ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 6, December 2013

Change in Internal Energy of Non-Spinning Black Holes in XRBS

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Abstract—This research paper derives an expression for change in internal energy of non-spinning black holes using the entropy change((δS) derived by Dipo Mahto et. al.(2011) and also calculates their values for different types of the test non-spinning black holes existing in X-ray binaries.

***Index Terms*—Internal energy, Entropy and XRBs.**

I. INTRODUCTION

Work by James Bardeen, Jacob Bekenstein Carter and Hawking in the early 1970s led to the formulation of the black hole mechanics. These laws describe the behaviour of a black hole in close analogy to the laws of thermodynamics relating mass to energy, area to entropy, and surface gravity to temperature [1]. Stephen Hawking (1971) showed under general conditions that the total area of the event horizons of any collection of classical black holes can never decrease, even if they collide and merge which results that the total entropy of a given system can never decrease. Dipo Mahto et al. have derived the formula for both the changes in energy (δE) and entropy (δS) represented by eq^n (i) $\delta E = \frac{\delta R_{bh} \cdot c^2}{4M}$ and (iia) $\delta S_{bh} = \frac{2\pi}{k \cdot c^2}\delta E$ (iib) $\delta S_{bh} = 2\pi\left(\delta R_{bh}\right)$ taking account the first law of black hole mechanics and mass-energy equivalence relation [2]. In 2012, Dipo Mahto et al. have derived a formula for the change in entropy of the non-spinning black holes with respect to change in the radius of event horizon ($\delta S_{bh} / \delta R_{bh} = 2\pi R_{bh}$), applying the first law of black hole mechanics with the relation for the change in entropy $\delta S = 8\pi M \delta M$. They have extended this work with proper operation, Bekenstein-Hawking formula for the entropy of black holes ($S_{bh} = A/4$) is obtained [3]. Dipo Mahto et al. calculated also the energy of different non-spinning black holes existing in XRBs and AGN on the basis of Kanak et al. model ($E_{BH} = K_{BH} R_s$)[4]. Dipo Mahto et al. discussed the derivation for internal energy of the non-spinning black holes using the first law of black hole thermodynamics and calculated their values of different test non-spinning black holes existing in X-ray binaries and Active galactic nuclei [5]. Dipo Mahto et al. derived expression for the change in internal energy and enthalpy of the black holes using first law of thermodynamics and showing that the change in internal energy and enthalpy are the manifestations of same thing at constant pressure and volume [6]. In the present research paper, we have derived an expression for change in internal energy of the non-spinning black holes using the entropy change((δS) derived by Dipo Mahto et. al.(2011) and also calculated their values for different types of the test non-spinning black holes existing in X-ray binaries.

II. DISCUSSION

The change in entropy of non-spinning black holes due to corresponding change in energy and the radius of event horizon is given by eq^n (1) and (2) respectively [2].

$$\delta S_{bh} = \frac{2\pi}{\kappa \cdot c^2}\delta E \qquad (1)$$

$$\delta S_{bh} = 2\pi\left(R_{bh}\delta R_{bh}\right) \qquad (2)$$

There are systems which may show no apparent mechanical energy, but may still be capable of doing work. They are said to possess internal energy. If an amount of heat δQ be added to a thermodynamical system, say a perfect gas, which expands by a volume dV against the pressure P, then from first law of thermodynamics. The change in internal energy of non-spinning black holes is given by [6].

$$dU = TdS \qquad (3)$$

Putting the values of eq^n (1) in eq^n (2), we have

$$dU = T 2\pi R_{bh} dR_{bh} \qquad (4)$$

In the case of black holes, $T = \frac{\kappa}{2\pi}$ where κ is the surface gravity of black hole. Putting this value in equation (4), we have

$$dU = \kappa R_{bh} dR_{bh} \qquad (5)$$

In the case of non-Spinning block hole. J=Q=0, the surface gravity of black holes[2,3,7,8].

$$\kappa = \frac{1}{4M} \qquad (6)$$

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Putting the equation (6) in the above equation, we have

$$dU = R_{bh} dR_{bh} / 4M \qquad (7)$$

The above expression shows the change in internal energy of non-spinning black holes which is the exactly the same to the expression for the change in internal energy as in the reference [6]. It may be supposed that there is negligible change in the radius of the event horizon due to change in internal energy of non-spinning black holes. Hence in the numerical calculations, the radius of event horizon (R_{bh}) can be taken into consideration instead of δR_{bh} . Here, we have calculated the change in internal energy (dU) using eq^n (7) for different test non-spinning black holes as listed in the table given below.

Table 1. Change in internal energy of the non-spinning black holes

1	**2**	**3**	**4**
S.No.	Mass of the black holes (M)	$R_{bh} = 2950\left(\frac{M}{M_\odot}\right)m$	Change in internal energy(joule) $dU = R_{bh} dR_{bh} / 4M$
1	$5M_\odot$	14750	4.9197×10^{-7}
2	$6M_\odot$	17700	5.9036×10^{-7}
3	$7M_\odot$	20650	6.8876×10^{-7}
4	$8M_\odot$	23600	7.8715×10^{-7}
5	$9M_\odot$	26550	8.8554×10^{-7}
6	$10M_\odot$	29500	9.8394×10^{-7}
7	$11M_\odot$	32450	10.8223×10^{-7}
8	$12M_\odot$	35400	11.8073×10^{-7}
9	$13M_\odot$	38350	12.7912×10^{-7}
10	$14M_\odot$	41300	13.7552×10^{-7}
11	$15M_\odot$	44250	14.8414×10^{-7}
12	$16M_\odot$	47200	15.7430×10^{-7}
13	$17M_\odot$	50150	16.7270×10^{-7}
14	$18M_\odot$	53100	17.7109×10^{-7}
15	$19M_\odot$	56050	18.6949×10^{-7}
16	$20M_\odot$	59000	19.6788×10^{-7}

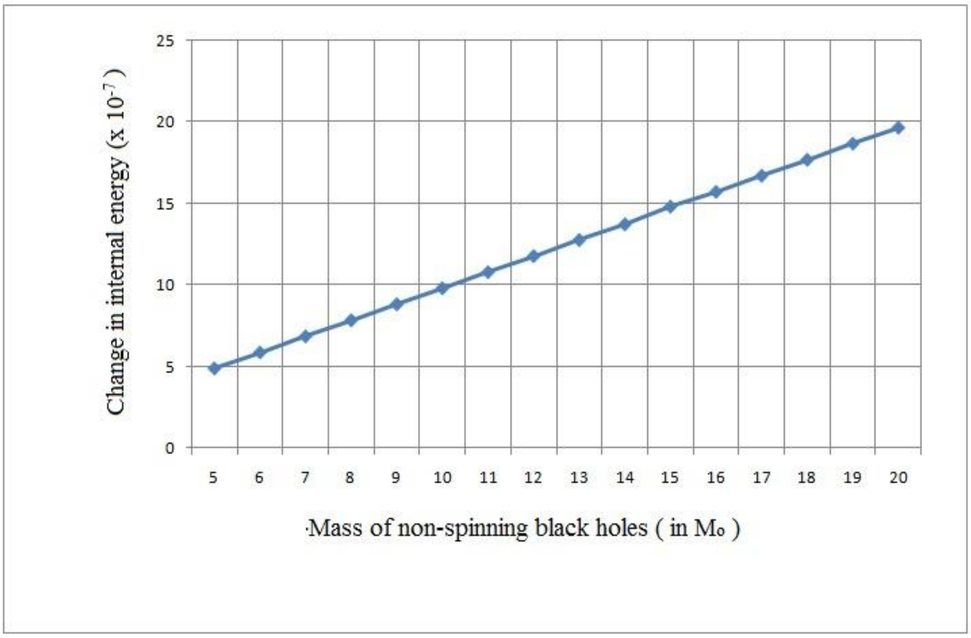

Fig 1: The graph plotted between the mass (in terms of solar mass) and change in internal energy (in joule) of the different test non-spinning black holes in X-ray binaries(XRBs).

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III. RESULT AND DISCUSSION

In the present work, we have derived an expression for the change in internal energy of non-spinning black holes using the entropy change(δS) derived by Dipo Mahto et. al.(2011) and also calculated their values for different types of the test non-spinning black holes existing in X-ray binaries. To discuss the relation between the mass of non-spinning black holes and change in internal energy, the graph is plotted between the mass of different test non-spinning black holes and their corresponding values of change in internal energy (fig.1) The graph plotted for XRBs is in a straight line and shows that there is a uniform variation between the mass of different test non-spinning black holes and their corresponding values of change in internal energy. The straight line also shows that there is a definite relation between the mass of non-spinning black holes and change in internal energy and gives the validity of the equation(7).

IV. CONCLUSION

In the study of present research work, we can draw the following conclusions:

(i)There is uniform variation in the change in internal energy due to increasing the mass of different test black hole candidates in XRBs and showing a definite relation between the change in internal energy and mass of black holes.

(ii)Larger the mass, greater is the change in internal energy of black holes and vice-versa.

(iii) Larger the radius of event horizon, greater is internal energy of black holes and vice-versa.

V. ACKNOWLEDGEMENT

The authors are grateful to the referee for pointing out the errors in the original manuscript and making constructive suggestions. The authors are grateful to the Principal, Dr. M.S. H. John of Marwari College who inspired always to continue their works. The authors are obliged to Dr. Gopi Kant Jha, Former Head & Prof. of Physics, L.N.M.U Darbhanga and Dr. Neeraj Pant, Associate Professor, Dept. of Mathematics, N.D.A. Khadakwasala, Pune for their inspiration and motivation.

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