# Possible experimental evidence to the converse Unruh effect in superconductors

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**Abstract:** Although there has not any direct evidence to the Unruh effect and Hawking radiation until now, the converse effect was maybe detected in superconductors. In a noteless experiment performed by scientists of USSR in 1984, a heat flow across the Josephson junction induced the a.c.component[1] and was interpreted to be a thermoelectric effect. Actually, the thermoelectric effect means a temperature gradient will generate an extra current. It occurs in a normal material but does not exist in superconductors. Here is a whole new effect that an extra phase difference rather than current is induced. We regard it as the converse Unruh effect where the temperature is corresponding to an acceleration. Then the temperature gradient will lead to an energy difference and consequential phase change just like the a.c.Josephson effect. Based on the postulate, the frequency formula dependent to the temperature difference $\omega = \frac{4\pi k\Delta}{\hbar^2 V_F}\int (T_1 - T_2)dl$ is given which is in the region of radiowaves and consistent with the mentioned experiment. We hope further experiments will be carried out soon to make clear the phenomenon.

**Key words:** Unruh effect; Josephson effect; graphene;

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Few effects of general relativity were observed because the light speed c is too fast. In 2005, fortunately, scientists of the University of Manchester found the Dirac equation $E\psi = -ci\hbar\sigma\nabla\psi$ of special relativity is invalid to electrons in graphene unless $c$ is replaced by the Fermi velocity $V_F$ whose value is just about c/300, i.e. $E\psi = -V_F i\hbar\sigma\nabla\psi$ [2]. Likewise, equations of general relativity can be applied to study these particles in a gravitational field provided $V_F$ takes the place of $c$. It is equivalent to that the light speed is "decreased" and effects are "magnified". Thereby, to study gravitational effects in graphene and condensed matter physics is helpful to test GR and understand gravity.

For example, the expression of the Unruh effect $kT = \frac{\hbar}{2\pi c}a$ in general relativity should now be $kT = \frac{\hbar}{2\pi V_F}a$ where $k$ is the Boltzman constant, $T$ is the temperature and $a$ is the acceleration. To prove it is still tenable in superconductors, we will use this relation to calculate the coherent length and make a comparison with the BCS theory.

Firstly, the acceleration corresponding to the critical temperature $T_c$ is $a_c = \frac{2\pi V_F kT_c}{\hbar}$. On the other hand, the superconducting energy gap is $E_g = 2\Delta$ and the equivalent rest energy of a quasiparticle is $\Delta = m_0 V_F^2$ which is half of the energy gap as analogue to Dirac's theory of the Fermi sea[3]. So, the force between two particles is

$$m_0 a_c = \frac{\Delta}{V_F^2}\frac{2\pi V_F kT_c}{\hbar} = \frac{2\pi\Delta kT_c}{\hbar V_F}$$

and the work will be $m_0 a_c \xi = E_g$ where $\xi$ is the coherent length. Consequently,

$$\xi = \frac{E_g}{m_0 a_c} = \frac{2\Delta}{m_0 a_c} = \frac{\hbar V_F}{\pi kT_c}$$

The magnitude order is consistent with the result $\xi = \frac{\hbar V_F}{\Delta} \xrightarrow{2\Delta = 3.53kT_c} \frac{\hbar V_F}{1.76kT_c}$ of the BCS theory. The difference of the coefficient is because the linear approximation $m_0 a_c \xi = E_g$ is too simple.

Now consider the conventional a.c. Josephson effect caused by an electric field to the junction.The change rate of the phase is

$$\frac{\partial}{\partial t}(\varphi_1 - \varphi_2) = \frac{2eU}{\hbar} = \frac{2\int e(F_1 - F_2)dl}{\hbar}$$

where $F$ is the intensity. If $U = 0$ but the temperature difference is nonzero,

$$\frac{\partial}{\partial t}(\varphi_1 - \varphi_2) = \frac{2\int m_0(a_1 - a_2)dl}{\hbar} = \frac{4\pi k\Delta}{\hbar^2 V_F}\int (T_1 - T_2)dl$$

Moreover, $\Delta$ is a variation depends on the temperature and a more precise formula in the case of $T_1 \neq T_2$ should be

$$\frac{\partial}{\partial t}(\varphi_1 - \varphi_2) = \frac{2\int (m_1 a_1 - m_2 a_2)dl}{\hbar} = \frac{4\pi k}{\hbar^2 V_F}\int (\Delta_1 T_1 - \Delta_2 T_2)dl$$

Such a frequency is in the radio region of the electromagnetic spectrum.

**References:**


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