration so, when we are talking about Acceleration it means we are talking about Gravity and it also means more the Acceleration, more the Gravity, and objects have more the energy and momentum.

Now take up an example of Hawking radiation. Hawking radiation is blackbody radiation that is predicted to be released by black holes, due to quantum effects near the event horizon. Hawking radiation reduces the mass and energy of black holes and is therefore also known as black hole evaporation. Because of this, black holes that do not gain mass through other means are expected to shrink and ultimately vanish. Without Hawking radiation, Blackhole might be violating the laws of thermodynamics. The physical insight of Hawking radiation may be gained by imagining that particle-antiparticle radiation is emitted from just beyond the event horizon. This radiation does not come directly from the black hole itself, but rather is a result of virtual particles being "excited" (by gaining energy and momentum with the help of the Blackhole Gravitational energy) by the black hole's gravitation into becoming real particles and we know that the longer the virtual particle exists, the closer its characteristics come to those of ordinary particles. As the particle-antiparticle pair was produced by the black hole's gravitational energy, the escape of one of the particles lowers the mass of the black hole. The escape of a virtual particle from the Blackhole as a Hawking radiation shown in a figure below.



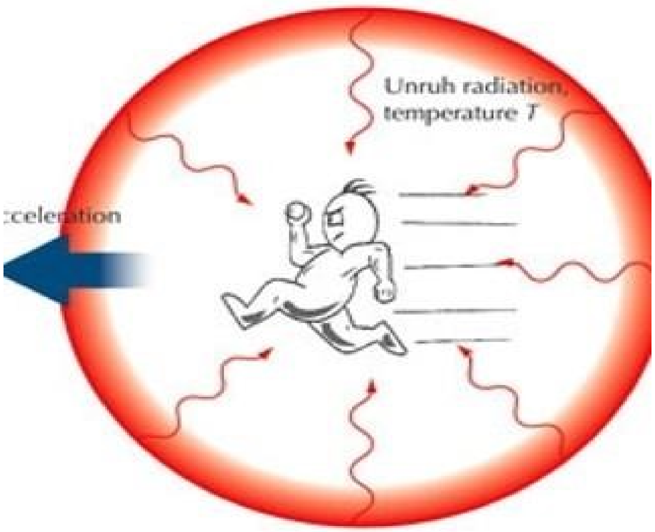
Hawking temperature is a temperature of escaping Hawking radiation. It is given by

$$T_H = \hbar g / 2\pi c k_B$$

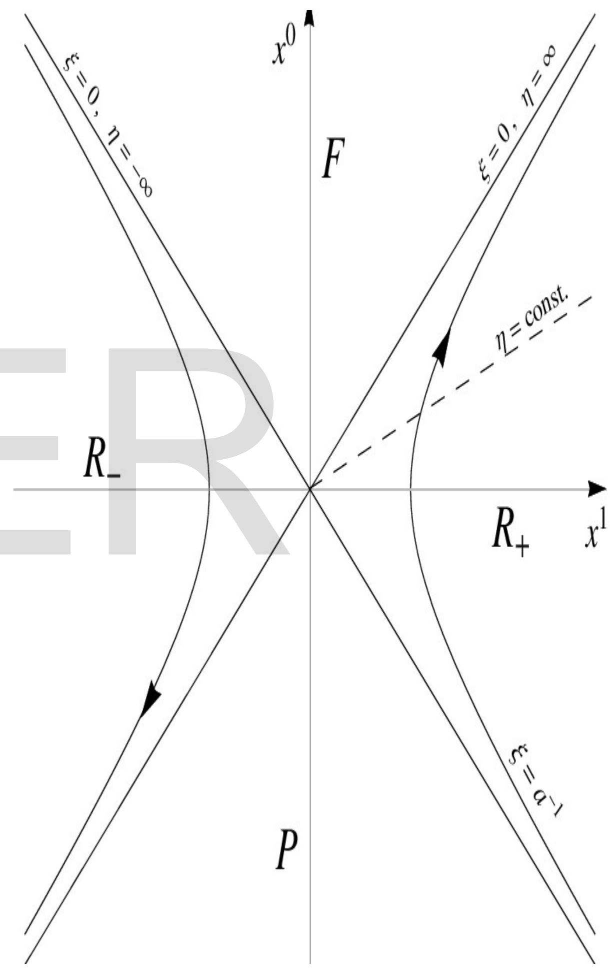
where g is the gravitational acceleration, k_B is the Boltzmann constant, $\hbar$ is the reduced Planck constant, and c is the speed of light.

Now, before I take up the case of the Unruh effect first, I would like to revise the concept (lots of you might already know) of Gravitational frame-dragging effect, which we going to use to formulate a new interpretation of Unruh effect. The gravitational frame-dragging effect is an effect in General Relativity in which the gravitational field can be considered as an extension of the object, and carries inertia, momentum, and energy - since a direct collision with the moving object can impart momentum to an external particle (in our case to a virtual particle), interaction with the object's gravitational field should allow "momentum exchange" too. Consequently, a moving gravitational field drags light and matter. This general effect is used by NASA to accelerate space probes, using the gravitational slingshot effect.

Finally, now I'm ready to take up the case of the Unruh effect. Unruh demonstrated theoretically that the notion of vacuum depends on the path of the observer through spacetime. So first, we examine what happens or how Vaccum behaves for the accelerated observer. When an observer accelerated ("Gravity"), means bends spacetime curvature, it observes blackbody radiation and the background appears warm for an accelerating reference frame, but why? When an observer accelerates it transfers its energy and momentum into continuously popping in and out virtual particles and we know that the longer the virtual particle exists, the closer its characteristics come to those of ordinary particles. So, how accelerating observer able to transfer its energy and momentum into virtual particles? To give an answer to that question, I use the same analogy which (given by Hawking) I used earlier in the process of creating the Hawking radiation in the strong gravitational field of Blackhole. When the virtual particles pop out near the Blackhole, they take energy from the strong gravitational field of Blackhole (by Gravitational frame dragging effect) then excites and increase their time lag between popping in and out, the more they increase their time lag the more they behave like ordinary particles. And finally, one gets into the event horizon and the other goes out as a Hawking radiation and decreases the mass of the Blackhole. Same here when an observer accelerates ("Gravity") and creates a curvature of spacetime around it, virtual particles pop out takes energy and momentum from the gravitational field of the accelerated observer by the phenomena called gravitational frame dragging. And this energy helps virtual particles to excites and increase their time lag. Finally, when virtual particles excite and appear to an accelerated observer as a blackbody radiation (Unruh radiation) and then, at last, the virtual particles annihilate each other with the increment in the temperature near the accelerated observer. So, more the acceleration, more the transfer of energy, more the virtual particles behave like ordinary particles, and more in the increment of temperature for the accelerated observer. The below image shows that how accelerated observer environment warmed up.



So, the inertial observer in Minkowski space with a uniform proper acceleration look like the figure that is given below and the uniform acceleration of inertial observer shows as in hyperbole.



But when observer uniformly accelerated (Minkowski spacetime) or the ground state of an inertial observer is seen as in thermodynamic equilibrium with a nonzero temperature. Why?

It is because in the Minkowski spacetime there is no curvature of spacetime and spacetime is flat it means general relativity cannot be applied here (So no gravitational frame dragging effect). In other words, for an inertial observer, there is no existence of Unruh effect and observer stays in thermodynamic equilibrium with a non-zero temperature.

Mathematical Formulation:

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The Unruh temperature, which is derived by William Unruh in 1976, is the effective temperature experienced by a uniformly accelerating detector in a vacuum field. The mathematical formula to calculate the Unruh temperature is going to be the same as derived by Unruh in 1976. He derived it as follows:

In special relativity, an observer moving with uniform proper acceleration a through Minkowski spacetime is conveniently described with Rindler coordinates. The line element in Rindler coordinates is

$$\mathrm{d}s^2 = -\rho^2\,\mathrm{d}\sigma^2 + \mathrm{d}\rho^2$$

where $\rho = 1/a$, and where σ is related to the observer's proper
time τ by $\sigma = a\tau$ (here $c = 1$). Rindler coordinates are related to the standard (Cartesian) Minkowski coordinates by

$$x = \rho\cosh(\sigma)$$
$$t = \rho\sinh(\sigma)$$

An observer moving with fixed ρ traces out a hyperbola in Minkowski space, therefore this type of motion is called hyperbolic motion.

An observer moving along a path of constant ρ is uniformly accelerating and is coupled to field modes which have a definite steady frequency as a function of σ. These modes are constantly Doppler shifted relative to ordinary Minkowski time as the detector accelerates, and they change in frequency by enormous factors, even after only a short proper time.

Translation in σ is a symmetry of Minkowski space: It is a boost around the origin. For a detector coupled to modes with a definite frequency in σ, the boost operator is then the Hamiltonian. In the Euclidean field theory, these boosts analytically continue to rotations, and the rotations close after 2π. So

$$e^{2\pi i H} = 1.$$

The path integral for this Hamiltonian is closed with period 2π which guarantees that the H modes are thermally occupied with temperature $1/2\pi$. This is not an actual temperature, because H is dimensionless. It is conjugate to the timelike polar angle σ, which is also dimensionless. To restore the length dimension, note that a mode of fixed frequency f in σ at position ρ has a frequency which is determined by the square root of the (absolute value of the) metric at ρ, the redshift factor. From the equation for the line element given above, it is easily seen that this is just ρ. The actual inverse temperature at this point is therefore

$$\beta = 2\pi\rho$$

Since the acceleration of a trajectory at constant ρ is equal to $1/a$, the actual inverse temperature observed is

$$\beta = \frac{2\pi}{a}.$$

Restoring units yields

$$k_{\mathrm{B}}T = \frac{\hbar a}{2\pi c}.$$

It means

$$T = \frac{\hbar a}{2\pi c k_{\mathrm{B}}},$$

The temperature of the vacuum, seen by an isolated observer accelerating at the Earth's gravitational acceleration of $g = 9.81\ \mathrm{m\cdot s^{-2}}$, is only 4×10^{-20} K. For an experimental test of the Unruh effect, it is planned to use accelerations up to $10^{26}\ \mathrm{m\cdot s^{-2}}$, which would give a temperature of about 400000 K.

Other Implications:

The Unruh effect would also cause the decay rate of accelerating particles to differ from inertial particles. Stable particles like the electron could have nonzero transition rates to higher mass states when accelerating at a high enough rate.

In 1997, Rainer Muller studies how the decay properties of particles are changed by acceleration. It is shown that under the influence of acceleration (1) the lifetime of particles is modified and (2) new processes (like the decay of the proton) become possible. This is illustrated by considering scalar models for the decay of muons, pions, and protons. My new interpretation of Unruh effect is also predicted that.

Secondly, in General Relativity, the rotation of a body gives it an additional gravitational attraction due to its kinetic energy; and light is pulled around (to some degree) by the rotation (Lense–Thirring effect). In other words, under general relativity, we observe a velocity-dependent dragging effect, since, for a rotating body, the tendency of the object to pull things around with it can be accounted for by the fact that the receding part of the object is pulling more strongly than the approaching part. So, my new interpretation of Unruh effect also predicted that if the acceleration is so large, means gravitational field is so strong, it can bend the virtual particles around it in a circular path (look like the circular ring formed around the accelerated observer), just as the same in Blackhole light bend in a circular path due to its strong gravitational field and make up a region, Photosphere.

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