

Volume 2, Issue 1

Research Article

Date of Submission: 13 Jan, 2026

Date of Acceptance: 03 Feb, 2026

Date of Publication: 12 Feb, 2026

On the Generation and Annihilation of Energy in the Early Universe

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Citation: Yoon, T. C. (2026). On the Generation and Annihilation of Energy in the Early Universe. *J Theor Exp Appl Phys*, 2(1), 01-06.

Abstract

It is said that the universe began with the Big Bang. As the universe was born from the Big Bang, time began to flow, and energy came into existence. It began to expand at the speed of light, becoming the present-day universe. At the point when the early universe began expanding, the age-old question, "Where did energy come from?" can be answered using the mathematical model of the Planck's law and the Planck units. The universe was born from nothing, as empty space with a Planck length. As time began to flow within this space, an unknown energy particle with the Planck mass, which would later be converted to energy, was simultaneously generated. This unknown particle is called the pep (pre-energy particle). As the early universe expanded, peps were continuously generated, producing peps equal to the mass and energy of the present-day universe. The internal temperature of the early universe reached the Planck temperature, 1.41678×10^{32} K. Now, this space became so hot that the early universe, unable to withstand the Planck temperature, experienced an event called the Big Bang, which began expanding at the speed of light. The Big Bang refers to a phase change where the pep is converted into energy. The Planck temperature is hot spot where energy is generated and annihilated. The generation and annihilation of energy demonstrates that time, energy, and temperature are interrelated. The idea that energy is generated and annihilated does not violate the law of conservation of energy but rather helps us understand the universe.

Introduction

In physics, the law of conservation of energy is one of the most fundamental laws for understanding and explaining nature. It states that the total amount of energy in an isolated system, where there is no external energy exchange, remains constant, neither created nor destroyed, although it can change form or be transferred. The law may not have applied at the birth of the early universe. This is because energy must inevitably be created after the universe has been born from nothing. Until now, it is believed that the Big Bang occurred at the birth of the universe, and while the source of energy is unknown, it was present along with the Big Bang, so the law of conservation of energy naturally applies.

After the universe was born, an unknown substance, which would later become energy, was created over a period. This unknown substance was not generated indefinitely. When the interior of the early universe was filled with this unknown substance and the temperature reached the Planck temperature, the unknown substance ceased to be generated. It underwent a phase change known as the Big Bang, transforming into energy and expanding at the speed of light, creating the present-day universe.

If we could obtain a blueprint documenting the creation and evolution of the universe, we could understand how it was designed, how it has evolved, and how it will evolve in the future. However, since such a blueprint is unavailable, scientists have observed and studied nature to discover and understand the numerous principles and laws that govern the evolution of the universe.

One of these hypotheses is the Big Bang theory. The universe was born from nothing, and immediately after its birth, something full of energy exploded, creating the universe we know today. To test this hypothesis, let's conduct a test.

There's a large room containing the universe. The room contains the universe. Now, let's take the universe out of the room. It's as simple as putting an elephant in a refrigerator. Now, the room is empty, devoid of energy or anything else. There's only vacuum. The size of the space from which the universe was taken out is unknown, but we can assume that the room that contained the universe occupies space like a solid in Euclidean geometry.

There's a stove outside the room. When we light the stove and start heating it, something happens. The room gradually begins to warm up. The temperature changes. This is like Planck's black-body radiation. The change in temperature means energy has been generated, and here, energy is generated because external heat energy is warming the room. Over time, the room becomes filled with energy. Even without any more external energy, the room filled with energy begins to expand due to increased internal pressure. This phenomenon can be considered as the Big Bang. After the Big Bang, the universe, with no force to suppress repulsion, expands at the speed of light.

The early universe was born from nothing. The early universe is a tiny ball with a radius called Planck length ($l_p=1.616255 \times 10^{-35}$ m). The time it takes for the early universe to be born is Planck time ($t_p=5.391247 \times 10^{-44}$ s). The early universe is a ball with a mass called Planck mass ($m_p=2.176434 \times 10^{-8}$ kg) of an unknown energy particle or a material particle. Since the early universe has no device to supply energy from the outside, energy is generated internally. The Planck mass generated inside the early universe is an 'unknown matter before it is converted to energy' that is too light to cause the Big Bang. For the early universe to cause the Big Bang, the matter inside the early universe must be 5.99849×10^{-8} kg. This is 2.75 times heavier than the unknown matter with the Planck mass. The internal temperature of the early universe is 1.1×10^{32} K, falling short of the Planck temperature $T_p=1.416784 \times 10^{32}$ K. This unknown matter, containing Planck mass, created at the birth of the early universe before being converted into energy, is called the pep (the pre-energy particle). A likely candidate is the pair production of a particle-antiparticle with Planck mass. When these particles collide, they annihilate and are converted into energy.

Time begins to flow in the early universe as it is born. As time begins to flow, its volume expands at Planck time intervals, and peps increase proportionally to this expansion. The length of the rest period between each Planck time interval is unknown, but assuming there is no rest period, the early universe begins to expand at the speed of light.

A pep is an unknown particle that has an enormous mass within the newly formed early universe but is too small to have caused the Big Bang to become the present-day universe. When the early universe begins to expand, peps accumulate inside the early universe in proportion to the increase in volume. Enough peps accumulate to convert into the total amount of matter and energy that the universe currently contains. Now, if the total mass of peps in the early universe is converted into temperature, it reaches the Planck temperature, which eventually causes the Big Bang. The Big Bang is a phase change. At the time, all peps are converted into energy. At the time of the Big Bang, the radius of the universe was 2.688×10^{-15} m, which is about 1/4 the radius of an atomic nucleus. 8.968×10^{-24} s have passed since the birth of the early universe. During this time, 4.23×10^{60} peps are generated.

Now, all the conditions for the Big Bang are in place. When the Big Bang occurs, all peps are converted into energy, providing the energy for the universe to expand. This force is called the repulsive force and is one of the fundamental forces of the universe. The repulsive force, or internal pressure, is of the same dimension as pressure.

After the Big Bang, in the early universe, no more peps are generated, and the baby universe expands at the speed of light. When the temperature of the universe reaches 1.076×10^{13} K, some of the energy has been converted into imps (invisible material particles, aka dark matter)¹, and releases gravity. At 2.669×10^{10} K, imps combine with two down quarks and one up quark to form neutrons. At the time, the supply of quarks is not endless; only about one-sixth of imps are converted into neutrons. Neutrons are the visible particles of matter that make up the universe and form the fundamental building blocks of the universe. The force that governs neutrons and protons is called quark interaction. Neutrons are material particles with a mean lifetime of 15 minutes, and they do not interact with each other. If neutrons had decayed into protons at such high temperatures where they were born, the newly generated protons would interact with other neutrons to form deuterium nuclei or heavier nuclei. Then, there would be no more protons left in the universe. Fortunately, if neutrons do not decay at such high temperatures, but rather below ~ 107 K, then quark interactions between protons and neutrons would not interact, which explains the high proton fraction observed in the universe today.

While neutrons convert to protons, quark interactions generate an electromagnetic field within the proton, releasing electromagnetic forces. Under certain conditions, quark interactions can remove the electromagnetic field from protons, causing them to revert to neutrons.

Now, let's rewind the timeline of the present universe.

All matters in the universe convert to energy at 1.076×10^{13} K.² This is the temperature at which visible matter disappears. Energy has a wavelength, so as temperature increases, the wavelength shortens. If the temperature increases indefinitely, the wavelength should become indefinitely shorter. However, as the wavelength shortens, the energy contained within the wavelength also becomes relatively heavier, so the wavelength cannot become indefinitely shorter. At a certain temperature, the energy contained within the wavelength begins to escape. This temperature is the Planck temperature, 1.416784×10^{32} K. This temperature is the temperature at which energy is converted into a pep and at the same time, the temperature at which energy is annihilated. The time it takes for each pep to disappear is the Planck time. However, this assumption will not actually occur, as there is no force opposing the repulsive force that drives the expansion of the universe.

Therefore, the universe is expected to expand forever and to face thermal death.

Planck's Law as a Model for the Early Universe

Scientists have rewound time to explain where the early universe came from. They have concluded that the universe was created from nothing, and that the Big Bang, an event that signaled its beginning, occurred.

Therefore, at the time of the Big Bang, the universe must have had energy to expand at the speed of light. Although the early universe was born from nothing, the law of conservation of energy states that energy is neither generated nor annihilated. This leads us to conclude that energy already existed within the early universe when it was born. However, since the universe originated from nothing, energy must also have been generated from nothing. The idea of generation and annihilation of energy is a natural concept.

The units applicable to the creation of the early universe are known as the Planck scale, including Planck length, Planck mass, Planck time, and Planck temperature. These units are based on the universal gravitational constant G. Energy does not interact with gravity, but only pressure. However, like matter with mass, energy can be converted to mass according to the energy-mass equivalence principle. Peps, the matter generated in the early universe, may not be particles that have energy convertible into mass, but rather particles that have real mass and gravity.

The early universe was born from nothing as a sphere with a Planck length. This space was empty, but over Planck time, an unknown substance called pep (pre-energy particle) was generated before it was converted into energy called Planck mass. Since a single pep contains insufficient energy to trigger the Big Bang, the early universe continued to expand, generating peps. When the internal temperature of the early universe soars to the Planck temperature, the internal pressure between pep particles increased, triggering a repulsive force, resulting in the Big Bang. After the Big Bang, all peps were converted into energy and the universe expanded at the speed of light.

After the early universe was born from nothing as an empty space with a Planck length, within Planck time, energy called Planck mass was created, and when the temperature reached the Planck temperature, the repulsive force within the early universe was governed by the following relationship from Planck's law:

$$R = \frac{U}{V} = \int_0^{\infty} U(\nu, T) d\nu = \omega T^4, \quad (1)$$

where R, sometimes it is called the radiation energy density, is the repulsive force, U is the total energy of the universe, V is the volume of the universe, T is the temperature of the universe in Kelvin, and ω is the Planck's radiation energy density constant of the universe.³ The radiation energy density constant ω is

$$\omega = \frac{8\pi^5 k^4}{15c^3 h^3} = 7.56573 \times 10^{-16} \text{Jm}^{-3} \text{K}^{-4}. \quad (2)$$

And the Planck's Law $U(\nu, T)$ is given as

$$U(\nu, T) = \frac{8\pi h \nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{kT}} - 1}, \quad (3)$$

where ν is the frequency, h is the Planck constant, κ is the Boltzmann constant, and c is the speed of light in vacuum.

R is a repulsive force, and it is related to the pressure p as follows:

$$R = \frac{E}{V} = \frac{\int dE}{\int dV} = \frac{\int 2Fdr}{\int A dr} = \frac{2F \cdot \text{distance}}{A \cdot \text{distance}} = \frac{2F}{A} = p, \quad (4)$$

where F is the force, A is the surface area, and p is the pressure. Here, the new definition $E=mv^2$ is used instead of the classical definition $E = \frac{1}{2}mv^2$. Therefore, instead of $p = F/A$, we newly define $p = 2F/A$. A is also defined as surface area, not area.

Ideal Gas Law

Energy is the phenomenon of energetic particles vibrating with wavelength. This is called a photon, and photon gas is described by physical quantities that conform to the ideal gas law.

The ideal gas law states that the product of pressure p and volume V is proportional to the product of substance n and absolute temperature T:

$$pV = nRT, \quad (5)$$

where R is the molar gas constant.

$E=pV$ from (4) and by using the Boltzmann constant $k=R/N_A$ (N_A being the Avogadro constant), we get

$$E = NkT, \quad (6)$$

where N is the number of molecules of gases. In classical physics, the energy associated with gases, $E = \frac{3}{2}nRT$,⁵ has

been changed to $E=nRT$ because the area acting on the pressure must be the surface area, as in (4).

The Planck-Einstein relation, or simply the Planck relation, is given as

$$E = hv. \quad (7)$$

Combining both (6) and (7), we have

$$hv = kT. \quad (8)$$

This equation indicates that the energy per ideal gas particle is proportional to the temperature. This can also be inferred from equation (3).

From (8),

$$T = \frac{hv}{k} = \frac{E}{k}. \quad (9)$$

Since the mass of an imp is estimated to have mass of $927.7 \text{ MeV}/c^2$, the temperature at which an imp is converted to energy is given as:

$$T = \frac{927.7 \times 10^6 * 1.602176634 \times 10^{-19} \text{ J}}{1.3806504 \times 10^{-23} \text{ J/K}} = 1.07655 \times 10^{13} \text{ K}.$$

Einstein Field Equations and Cosmic Energy

The total energy of the universe can be calculated from Einstein's field equations as follows:

$$R_{ik} - \frac{1}{2}g_{ik}R = \kappa T_{ik}. \quad (10)$$

Since the energy tensor on the right represents an equation that includes density (M/V), various solutions can be derived by linking it to the equation on the left.

In case $\kappa T^r_r = 4\pi G\sqrt{g^{\theta\theta}}$, we get

$$v^2 = \frac{2GM}{R}, \quad (11)$$

where G is the gravitational constant, M represents the mass of a celestial body, R represents the radius of the celestial body, and v represents the escape velocity of the celestial body.

In case $\kappa T^r_r = 3H^2$, we have

$$H^2R^2 = v^2, \quad \text{or}, \quad HR = v, \quad (12)$$

here, HR represents the escape velocity, and H represents the reciprocal of time, which represents the Hubble's parameter.

If the current radius of the universe is $R = 1.36718 \times 10^{26} \text{ m}$, then

$$\text{Hubble time } \frac{1}{H} = \frac{R}{c} = \frac{1.36718 \times 10^{26} \text{ m}}{2.99792458 \times 10^8 \text{ m/s}} = 4.56042 \times 10^{17} \text{ s}.$$

In case $\kappa T^r_r = 3Q$, and $v=c$, then we get by using the equation (1),

$$QR^2 = c^2, \quad Q \Rightarrow c^2 = \frac{\omega T^4 V}{3M}, \quad \text{or}, \quad U = \omega T^4 V = 3Mc^2. \quad (13)$$

Here, M is the rest mass of the matter-dominated universe, and U is a value calculated by converting the total energy of the entire universe into mass. The value closely matches the observed data, which shows that the universe is composed of 68% energy and 32% matter.

Temperature and Interactions

As the universe expands with the Big Bang, its temperature drops steadily. Starting at the Planck temperature of $1.41678 \times 10^{32} \text{ K}$, as the universe cools to $1.07655 \times 10^{13} \text{ K}$, some of the energy is converted into matter. This matter is invisible and is called imp (invisible material particle, aka dark matter). Along withimps, quarks are also generated. With the generation of an imp, gravity, a type of attractive force, is released, dominating the material world. When the temperature reaches $2.669 \times 10^{10} \text{ K}$,imps and quarks combine to generate visible particles called neutrons. The force that governs this phenomenon is called quark interaction. It is known that neutrons have half-life and are converted into protons through quark interaction.

Neutrons do not interact with each other. After a neutron with half-life decays into a proton, the proton interacts with other neutrons through quark interactions. If a neutron decays into a proton at the high temperature at which neutron was generated, the newly generated proton immediately combines with another neutron to form a deuterium nucleus. Consequently, no hydrogen atoms, the building blocks of the present-day universe, will remain. If the temperature of a neutron drops below $\sim 10^7 \text{ K}$, then the neutron undergoes beta decay through quark interactions, becoming a proton. At that time, neutrons and protons no longer interact with each other, and all free neutrons continue to decay into protons. This is why the universe we observe today is composed almost entirely of hydrogen atoms.

The force that influences the negative beta decay of a neutron into a proton and the positive beta decay of a proton into a neutron is called quark interaction. The quark interaction not only contributes to the generation of heavy elements, also generates an electromagnetic field within protons during the process of neutrons being converted to protons, releasing electromagnetic forces. This generates a world where electromagnetic forces, along with gravity, dominate.

Even when the temperature continues to drop to absolute zero, energy is not annihilated; instead, a form of zero-point energy remains. This is called thermal death.

If some forces were to emerge that could halt the expansion of the universe, or even cause it to contract, the universe would heat up again. This would be a reversal of the process, but the path back would not be the same as the present-day universe that came from the big bang.

The temperature at which neutrons convert to protons is estimated to be around 10^7 K. However, in the current universe, when this temperature is reached, protons undergo plus-beta decay, not converting to neutrons, but instead undergo proton-proton nuclear fusion. As the temperature continues to rise, protons convert to neutrons, creating heavy elements. As the temperature continues to rise, at $10^{11} \sim 10^{12}$ K, all protons in those heavy elements convert to neutrons, and the electromagnetic field also annihilates. This phenomenon is believed to be observed in neutron stars. At 1.172×10^{12} K, all neutrons dissociate into imps and charm quarks. At 1.076×10^{13} K, imps annihilate returning to energy. Gravity also annihilates. Energy continues to compress until it reaches the Planck temperature, where all energy disappears and returns to nothing. This is called the Big Crunch, and it is thought to be highly unlikely to occur eventually.

From this, we know that there are two hot spots or melting points. One is 1.416784×10^{32} K, the temperature at which energy is generated and annihilated. The other is 1.076×10^{13} K, the temperature at which particles called matter are generated and annihilated.

Furthermore, we can see that as temperature changes, the fundamental forces of the universe, known as fields, also appear and disappear. Repulsive force, an internal pressure, appears when energy is generated and governs the generation and annihilation of energy. Repulsive force is expressed as temperature, so when pressure, a force like repulsive force, is applied, temperature increases. Gravity, an attractive force, appears when matter is generated and governs the generation and annihilation of matter. Quark interaction is a force that appears in the process of generating a neutron when an imp combines with two down quarks and one up quark, and it is a force that converts a neutron into a proton or a proton into a neutron. It is an interaction that is involved in the generation of all heavy elements, conversion into stable elements, and annihilation of neutrons. It is also an interaction that generates an electromagnetic field inside a proton in the process of converting a neutron into a proton and annihilates the electromagnetic field in the process of converting a proton into a neutron. The electromagnetic force appears in the process of converting a neutron into a proton due to the action of quark interaction and is an interaction that is annihilated in the process of converting a proton into a neutron.

Acknowledgement

The author would like to express the sincerest gratitude to the Journal of Theoretical, Experimental, and Applied Physics and their staff for kindness and consideration in allowing this paper to be posted free of charge on the journal [1-13].

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3. The Planck era.
4. Boltzmann constant.
5. Planck's Law.
6. Ideal gas law.
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12. Pair product.
13. Hubble's law.

Foot Notes:

¹Imp is named for "the invisible material particle", and is a particle known as dark matter. Refer to "Phase changes and interactions of energy and matter in the universe viewed through temperature change".

²Imp deems estimated to have a mass of $927.7 \text{ MeV}/c^2$.

³Which appears in Planck's paper "Ueber das Gesetz der Energieverteilung in Normal spectrum", but is not used often because it is overshadowed by the Stefan-Boltzmann constant. Their relation is $\omega = 4/c \sigma$.

⁴Refer to "On the coupling constant $3/2$ of traditional kinetic theory of gases $PV = E = 3/2 k_B T$ ".