# BLACK HOLE CHEMISTRY

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The concept of black holes began in 1783 with the Royal Society's publication of a letter by geologist John Michell written to Henry Cavendish [1]. Michell arrived with this concept when thinking about a theoretical way to calculate a star's mass. Michell agreed with Newton's notion that light is composed of tiny material particles. He argued that similar to projectiles thrown upward from the Earth, such particles bursting from a star's surface would have their speed decreased by the star's gravitational attraction. He believed it could be possible to determine a star's mass by monitoring the decrease in the speed of light from that star [2]. Michell wondered how much of an impact this may have. He was aware that for a projectile to escape from the gravitational pull of a star, it must move faster than a particular threshold speed. The star's size and mass essentially determine this "escape velocity". He asked himself: ''What would happen if the gravitational pull of a star was so great that its escape velocity was greater than the speed of light?''. Then, Michell understood that the light had to come back to the surface. Ole Roemer had discovered the estimated speed of light a century earlier, thus he knew it.

Therefore, considering an identical average density, Michell could easily determine that for a star larger than 500 times the size of the Sun, the escape velocity would be more than the speed of light. Since light cannot leave such a body, it would be undetectable to the outer world. This was Michell's concept of a "dark star," later referred to as ''black hole'' [2].

Michell was incorrect on one issue, even though he still provided the correct response. Despite the local intensity of gravity, light travels through space at a constant speed, as it is now understood thanks to Einstein's theory of relativity from 1905. Therefore, Michell's suggestion to determine a star's mass by determining the speed of light would not have been successful. However, he was right when he said that if an object's escape velocity is greater than the speed of light, it must be invisible. This idea was far in advance of current understanding of science; therefore, it didn't have a significant impact [2].

Following the publication of Einstein's theory of general relativity in 1916, the concept of black holes was rediscovered.
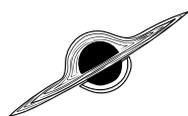
The equations developed by Einstein were later solved by Karl Schwarzschild for the situation of a black hole, which he conceptualized as a spherical volume of twisted space encircling an intense mass and as entirely imperceptible to the outside world. Then, research by Robert Oppenheimer and others generated the hypothesis that collapse of a large star could create such an entity. Physicist John Wheeler first used the phrase "black hole" in 1968 after finding more specifics about the characteristics of black holes [2]. Then, black holes predicted by gravitational physics contradict the principles of thermodynamics as they would need to be at absolute zero temperature because of their strong gravitational attraction preventing them from emitting anything. Hypothetically, the whole system would seem to contain less entropy if a hot object was captured by a dark star that is considered to have no temperature. The Second Law of Thermodynamics stating heat moves from hotter to cooler areas in any spontaneous process and that overall entropy of the system must rise, could be disrupted in this instance [3].

In 1972, Jakob Bekenstein identified the contradiction of the Second Law of Thermodynamics by understanding the dimensions of a black hole's event horizon, which is a limit in astrophysics beyond which no observer from the outside is able to impact by an event [4], must ultimately be related to its thermodynamic entropy [5]. A year later, Stephen Hawking introduced the concept of a black hole's temperature, and black hole thermodynamics emerged as a separate field in physics very soon [6].

Initially, Jacob Bekenstein introduced the mathematical connection between black holes and thermodynamics in 1973 when he proposed the idea of black hole entropy.

Bekenstein argued that black holes must have entropy proportional to the area of the event horizon [7], and this theory claimed that black holes appear as thermodynamic systems in addition to gravitational bodies. Stephen Hawking showed that black holes emit thermal radiation, which is known as Hawking radiation, at a temperature called the Hawking temperature according to the quantum field theory [8]. Thus, these findings demonstrated that black holes can be described using the principles of classical thermodynamics.

The concept of thermodynamic pressure was neglected for a while, making black hole thermodynamics completely distinct from any thermodynamics typically used in laboratory settings. Later, the concept of vacuum pressure emerged as vacuum energy, expressed through a cosmological constant, about 40 years after black hole thermodynamics first appeared. Additional studies revealed that black holes perform similar to thermodynamic systems analysed by chemists. Subsequently, black hole thermodynamics evolved into what's known as Black Hole Chemistry over the next fifteen years thanks to the extensive research [9,10].

The classical principle of thermodynamics is connected to the physical features of black holes. It can be shown that black holes are statistically and theoretically similar to thermodynamic systems:

The Zeroth Law of Thermodynamics, which concerns thermal equilibrium, is related to black hole mechanics in how a uniform temperature beyond the event horizon is determined by constant surface gravity [11].

The First Law of Thermodynamics, emphasizing energy conservation, is related with how variations in temperature, entropy, electric charge, and angular momentum interact within black hole mechanics.

The Second Law of Thermodynamics, which concerns entropy increase, is related to how entropy grows as the area of the event horizon expands over time [7]. The Third Law of Thermodynamics, which states the impossibility of reaching absolute zero, is related to the event horizon remaining unchanged as the temperature approaches zero, which indicates the difficulty of achieving absolute zero [12]. Thus, these interactions suggest that thermodynamic factors, including energy, temperature, and entropy, can be used to describe black holes.

According to the four principles of black hole dynamics, the field of the event horizon needs to be identified with entropy and the surface gravitational field of a black hole with temperature, ideally related by proportionality constants. If black holes are regarded as completely gravitational objects, they have zero temperature and zero entropy according to the no-hair theorem [8]. Therefore, the fundamentals of black hole mechanics remain unchanged. However, it is discovered that black holes release thermal radiation which is known as Hawking emission at a temperature derived from quantum-mechanical considerations:

$$T_H = \frac{\hbar c^3}{8\pi G k_B M}(1)$$

Where, $\hbar$ is Planck constant, c is speed of light, G is Newton constant, k_B is Boltzman constant, and M is the mass of a non-rotating black hole. The equation (2) establishes the proportionality constant of the Bekenstein– Hawking entropy from the first law of black hole thermodynamics:

$$S = \frac{1}{4}\frac{k_B c^3}{G\hbar}A\,(2)$$

Where A is the area of the event horizon and ¼ arises from combining quantum mechanics, general relativity, and thermodynamics. Neither p,ressure nor volume was included in classical black hole thermodynamics; however, this gap was addressed through research in Anti-de Sitter (AdS) space. The cosmic constant can be considered a negative pressure in AdS space as:

$$P = -\frac{\Lambda}{8\pi}(3)$$

Where, Λ is the cosmological constant from Einstein's field equations. Consequently, the volume of a thermodynamic black hole is described as:

$$V = \left(\frac{\partial M}{\partial P}\right)_{S,Q,J}(4)$$

The equations (3) and (4) make it possible to explore black holes utilizing P-V diagrams in a manner identical to that of classical gases [13] and this method is the basis of Black Hole Chemistry as well as one of the initial steps into examining black holes as chemical systems.

Consequently, "black stars" and "black holes" are different terms and black holes perform as thermodynamic systems in addition to being mysterious cosmic objects. Today, scientists recognize that black holes possess temperature and entropy, similar to thermodynamic systems, based on Bekenstein's and Hawking's studies. Moreover, subsequent research has also revealed that black holes can exhibit pressure, volume, and even phase changes, which are identical to phase transitions in fluids. Then, Black Hole Chemistry has emerged as a distinct field as a result of these studies.

This area of study helps scientists establish connections between thermodynamics, gravitation, and quantum physics. This could ultimately lead to a deeper understanding of the cosmos as well as a reference for future studies since research in this field is still ongoing with the aim of expanding the understanding of black hole thermodynamics.

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