

Thermodynamics First Law For The Charged Euler-Heisenberg Anti-De Sitter Black Hole Using Foliation

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ABSTRACT

In this paper, we followed the foliation approach introduced by (Siddiqui et al. 2011) to develop the black hole thermodynamics first law for the charged Euler-Heisenberg Anti-de Sitter space time, as probable it is observed that its field equation from induced metric using foliation along with virtual displacement of its hypersurface conforming to the horizon of the black hole can be expressed as a thermodynamics first law of black hole with very short manipulation.

Keyword Euler-Heisenberg, Anti-de Sitter (AdS), Black Hole (BLKHL), Thermodynamics (TDS)

1 Introduction

The word *foliation* arise from *folia* which is a Latin word meaning leaf. In seventeenth century the theory of differential equation give rise to the concept of foliation or slicing when the solution space trajectories are viewed as foliation's leaves. Process of decomposition of n -dimensional manifold M , into sub-manifolds, which have the identical dimension q , for all is called foliation [1]. The leaves of foliation are comprised of sub-manifolds. The co-domain p , of a foliation is outlined as $p = n - q$. Foliation via *hyper-surface* is the term use to describe a foliation of co-dimension one. Reeb [2], Ehresmann [3] and the former are the innovators of foliation and Poincare coined the term foliation.

The Einstein field equation have several singular solutions that correspond to BLKHL space- time and are physically plausible [4]. The horizon in these space-times has special relevance due to its geometry. The space-time is frequently foliated [5]-[23] by a series of hyper-surfaces that can be null or space-like in order to study the dynamics of such geometries. Jacobson [24] was the first to explain the link among the first law of BLKHL-TDS and the Einstein field equation, Padmanabhan [25] then developed a broad framework to comprehend the TDS of horizon. Af- terwards, lots of work has been done for various space-time geometries in this direction [26]-[36].

The Lagrangian of Euler-Heisenberg having electrodynamics was firstly well-thought-out in 1936 [49]. The theory of Euler-Heisenberg is extra precise conventional approximation of Quantum electrodynamics (QED) as compared to Maxwell's theory, with the fields having high intensity. Taking vacuum as an explicit kind of medium, and the attributes of magnetization and polarization are viewed as a cluster of charges that are virtual and neighbouring the real charges [50]. In order to sense the consequences, the theory of Euler-Heisenberg has been anticipated in [51]. Since this theory has fascinating features physically, so it was a ordinary consequence to unite the Euler-Heisenberg Lagrangian with the Ricci scalar through the volume element to explore for the black holes. The first solution that generate black hole to the Euler-Heisenberg electrodynamics was derived in [52], where solutions that are analytic were found for the case of magnetic charges, also discuss electric charges with dyons. Black holes having electric charges were taken in [53] and [54], where in research paper [54], studied the geodesic structure. In [55] charged particles motion about the Ads Euler-Heisenberg black hole were considered. The TDS of these BLKHL's were discussed in ([56]-[57]), whereas the quasi normal means were manipulated in [58]. The black holes having rotation were initiated in ([59]-[60]), while the Euler-Heisenberg Lagrangian was presented along with altered modified gravities theory in ([61]-[63]) and the conforming black holes were investigated. Lastly, the shadow study of Euler-Heisenberg BLKHL was explored in [64].

The theory of Euler-Heisenberg defines precisely the behaviour of magnetic and electric charges. Though, in the company of a stout field of gravitation in astrophysical environment, for example close to the horizon of an astrophysical black hole, the electric charge is taken to be negligible because of the occurrence of plasma (electric charged particles that result in electric conductive plasma) about astrophysical BLKHL's that defuses electric charge. In [65] the upper bounds of electric charge in astrophysical BLKHL's are studied. Where magnetically charged BLKHL could not be defused with usual matter [66]. Current astrophysical remarks exhibit that numerous stronger radio source results in two releasing regions positioned on reverse spots of a galaxy. To enlighten these astrophysical conclusions a theory was projected that the magnetic fields along with particles having high energy are accountable for the bluster of the galactic halo in a massive blast. Then, a conceivable description was projected that such blasts could be produced by gravitational collapse and such a model was accessible in [67] having a conformation that comprises solitary electromagnetic field in the form of parallel magnetic lines that are detained together by its gravitational attraction. This theory is defined as a demanding static cylindrically-symmetric solution of Einstein-Maxwell equations ([68]-[70]). From the overhead debate it would be very fruitful to recognize the study of a magnetic field in the occurrence of matter. To study this effect, the theory of Euler-Heisenberg can offer a very consistent framework. Black holes involving nonlinear electrodynamics, in recent years attract prodigious attention. Particularly, that theory is regarded as low-energy limit by D-brane physics or string theory,

where Lagrangians that are nonlinear electrodynamic could be produced. The AdS black holes TDS of the Born-Infeld (BI) with charge are well-thought-out in ref. [40]. The BI vacuum polarization presence directs a rich BLKHL phase transition. That work is too prolonged to BLKHL of higher dimension in [41]. Another broadly related non-perturbative effective Lagrangian of nonlinear electromagnetic fields instigate from Euler and Heisenberg [42]. In the framework of quantum electrodynamics, Schwinger rearticulated it in [43]. Also the solution of BLKHL conforming with the active Lagrangian are done in [44].

Siddiqui et al. [45] using foliation established an elegant and simpler procedure of driving the BLKHL thermodynamics first law for the Schwarzschild and Reissner-Nordstrom BLKHL respectively. Also that approach confirms its validity in ([46]-[47]) by deriving TDS first laws of Kerr and Kerr Newman BLKHL respectively. There, rather of getting Einstein's equations of BLKHL and investigate thermal interpretation near the event horizon, their key objective is to use a foliation of the BLKHL spacetime so that the event horizon corresponds to a specific hyper-surface. After that field equations are carried out for the induced metric of BLKHL to achieve the former thermal investigation. The main benefit of using that procedure is that, in place of handling the Einstein equations of an n -dimensional BLKHL, one deals the Einstein equations of $(n - 1)$ -dimensional BLKHL's induced metric. Thus in the next section, we followed a theme presented at (Siddiqui et al. (2011)) for the Schwarzschild and Reissner-Nordstrom black holes to obtain the TDS first law of Charged Euler-Heisenberg Anti-de Sitter BLKHL. Conclusion of the research is expressed in last section.

2 First Law of Charged Euler-Heisenberg Anti-de Sitter BLKHL

An action of the Euler Heisenberg geometry having cosmological constant in $(3 + 1)$ dimensional space-time is given by [48]

$$S = \frac{1}{4\pi} \int_{M^4} d^4x \sqrt{-g} \left[\frac{1}{4} (R - 2\Lambda) - L(F, G) \right], \quad (1)$$

$$L(F, G) = -F^2 + \frac{a}{2} F^2 + \frac{7a}{8} G^2 \quad (2)$$

Here R , Λ and g are the Ricci curvature, cosmological constant and determinant of the metric tensor, respectively. The term $L(F, G)$ is the Lagrangian of the nonlinear electrodynamics which depends on the electromagnetic invariants $F = \frac{1}{2} F_{\epsilon\tau} F^{\epsilon\tau}$. The Maxwell field strength $F_{\epsilon\tau} = \partial_\epsilon \omega_\tau - \partial_\tau \omega_\epsilon$, and ω_ϵ represents the conforming potential vector. In order to calculate the strength of quantum electrodynamics (QED) correction, formula (2) having parameter a which relates the charge and mass of the electron, can be regarded as the QED parameter.

The Einstein field equations in (3 + 1) dimensional space time is:

$$G_{ab} = -8\pi T_{ab} \quad (a, b = 0, 1, 2, 3) \quad (3)$$

where G_{ab} is the Einstein and T_{ab} is Stress-energy tensors. Line element of the charged Eu- ler Heisenberg AdS BLKHL which is static and symmetric spherically [37] with gravitational constants $G = c = 1$ is given as

$$ds^2 = -h(r)dt^2 + \frac{1}{h(r)}dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2) \quad (4)$$

whereas

$$h(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2} - \frac{\Lambda r^2}{3} - \frac{aQ^4}{20r^6}$$

The BLKHL's mass indicated by M , angular momentum by a and electrical charge by Q . The cosmological constant is Λ , expresses pressure by $P_{8\pi} = -\frac{\Lambda}{8\pi}$ [38]. The thermal variables related

with the event horizon of the charged Euler-Heisenberg Anti-de Sitter BLKHL are the entropy

$S = \frac{A}{4} = r^2\pi$ (where A represents the horizon's area), electric potential $\phi = \frac{\partial M}{\partial Q}$ and the tem-

perature is $T = -\frac{1}{4\pi} h'(r)$.

Consider the foliation of the charged Euler-Heisenberg Anti-de Sitter BLKHL space-time by taking r as a constant (suppose k) hyper-surface, thus BLKHL horizon relate's with a specific hyper-surface. The BLKHL induced metric is given by:

$$ds^2 = -h(k)dt^2 + k^2d\theta^2 + k^2 \sin^2\theta d\phi^2$$

At $h(k) =$

0,

$$M = \frac{k}{2} + \frac{Q^2}{2k} - \frac{\Lambda k^3}{6} - \frac{aQ^4}{40k^5}, \quad (5)$$

$$T = \frac{h'(k)}{4\pi} = \frac{1}{4k\pi} \left(1 - \frac{2}{k^2} - \frac{Q^2}{k^4} - \frac{aQ^3}{10k^5} - k^2\Lambda \right), \quad (6)$$

$$S = \frac{A}{4} = k^2\pi, \quad (7)$$

$$\phi = \frac{\partial M}{\partial Q} = \frac{Q}{k} - \frac{aQ^3}{10k^5}, \quad (8)$$

and

$$V = \frac{4k^3\pi}{3}. \quad (9)$$

Where V is the volume enclosed by the horizon. Taking differential of Eq. (5)

$$dM = \frac{1}{2} \left(1 - \frac{Q^2}{k^2} - \Lambda k^2 + \frac{aQ^4}{4k^6} \right) dk + \left(\frac{Q}{k} - \frac{aQ^3}{10k^5} \right) dQ - \frac{Q^4}{40k^5} da \quad (10)$$

The (0, 0) component of the Einstein's Tensor for the induced metric is:

$$G_{00} = \frac{h(k)}{k^2} = \frac{1}{k^2} \left(1 - \frac{2M}{k} + \frac{Q^2}{k^2} - \frac{\Lambda k^2}{3} - \frac{aQ^4}{20k^6} \right)$$

and

$$T_{00} = -P$$

Thus the Einstein field equation (3) takes the form

$$\frac{1}{2} \left[1 - \frac{2M}{k} + \frac{Q^2}{k^2} - \frac{\Lambda k^2}{3} - \frac{aQ^4}{20k^6} \right] = 4\pi P k^2$$

Considering a virtual displacement dk , while using k as a parameter and for the hyper-surface given by Eq.(10)

$$\frac{1}{2} \left[\frac{2M}{k} + \frac{Q^2}{k^2} - \frac{\Lambda k^2}{3} - \frac{aQ^4}{20k^6} \right] dk = 4\pi P k^2 dk$$

Using the hyper surface corresponding to event horizon $f(k) = 0$ along with adding and subtracting $\frac{dk}{2} + \frac{Q^2 dk}{2k^2} + \frac{aQ^4 dk}{8k^6} + \frac{\Lambda k^2 dk}{2}$, we have

$$\frac{dk}{2} - \frac{dk}{2} + \frac{Q^2 dk}{2k^2} - \frac{Q^2 dk}{2k^2} + \frac{aQ^4 dk}{8k^6} - \frac{aQ^4 dk}{8k^6} + \frac{\Lambda k^2 dk}{2} - \frac{\Lambda k^2 dk}{2} = r_u \left(\frac{4\pi k^3}{3} \right)$$

Combining 2nd,3rd,5th and 6th term produce $-TdS$ then adding and subtracting $\frac{QdQ}{aQ^3 dQ}$,

and $\frac{Q^4}{40k^5} da$ we have $k = 10k^5$

$$dk - Q^2 dk - aQ^4 dk - \Lambda k^2 dk - QdQ - QdQ - aQ^3 dQ - aQ^3 dQ - Q^4 - Q^4$$

$$-TdS + \frac{QdQ}{2k} - \frac{aQ^3dQ}{2k^2} + \frac{Q^2d}{8k^6} - \frac{aQ^4d}{2k} - \frac{\Lambda k^2 dk}{2} - \frac{Q^4}{40k^5} da - \alpha da = PdV$$

7th and 8th term gives us $-\phi dQ$, we have

$$-\phi dQ + \frac{QdQ}{k} - \frac{aQ^3dQ}{10k^5} + \frac{Q^2d}{2k^2} - \frac{aQ^4d}{8k^6} - \frac{\Lambda k^2 dk}{2} - \frac{Q^4}{40k^5} da - \alpha da = PdV + TdS$$

where $\alpha = \frac{Q^4}{40k^5}$

$$dM - \alpha da = PdV + TdS + \phi dQ$$

We finally get the desired first law of BLKHL thermodynamics:

$$dE = TdS + \phi dQ + PdV. \quad (11)$$

Where $dE = dM - \alpha da$ represent energy of the Euler-Heisenberg Anti-de Sitter Black Hole.

3 Conclusion:

The article explore the foliation's concept, it is evident that the followed procedure is found to be very simpler, for the derivation of first law of black hole TDS, by Taking $r = \text{constant}$ hypersurfaces, for the charged Euler-Heisenberg Anti-de Sitter spacetimes. The induced metric of the BLKHL has Einstein field equation, that can be expressed in TDS variables as TDS first law. As probable, it is initiated that the Einstein's field equation of the induced metric conforming to the horizon could be inscribed as a first law of black hole TDS. It is to be revealed that the practise implemented is ample easier, to attain such results, the main reason is that as one has to fundamentally associated with $(n - 1)$ -dimensional induced metric instead use this technique of n - for further dimensional BLKHL geometries. spacetime. It is to be more fascinating to

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