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Research Article

Phase Transition and Entropy Force between Two Horizons in $(n+2)$-Dimensional de Sitter Space

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In this paper, the effect of the space-time dimension on effective thermodynamic quantities in $(n+2)$-dimensional Reissner-Nordstrom-de Sitter space has been studied. Based on derived effective thermodynamic quantities, conditions for the phase transition are obtained. The result shows that the accelerating cosmic expansion can be attained by the entropy force arisen from the interaction between horizons of black holes and our universe, which provides a possible way to explain the physical mechanism for the accelerating cosmic expansion.

1. Introduction

It is well known that the cosmic accelerated expansion indicates that our universe is an asymptotical de Sitter one. Moreover, due to the success of AdS/CFT, it prompts us to search for the similar dual relationships in de Sitter space. Therefore, the research of de Sitter space is not only of interest to the theory itself, but also the need of the reality.

In de Sitter space, the radiation temperature on the horizon of black holes and the universe is generally not the same. Therefore, the stability of the thermodynamic equilibrium cannot be protected in it, which makes troubles to corresponding researches. In recent years, the study on thermodynamic properties of de Sitter space is getting more and more attention [1–12]. In the inflationary period, our universe seems to be a quasi de Sitter space, in which the cosmological constant is introduced as the vacuum energy, which is a candidate for dark energy. If the cosmological constant corresponds to dark energy, our universe will go into a new phase in de Sitter space. In order to construct the entire evolutionary history of our universe and understand the intrinsic reason for the cosmic accelerated expansion, both the classic and quantum nature of de Sitter space should be studied.

For a multihorizon de Sitter space, although different horizons have different temperatures, thermodynamic quantities on horizons of black holes and the universe are functions depended on variables of mass, electric charge, cosmological constant, and so on. Form this point of view, thermodynamic quantities on horizons are not individual. Based on this fact, effective thermodynamic quantities can be introduced. Considering the correlation between horizons of black holes and the universe, we have studied the phase transition and the critical phenomenon in RN-dS black holes with four-dimension and high-dimension by using effective thermodynamic quantities, respectively. Moreover, the entropy for the interaction between horizons of black holes and the universe is also obtained [13–17]. When we consider the cosmological constant as a thermodynamic state parameter with the thermodynamic pressure, the result shows that de Sitter space not only has a critical behavior similar to the van der Waals system [17, 18], but also take second-order phase transition similar to AdS black hole [19–29]. However, the first-order phase transition similar to the AdS black hole is not existing. In this work, we investigate the issue of the phase transition in a high-dimensional de Sitter space and analyze the effect of the dimension on the phase transition and the entropy produced by two interactive horizons.

Nine years ago, Verlinde [30] proposed to link gravity with an entropic force. The ensuing conjecture was proved recently [31, 32], in a purely classical environment and then extended to a quantal bosonic system in Ref. [31]. In 1998, the result of the observational data from the type Ia supernovae (SNe Ia) [33, 34] indicates that our universe presently experiences an accelerating expansion, which contrasts to the one given in general relativity (GR) by Albert Einstein. In order to explain this observational phenomenon, a variety of proposals have been proposed. The theory of "early dark energy" proposed by Riess et al. [35, 36] is one of them, where dark energy [37, 38] as an exotic component with large negative pressure seems to be the cause of this observational phenomenon. According to the observations, dark energy occupies about 73% in cosmic components. Therefore, one believes that the present accelerating expansion of our universe should be caused by dark energy. Then a lot of dark energy models have been proposed. However, up to now, the nature of dark energy is not clear.

Based on the entropy caused by the interaction between the horizons of black holes and the universe, the relationship between the entropy force and the position ratio of the two horizons is obtained. When the position ratio of the black hole horizon to the universe horizon is greater (less) than a certain value, the entropy force between the two horizons is repulsive (attractive), which indicates that the expansion of the universe horizon is accelerating (decelerating). While when it equal to a certain value, the entropy force is absent, and then the expansion of the universe horizon is uniform. According to this, we suppose that the entropy force between the two horizons can be seen as a candidate to cause the cosmic accelerated expansion.

This paper is organized as follows. According to Refs. [16–18], a brief review for the effective thermodynamic quantities, the conditions for the phase transition, and the effect of the dimension on the phase transition in $(n+2)$-dimensional Reissner-Nordstrom-de Sitter (DRNdS) space is given in the next section. In Section 3, the entropy force of the interaction between horizons of black holes and the universe is derived, and then the effect of the dimension on it is explored. Moreover, the relationship between the entropy force and the position ratio of the two horizons is obtained. Conclusions and discussions are given in the last section. The units $G=\hbar=k_B=c=1$ are used throughout this work.

2. Effective Thermodynamic Quantities

The metric of $(n+2)$-dimensional DRNdS space is [39]

$$ds^2 = -f(r)dt^2 + f^{-1}(r)dr^2 + r^2 d\Omega_n^2, \tag{1}$$

where the metric function is

$$f(r) = 1 - \frac{\omega_n M}{r^{n-1}} + \frac{n\omega_n^2 Q^2}{8(n-1)r^{2n-2}} - \frac{r^2}{l^2}, \quad \omega_n = \frac{16\pi G}{n\mathrm{Vol}(S^n)}. \tag{2}$$

Here, G is the gravitational constant in $(n+2)$-dimensional space, l is the curvature radius of dS space, $Vol(S^n)$ denotes the volume of a unit n–sphere $d\Omega_n^2$, M is an integration constant, and Q is the electric/magnetic charge of the Maxwell field.

In $(n+2)$-dimensional DRNdS space, positions of the black hole horizon r_+ and the universe horizon r_c can be determined when $f(r_{+,c})=0$. Moreover, thermodynamic quantities on these two horizons satisfy the first law of thermodynamics, respectively [3, 5, 39]. However, thermodynamic systems denoted by the two horizons are not independent, since thermodynamic quantities on them are functions depended on variables of mass M, electric charge Q, and cosmological constant l^2 satisfy the first law of thermodynamics. When parameters of state of $(n+2)$-dimensional DRNdS space satisfy the first law of thermodynamics, the entropy is [16–18]

$$S = \frac{\mathrm{Vol}(S^n)}{4G} r_c^n \left(1 + x^n + f_n(x)\right) = S_{c,+} + S_{\mathrm{AB}}, \tag{3}$$

where $x=r_+/r_c$, $S_{c,+}=(\mathrm{Vol}(S^n)/4G)r_c^n(1+x^n)$ and $S_{AB}=(Vol(S^n)/4G)r_c^n f_n(x)$ are entropies with and without the interaction between the two horizons, respectively, and

$$f_n(x) = \frac{3n+2}{2n+1}\left(1-x^{n+1}\right)^{n/(n+1)} - \frac{(n+1)\left(1+x^{2n+1}\right) + (2n+1)\left(1-2x^{n+1}-x^{2n+1}\right)}{(2n+1)(1-x^{n+1})}. \tag{4}$$

The volume of $(n+2)$-dimensional DRNdS space is [3, 7, 13]

$$V = V_c - V_+ = \frac{\mathrm{Vol}(S^n)}{(n+1)} r_c^{n+1}\left(1-x^{n+1}\right). \tag{5}$$

When parameters of state of $(n+2)$-dimensional DRNdS space satisfy the first law of thermodynamics, the effective temperature is [16–18]

$$\begin{aligned} T_{\mathrm{eff}} &= \left(1-x^{n+1}\right)\frac{(\partial M/\partial x)_{r_c}\left(1-x^{n+1}\right) + r_c x^n (\partial M/\partial r_c)_x}{\mathrm{Vol}(S^n) r_c^n x^{n-1}\left(1+x^{n+2}\right)} \\ &= \frac{B(x)}{\mathrm{Vol}(S^n) r_c x^{2n-1}\omega_n\left(1+x^{n+2}\right)}, \end{aligned} \tag{6}$$

where

$$\begin{aligned}
B(x) &= x^n\left[(n-1)x^{n-2}-(n+1)x^n+2x^{2n-1}+(n-1)x^{2n-1}\left(1-x^2\right)\right] \\
&\quad - \frac{n\omega_n^2 Q^2\left[(n-1)x^{n+1}\left(1-x^{2n}\right)-2nx^{n+1}+(n-1)+(n+1)x^{2n}\right]}{8(n-1)r_c^{2n-2}} \\
&= x^n\left[(n-1)x^{n-2}-(n+1)x^n+2x^{2n-1}+(n-1)x^{2n-1}\left(1-x^2\right)\right] \\
&\quad - \frac{2\phi_c^2(n-1)\left[(n-1)x^{n+1}\left(1-x^{2n}\right)-2nx^{n+1}+(n-1)+(n+1)x^{2n}\right]}{n},
\end{aligned} \tag{7}$$

where $\phi_c = (n/4(n-1))(\omega_n Q/r_c^{n-1})$ is electric potential on the universe horizon. The effective pressure P_{eff}, isochoric heat capacity C_{veff}, and isobaric heat capacity $C_{P_{\text{veff}}}$ in $(n+2)$-dimensional DRNdS space are

$$P_{\text{eff}} = \frac{D(x)}{\omega_n \text{Vol}(S^n)(1-x^{n+1})r_c^2 x^{n-1}(1+x^{n+2})}, \tag{8}$$

where

$$\begin{aligned}
D(x) &= \left[(n-1)x^{n-2}-(n+1)x^n+2x^{2n-1}-\frac{n\omega_n^2Q^2\left(2nx^{n+1}-(n-1)-(n+1)x^{2n}\right)}{8(n-1)r_c^{2n-2}x^n}\right]\times\left(1+x^n+f(x)\right) \\
&\quad - \left[(n-1)x^{n-1}\left(1-x^2\right)-\frac{n\omega_n^2Q^2\left(1-x^{2n}\right)}{8r_c^{2n-2}x^{n-1}}\right]\left(x^{n-1}+\frac{f'(x)}{n}\right)\left(1-x^{n+1}\right),
\end{aligned} \tag{9}$$

$$\begin{aligned}
C_V &= T_{\text{eff}}\left(\frac{\partial S}{\partial T_{\text{eff}}}\right)_V = T_{\text{eff}}\frac{(\partial S/\partial r_c)_x(\partial V/\partial x)_{r_c}-(\partial S/\partial x)_{r_c}(\partial V/\partial r_c)_x}{(\partial V/\partial x)_{r_c}(\partial T_{\text{eff}}/\partial r_c)_x-(\partial V/\partial r_c)_x(\partial T_{\text{eff}}/\partial x)_{r_c}} \\
&= \frac{1}{4G(1-x^{n+1})}\times\frac{-\text{Vol}(S^n)r_c^n B(x)nx^n\left(1+x^{n+2}\right)^2}{\bar{B}(x)x^{n+1}(1+x^{n+2})-(1-x^{n+1})x(1+x^{n+2})B'(x)-B(x)[2n-1+(3n+1)x^{2n+2}]}
\end{aligned} \tag{10}$$

where

$$\begin{aligned}
\bar{B}(x) &= x^n\left[(n-1)x^{n-2}-(n+1)x^n+2x^{2n-1}+(n-1)x^{2n-1}\left(1-x^2\right)\right] \\
&\quad - \frac{n\omega_n^2Q^2(2n-1)\left[(n-1)x^{n+1}\left(1-x^{2n}\right)-2nx^{n+1}+(n-1)+(n+1)x^{2n}\right]}{8(n-1)r_c^{2n-2}}, \\
B'(x) &= \frac{dB(x)}{dx}, D'(x) = \frac{dD(x)}{dx}, \\
C_{P_{\text{eff}}} &= T_{\text{eff}}\left(\frac{\partial S}{\partial T_{\text{eff}}}\right)_{P_{\text{eff}}} \\
&= T_{\text{eff}}\frac{(\partial S/\partial r_c)_x(\partial P_{\text{eff}}/\partial x)_{r_c}-(\partial S/\partial x)_{r_c}(\partial P_{\text{eff}}/\partial r_c)_x}{(\partial P_{\text{eff}}/\partial x)_{r_c}(\partial T_{\text{eff}}/\partial r_c)_x-(\partial P_{\text{eff}}/\partial r_c)_x(\partial T_{\text{eff}}/\partial x)_{r_c}} \\
&= r_c^n\frac{\text{Vol}(S^n)B(x)E(x)}{4GH(x)},
\end{aligned} \tag{11}$$

where

$$E(x) = \left[nx^{n-1} + f'(x)\right]\left[\bar{D}(x) - 2D(x)\right]\left(1 - x^{n+1}\right)x\left(1 + x^{n+2}\right) - n\left[1 + x^n + f(x)\right]\left\{D'(x)x\left(1 - x^{n+1}\right)\left(1 + x^{n+2}\right) - D(x)\left[(n-1) - 2nx^{n+1} + (2n+1)x^{n+2} - (3n+2)x^{2n+3}\right]\right\},$$

$$H(x) = \bar{B}(x)\left\{D'(x)x\left(1 - x^{n+1}\right)\left(1 + x^{n+2}\right) - D(x)\left[(n-1) - 2nx^{n+1} + (2n+1)x^{n+2} - (3n+2)x^{2n+3}\right]\right\} + \left(1 - x^{n+1}\right)\left[\bar{D}(x) - 2D(x)\right] \cdot \left[x\left(1 + x^{n+2}\right)B'(x) - B(x)\left[2n - 1 + (3n+1)x^{2n+2}\right]\right].$$

$$\bar{D}(x) = \frac{n\omega_n^2 Q^2\left(2nx^{n+1} - (n-1) - (n+1)x^{2n}\right)}{4r_c^{2n-2}x^n} \cdot \left(1 + x^n + f(x)\right) - \frac{n(n-1)\omega_n^2 Q^2\left(1 - x^{2n}\right)}{4r_c^{2n-2}x^{n-1}} \cdot \left(x^{n-1} + \frac{f'(x)}{n}\right)\left(1 - x^{n+1}\right). \tag{12}$$

The coefficient of isobaric volume expansion and isothermal compressibility in $(n+2)$- dimensional DRNdS space is given by

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T_{\text{eff}}}\right)_{P_{\text{eff}}} = \frac{1}{V}\frac{(\partial V/\partial r_c)_x(\partial P_{\text{eff}}/\partial x)_{r_c} - (\partial V/\partial x)_{r_c}(\partial P_{\text{eff}}/\partial r_c)_x}{(\partial P_{\text{eff}}/\partial x)_{r_c}(\partial T_{\text{eff}}/\partial r_c)_x - (\partial P_{\text{eff}}/\partial r_c)_x(\partial T_{\text{eff}}/\partial x)_{r_c}} = -\frac{\omega_n(n+1)\text{Vol}(S^n)x^{2n-1}\left(1 + x^{n+2}\right)}{H(x)} \cdot r_c\left\{x^{n+1}\left[\bar{D}(x) - 2D(x)\right]\left(1 + x^{n+2}\right) + D'(x)x\left(1 - x^{n+1}\right)\left(1 + x^{n+2}\right) - D(x)\left[(n-1) - 2nx^{n+1} + (2n+1)x^{n+2} - (3n+2)x^{2n+3}\right]\right\}.$$

$$\kappa_{T_{\text{eff}}} = -\frac{1}{V}\left(\frac{\partial V}{\partial P_{\text{eff}}}\right)_{T_{\text{eff}}} = \frac{1}{V}\frac{(\partial V/\partial r_c)_x(\partial T_{\text{eff}}/\partial x)_{r_c} - (\partial V/\partial x)_{r_c}(\partial T_{\text{eff}}/\partial r_c)_x}{(\partial P_{\text{eff}}/\partial x)_{r_c}(\partial T_{\text{eff}}/\partial r_c)_x - (\partial P_{\text{eff}}/\partial r_c)_x(\partial T_{\text{eff}}/\partial x)_{r_c}} = \frac{r_c^2\omega_n(n+1)\text{Vol}(S^n)\left(1 - x^{n+1}\right)x^{n-1}\left(1 + x^{n+2}\right)}{H(x)} \times \left\{\left(1 - x^{n+1}\right)\left[x\left(1 + x^{n+2}\right)B'(x) - B(x) \times \left[2n - 1 + (3n+1)x^{2n+2}\right]\right] - x^{n+1}\left(1 + x^{n+2}\right)\bar{B}(x)\right\}. \tag{13}$$

Numerical solutions for the isobaric heat capacity $C_{P_{\text{eff}}}$ and coefficients of isobaric volume expansion α and isothermal compressibility $\kappa_{T_{\text{eff}}}$ with the position ratio of the black hole horizon to the universe horizon x have been given in Figures 1–3, respectively. From the figures, it is clear that the values of $C_{P_{\text{eff}}}$, α, and $\kappa_{T_{\text{eff}}}$ have sudden change with the charge of the space-time is a constant, which is similar to the van der Waals system. Moreover, as the dimension of the space increases, the value of x to denote the sudden change also increases. This indicates that the point of the phase transition is closely related to the dimensions of the space-time.

From Table 1, it is clear that the phase transition point is different with different dimensions. Moreover, as the dimension increases, the critical value of the phase transition point and the effective pressure and temperature are all increased.

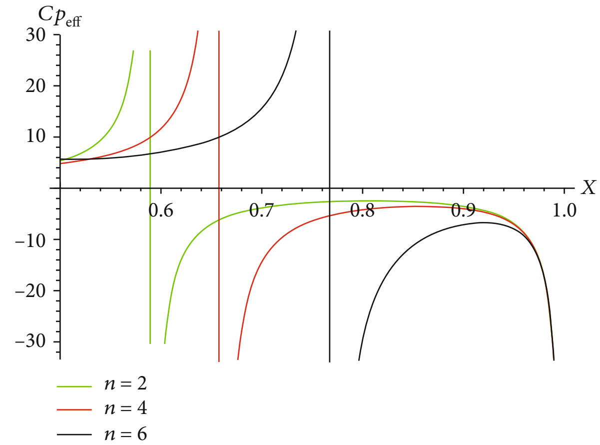

Figure 1: (color online). $C_{P_{\text{eff}}} - x$ diagram for $Q = 0.01$, $r_c = 1$, and $n = 2; 4; 6$, respectively.

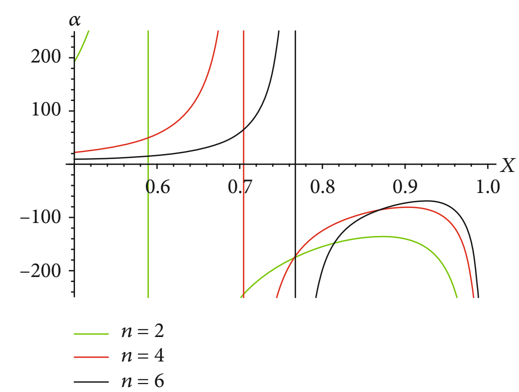

Figure 2: (color online). $\alpha - x$ diagram for $Q = 0.01$, $r_c = 1$, and $n = 2; 4; 6$, respectively.

3. Entropy Force

The entropy force of a thermodynamic system can be expressed as [30–32, 40–43]

$$F = -T\frac{\partial S}{\partial r}, \tag{14}$$

where T is the temperature and γ is the radius.

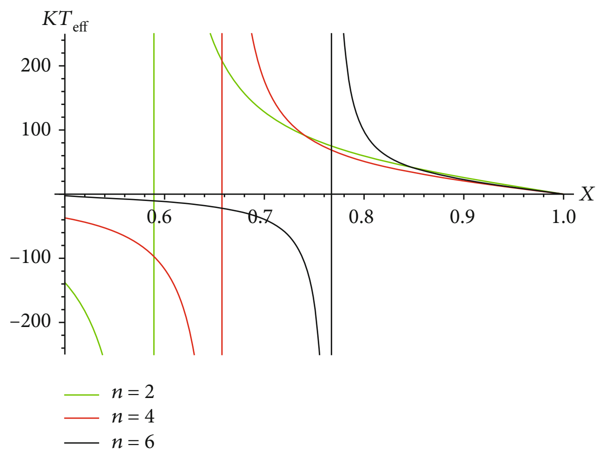

Figure 3: (color online). $\kappa_{T_{\text{eff}}} - x$ diagram for $Q = 0.01$, $r_c = 1$, and $n = 2\,;4\,;6$, respectively.

From Eq. (3), the entropy caused by the interaction between horizons of black holes and the universe is

$$S_{\text{AB}} = \frac{\text{Vol}(S^n)}{4G} r_c^n f_n(x). \tag{15}$$

Table 1: Critical values of the effective thermodynamic system for different n.

	$n=2$	$n=4$	$n=6$
x_c	0.5894	0.7053	0.7674
T^c_{eff}	0.0301	0.1127	0.2095
P^c_{eff}	0.0238	0.0952	0.1825

From Figure 4, it shows that as the dimension increases, the intersectional point of the curve and the x–axis is moving to the right. In other words, the value of x_0 increases with the dimension, which denotes the point where the entropy caused by the interaction between horizons of black holes and the universe changes between positive and negative values. The entropy given in Eq. (4) does not contain explicit electric charge Q dependent Q terms.

From Eq. (14), the entropy force of the two interactive horizons can be given as

$$F = -T_{\text{eff}} \left(\frac{\partial S_{\text{AB}}}{\partial r}\right)_{T_{\text{eff}}}, \tag{16}$$

where T_{eff} is the effective temperature of the considering case and $r = r_c - r_+ = r_c(1-x)$.Then, it gives

$$\begin{aligned} F(x) &= -T_{\text{eff}} \frac{\left(\partial S_f/\partial r_c\right)_x \left(\partial T_{\text{eff}}/\partial x\right)_{r_c} - \left(\partial S_f/\partial x\right)_{r_c} \left(\partial T_{\text{eff}}/\partial r_c\right)_x}{(1-x)\left(\partial T_{\text{eff}}/\partial x\right)_{r_c} + r_c\left(\partial T_{\text{eff}}/\partial r_c\right)_x} \\ &= \frac{-B(x) r_c^{n-2}}{4Gx^{2n-1}\omega_n\left(1+x^{n+2}\right)} \\ &\quad \times \frac{n f_n(x)\left[x\left(1+x^{n+2}\right)B'(x) - B(x)\left[2n-1+(3n+1)x^{2n+2}\right]\right] + x\left(1+x^{n+2}\right)\bar{B}(x) f_n'(x)}{(1-x)\left[x\left(1+x^{n+2}\right)B'(x) - B(x)\left[2n-1+(3n+1)x^{2n+2}\right]\right] + x^2\bar{B}(x)\left(1+x^{n+2}\right)}. \end{aligned} \tag{17}$$

Figure 5 shows that the entropy force increases with the dimension. Moreover, when $n = 2$ and $x = x_0 = 0.9009$, $n = 4$ and $x = x_0 = 0.9035$, and $n = 6$ and $x = x_0 = 0.9224$, $F(x_0) = 0$, respectively. It indicates that the value of x_0 increases with the dimension, which denotes the point where the direction of the entropy force changes.

Figure 6 shows that when $Q = 0.001$ and $x = x_0 = 0.9014$, $Q = 0.01$ and $x = x_0 = 0.9009$, and $Q = 0.1$ and $x = x_0 = 0.8120$, $F(x_0) = 0$, respectively. It implies that as the electric charge increases, the value of x_0 decreases, which denotes the point where the entropy force changes between positive and negative values.

From Figure 5, we can obtain that when $x \longrightarrow 1$, $F(x \longrightarrow 1) \longrightarrow \infty$, and then according to Eq. (6), $T_{\text{eff}} \longrightarrow 0$. This result indicates that the interaction between horizons of black holes and the universe tends to infinity, which contrasts to the third law of thermodynamics. In order to protect the laws of thermodynamics, the black hole horizon and the cosmological horizon cannot coincide with each other. Based on this fact, we take $1 - \Delta x$ as the maximum value of x, where Δx is a minor dimensionless quantity. The value of Δx can be determined by the speed of the cosmic accelerated expansion at the position x.

According to the expression of the entropy force, when $x_0 < x < 1 - \Delta x$, $F(x) > 0$, which indicates that the interaction between horizons of black holes and the universe is repulsive. Consequently, the expansion of the cosmological horizon can be accelerated by the entropy force in the absence of other forces. In Figure 5, it is known that the entropy force is different at different positions. Thus, the expansion of the universe is variable acceleration in the interval of $x_0 < x < 1 - \Delta x$. While when $0 < x < x_0$, $F(x) < 0$, which indicates that the interaction between horizons of black holes and the universe is attractive, and then the expansion of the universe is a variable deceleration in this interval.

From Figure 5, we find that when the area enclosed by the curve $F(x) - x$ and the x − axis with the interval of $x_0 < x < 1 - \Delta x$ is larger than the area enclosed by the same

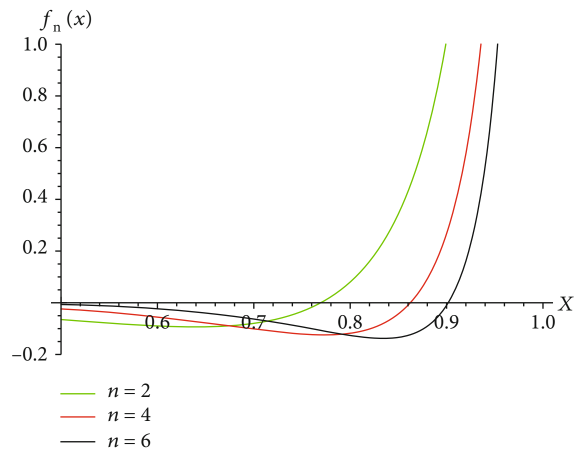

FIGURE 4: (color online). $f_n(x) - x$ diagram for $(Vol(S^n)/4G) = 1$, $r_c^n = 1$, and $n = 2\,;4\,;6$, respectively.

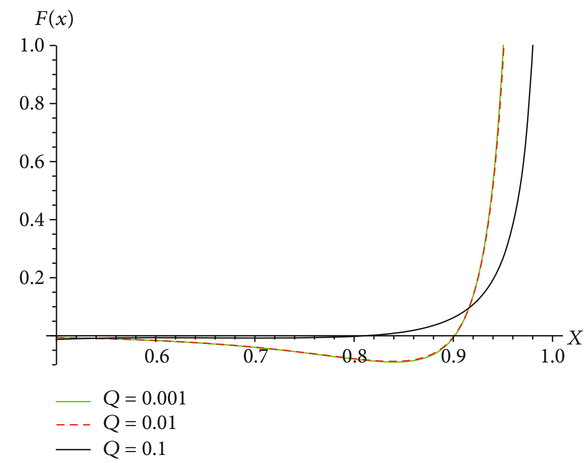

FIGURE 6: (color online). $F(x) - x$ diagram for $n = 2$, $r_c = 1$, and $Q = 0.001\,;0.01\,;0.1$, respectively.

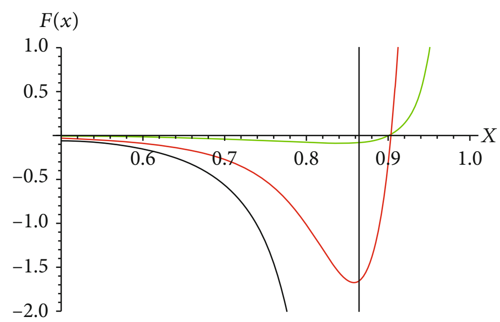

FIGURE 5: (color online). $F(x) - x$ diagram for $Q = 0.01$, $r_c = 1$, and $n = 2\,;4\,;6$, respectively.

curve and the $x-$axis with the interval of $0 < x < x_0$, the cosmic expansion is from acceleration to deceleration. It gives an expanding universe. While when the former area is less than or equal to the latter one, the cosmic expansion is from acceleration to deceleration. Moreover, when these two areas are equal at the position ratio x, which belongs to the interval of $\bar{x} < x < x_0$, the universe is accelerated shrinkage from the position ratio $\bar{x}$ to the position ratio x_0, where $\bar{x}$ is determined when the area between the curve and the x-axis with the interval of $[\bar{x}, 1 - \Delta x]$ is zero. After the universe shrink to the position ratio $x = 1 - \Delta x$, the evolution of the universe begins the next cycle. It gives an oscillating universe.

4. Conclusions

When horizons of black holes and the universe are irrelevant, thermodynamic systems of them are independent. Since the radiational temperature on them is different, the requirement of thermodynamic equilibrium stability cannot be met. Therefore, the space is unstable. While when they are related, the effective temperature T_{eff} and pressure P_{eff} for DRNdS space can be obtained from Eqs. (6) and (8). According to curves $C_{P_{\text{eff}}} - x$, $\alpha - x$, and $\kappa_{T_{\text{eff}}} - x$, when $x = x_c$, the phase transition of DRNdS space-time occurs. Since its entropy and volume are continuous, the phase transition is the second-order one according to Ehrenfest's classification. It is similar to the case that occurred in AdS black holes [19–24, 44, 45]. From Eq. (10), we find that the isochoric heat capacity C_v of DRNdS space is nontrivial, which is similar to the system of van der Waals, but different from AdS black holes. In the second 2, the effect of the dimension on the phase transition point is analyzed, which lays the foundation for the further study of the thermodynamic characteristics of the high-dimensional complex dS space.

From Figure 5, we find that when the area enclosed by the curve $F(x) - x$ and the $x-$axis with the interval of $x_0 < x < 1 - \Delta x$ is larger than the area enclosed by the same curve and the $x-$axis with the interval of $0 < x < x_0$, the cosmic expansion is from acceleration to deceleration. It gives an expanding universe. While when the former area is less than or equal to the latter one, the cosmic expansion is from acceleration to deceleration. Moreover, when these two areas are equal at the position ratio x, which belongs to the interval of $\bar{x} < x < x_0$, the universe is accelerated shrinkage from the position ratio $\bar{x}$ to the position ratio x_0, where $\bar{x}$ is determined when the area between the curve and the $x-$axis with the interval of $\bar{x}, 1 - \Delta x$ is zero. After the universe shrink to the position ratio $x = 1 - \Delta x$, the evolution of the universe begins the next cycle. It gives an oscillating universe.

Whether the universe is an expanding one or an oscillating one is determined by the value of the minor dimensionless quantity. From Figures 5 and 6, we find that the position, where the entropy force changes between positive and negative values, is greatly affected by the dimension, but commonly by the electric charge. Therefore, the effect of the dimension on the cosmic expansion is greater than the electric charge. Moreover, since the curve $F(x) - x$ is continuous at the phase transition point x_c, the entropy force can not be affected by the phase transition in the space with a given dimension and electric charge. The amplitude and the value of the entropy force are only determined by the position ratio x. According to our research result, the entropy force between horizons of black holes and the universe can be taken as one of the reasons for the cosmic expansion, which provides a new approach for people to explore the physical mechanism of the cosmic expansion.

Data Availability

In this work, results are numerical solutions obtained from the theoretical aspect without taking any data. Therefore, no data is used in our manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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