IAA Lunch Talk

Unruh effect and the origin of gravity

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Outline

-Introduction, Unruh effect

-Physical implications

-Gravity, a non-fundamental force?

-Summary

The Unruh effect (or sometimes Fulling–Davies–Unruh effect) is the prediction that an accelerating observer will observe black-body radiation where an inertial observer would observe none.

A thermometer waved around in empty space will record a non-zero temperature.

Introduction

The **Unruh temperature**, derived by William Unruh in 1976, is the effective temperature experienced by a uniformly accelerating detector in a vacuum field. It is given by:[4]

$$T = \frac{\hbar a}{2\pi c k}$$

where:

- a is the local acceleration
- k is the Boltzmann constant
- $\hbar$ is the reduced Planck's constant
- c is the speed of light

Thus, for example, an acceleration of $2.4661 \times 10^{20} m/s^2$ corresponds to a temperature of 1 K. The Unruh temperature has the same form as the Hawking temperature $T_H = \frac{\hbar g}{2\pi c k}$ of a black hole, which was derived (by Stephen Hawking) independently around the same time. It is, therefore, sometimes called the Hawking–Unruh temperature.[5]

Thanks, Wikipedia.

Some numbers

- The temperature of the vacuum, seen by an observer accelerated at the Earth's gravitational acceleration of $g = 9.81\ m/s^2$ is only 4×10^{-20} K. For an experimental test of the Unruh effect it is planned to use accelerations up to $10^{26}\ m/s^2$, which would give a temperature of about 400,000 K
- at a vacuum Unruh temperature of 3.978×10^{-20} K, an electron would have a de Broglie Wavelength of 540.85 meters, and a proton at that temperature would have a wavelength of 12.62 meters. If electrons and protons were in intimate contact in a very cold vacuum, they would have rather long wavelengths and interaction distances.
- At one astronomical unit from the Sun, the acceleration is $0.005932\ m/s^2$. This gives an Unruh temperature of 2.41×10^{-23} K. At that temperature, the electron and proton wavelengths are 21.994 km and 513 m, respectively. Uranium atom will have a wavelength of 2.2 m at such a low temperature.

Implications

- The Unruh effect would cause the decay rate of accelerated particles to differ from inertial particles. Stable particles like the electron could have nonzero transition rates to higher mass states when accelerated fast enough.
- Unruh's prediction that an accelerating detector would see a thermal bath is not controversial, but the interpretation of the transitions in the detector in the non-accelerating frame is questioned. It is believed that each transition in the detector is accompanied by the emission of a particle, and that this particle will propagate to infinity and be seen as Unruh radiation, which is not universally accepted.
- Skeptics accept that an accelerating object heats up at the Unruh temperature, but they do not believe that this leads to the emission of photons, arguing that the emission and absorption rates of the accelerating particle are balanced.
- Under experimentally achievable conditions for gravitational systems this effect is too small and its observation is very difficult.
- Any ideas for astrophysical effects? The obvious one, at the horizon of a BH is already taken, think of the other possibilities!

Gravity and thermodynamics

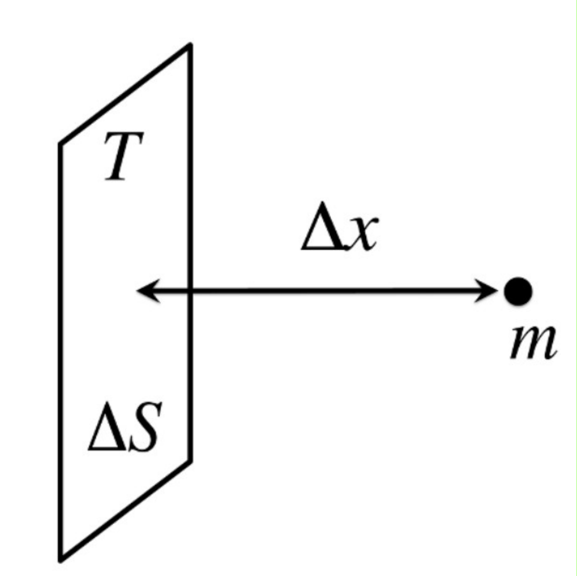
- Gravity dominates at large distances, but is very weak at small scales.
- It is tested only up to distances of the order of 1mm.
- It does not combine well with QM-it even has a different family of mathematical solutions than the rest of physics: in the equations of motion the Lorentz force law implies Maxwell eqs., (more generally Yang-Mills eqs.), and in gravity theory particle motion under gravity does not imply Einstein's equations of gravitation. In practice this means that we can deduce Maxwell's eqs. from observations, and we can not do the same to deduce Einstein's eqs., we need additional assumptions (sure, we can *test* the field equations once we have them).
- Equations of gravity closely resemble the laws of thermodynamics and hydrodynamics, rather than electromagnetism. Maybe this is because they are the same kind of macroscopic description-then gravity would be an *emerging* effect, that is, it emerges from a microscopic description that does not know about "gravitational force".
- What is, then, the origin of "gravity"? One possibility is that it is information, or rather, amount of information needed to describe the matter and its location. This leads to measuring of **entropy**.

Entropic force

- An entropic force is an effective macroscopic force that originates in a system with many degrees of freedom by the statistical tendency to increase its entropy.
- There is no fundamental field associated with an entropic force.
- Space can be understood as a device to describe the positions and movements of particles=a storage for information associated with matter, and this information can be described by entropy. If there is a well defined notion of time, we can define energy, and, via the statistical physics, temperature.
- Now comes Unruh’ effect: acceleration and temperature are closely related.

Thought experiment with screen

- Imagine that space is sliced into screens which contain information, and there is a particle of mass m, approaching it.
- Based on Bekenstein BH argument we can write that the change of entropy associated with the information on the boundary equals $\Delta S = 2\pi k_B$ when $\Delta x = \hbar/mc$



- If there is some reason that particle is from one, and not another side of the membrane, assuming that the change in entropy near the screen is linear with Δx, we can write $\Delta S/\Delta x = 2\pi m c k_B/\hbar$

If the membrane carries a temperature T, effective (enthropic) force on the particle is $F\Delta x = T\Delta S$. Put in the Unruh's law of temperature for accelerated motion, gives F=ma. Hello Newton! Let's check what apples do!

Newton’s law of gravity

- Imagine not an open membrane, but a closed surface, and let it be a spherical surface. To derive the law of gravitation, we need only the statement that to have a force, we need a temperature, we do not even need the Unruh law.
- Think about the boundary as a storage device for information. Number *the total information with N, and then assume it is proportional with the area A* of the sphere, then $N \propto Ac^3/\hbar$. If we call the constant of proportionality G, we can write $N = Ac^3/G\hbar$.
- If the total energy in the system is divided evenly over N bits of information, the equipartition of energy tells us that the energy per bit is $E=0.5Nk_BT$. If then $E=mc^2$, and $A=4\pi R^2$ we get $F=GMm/R^2$. Any apples around?
- When geometry is re-written in space-time terms and SR taken into account, one obtains Einstein's eqs. Sure, there is lots of assumptions in this “derivation”, but what is interesting is logics of it, which is showing gravity as an entropic force.

Summary

-You learned about Unruh effect

-Gravity might be a non-fundamental force