
AI translation · View original & related papers at
chinaxiv.org/items/chinaxiv-202312.00162

Can the Mass-Energy Equation be Realized in Rotating Black Holes at Galactic Centers? Post-print

Authors: Ge Bao'an¹, Bu Defu²

Date: 2023-12-13T00:00:00+00:00

Abstract

The mass-energy equation derived by Einstein is discussed. This equation implies a possible interconversion between energy and mass. While the conversion from mass to energy through nuclear reactions is well established, the possibility of energy being converted into matter under certain conditions is explored. This investigation includes an introduction to relevant experiments in particle physics, with particular emphasis on models for the origin of jet material in a class of astrophysical black holes, which may provide important examples of energy-to-matter conversion.

Full Text

Progress in Astronomy, Vol. 41, No. 3, September 2023

doi: 10.3969/j.issn.1000-8349.2023.03.11

Can the Mass-Energy Equation be Realized in Rotating Black Holes at Galactic Centers?

GE Bao-an¹, BU De-fu²

(1. Tianjin Association for Science and Technology, Tianjin 300041, China;
2. Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China)

Abstract

This paper discusses the mass-energy relationship derived by Einstein. The equation suggests the possibility of mutual conversion between energy and mass.

While the conversion from mass to energy through nuclear reactions is well established, whether energy can be converted into matter under certain conditions remains an open question. We explore this issue by reviewing relevant experiments in particle physics and highlight that models for the origin of jet material in astrophysical black holes may provide important examples of energy-to-matter conversion.

Keywords: mass-energy equation; photon; black hole; conservation

Main Text

The year 1905 marked the pinnacle of Albert Einstein’s intellectual eruption, establishing him as the greatest and most influential scientist of the 20th century. In that remarkable year, he authored numerous scientific papers, five of which—including his special theory of relativity—remain familiar to physicists today, with four continuing to exert profound influence on modern physics. At the time, the paper that attracted the most attention from the physics community addressed the photoelectric effect and resolved the “ultraviolet catastrophe”: “On a Heuristic Viewpoint Concerning the Production and Transformation of Light.” In this work, Einstein accepted Planck’s hypothesis of energy quantization from his blackbody radiation formula and proposed the “light quantum” hypothesis, successfully resolving the puzzles that had emerged from photoelectric effect experiments. This paper earned him the 1921 Nobel Prize in Physics and established him as one of the earliest founders of quantum mechanics.

Ironically, his paper on special relativity, “On the Electrodynamics of Moving Bodies,” did not receive comparable recognition from contemporary physicists. Even less attention was paid to the subsequent paper derived from it: “Does the Inertia of a Body Depend Upon Its Energy Content?”—the work introducing the mass-energy equation. Perhaps the physics community’s research interests lay elsewhere at the time. Recently, however, *Physics World* conducted a readers’ poll to select the “greatest equations” in history, and the once-overlooked mass-energy equation ranked fifth among the top ten. Some scholars have even suggested that among the three “essences” Earth’s civilization might leave for others, the concise mass-energy equation would be included.

Einstein described a fundamental principle underlying diverse cosmic phenomena with his most beautiful and elegant formula. Among the principles, axioms, and theorems accumulated over millennia of physics, the mass-energy equation most precisely captures the essence of the myriad phenomena occurring on Earth and in the accessible universe: mass (matter) and energy are equivalent and potentially interchangeable. As a serious scientist, Einstein remained cautious, never explicitly stating that they could be converted into one another. During his era, neither experimental evidence nor conceptual frameworks existed to demonstrate such conversion. After all, physics is an experimentally grounded science, and his original paper presented the formula as $M = E/C^2$ —a form that itself appeared as an exploratory proposition. He merely intended to show

that mass and energy are the same entity, two sides of a single coin. The formula only indicated that matter contains energy, representing an alternative expression of energy, and served as a further corollary to the unification of space and time proposed in his electrodynamics paper: the unification of mass and energy.

The mass-energy equation explains numerous natural phenomena, including the Sun's ability to provide light and heat to Earth stably for billions of years, and it inaugurated humanity's nuclear age. Yet from a fundamental physics perspective, this elegantly simple formula contains implications that physicists still do not fully comprehend. Einstein neither elaborated on its mechanism, proposed experiments to probe its deeper meaning, nor suggested "thought experiments" to verify its implications, as he had done for special relativity.

The equation itself expresses that mass (matter) contains latent energy, while energy concentration constitutes mass (matter). Their relationship is one of equivalence, where neither quantity exists independently—they are interdependent. A certain amount of energy corresponds to a certain amount of mass, and vice versa. Not only is energy conserved, but from the mass-energy relationship, mass is also conserved. Mass cannot be destroyed, nor does energy disappear; they can only transform into each other, differing merely in their units of measurement. They constitute a pair of fundamental forms of the universe with equal significance. However, the equation also suggests that under certain conditions, matter and energy might exchange forms through some mechanism. Radioactivity, nuclear reactions, and thermonuclear reactions have all confirmed that both on Earth and in space, matter can convert to released energy with tremendous power. The reverse transformation, however, has rarely been discussed and remains a non-mainstream topic, though some researchers have explored its experimental possibilities.

The Breit-Wheeler effect, proposed in 1934, envisioned photon-photon collisions directly producing electron-positron pairs. The original experimental design faced immense challenges, requiring a laser composed of gamma-ray photons emitted within a highly concentrated ion beam. At the time—and even currently—such lasers have not been developed. The physicists themselves considered the experiment nearly impossible. They proposed an alternative approach using accelerated heavy ions as a light source rather than photon beams, because highly charged atomic nuclei produce strong electromagnetic fields under extreme acceleration, exhibiting photon-like properties under certain conditions. The theory suggested that when an ion moves through a particle accelerator, it becomes surrounded by a cloud of photons. When two such ions accelerate toward each other at high speed and nearly collide, their photon clouds interact. Some of these photons become highly accelerated, and collisions between high-energy photons produce electron-positron pairs. According to reports in the May 6, 2021 issue of *Optica*, a group of Korean scientists is attempting to study photon-photon interactions producing electron-positron pairs using high-intensity lasers.

Even with this alternative approach, the experiment remained extremely dif-

difficult under contemporary conditions. Nevertheless, the verification strategy these physicists left for future generations demonstrated remarkable scientific pioneering courage. The second law of thermodynamics constrained thinking, reminding physics authorities—including perhaps Einstein himself—that it should be impossible to reconcentrate, compress, and confine dispersed energy, or to convert energy packets (photons) into known forms of matter with mass. Perhaps only within the “singularity” postulated by Big Bang theory could energy transform into matter, as all physical laws would cease to function there. To this day, we lack experimental methods to create or reproduce such singularities, relying only on mathematical deduction and logical inference—a limitation that constitutes one reason the Big Bang theory continues to face criticism. For a long time, the mass-energy equation could only be regarded as a one-way conversion formula. Einstein himself cautiously formulated it as a question: $M = E/C^2$. Yet when physicists discuss the mass-energy equation, whether in classrooms or seminars, they universally express it as $E = mc^2$, and the equation has been broadly accepted in this form.

More than a century has passed since the equation’s derivation. Recently, a group of physicists revisited the Breit-Wheeler effect and, using the “accelerated heavy ion” method, successfully conducted the experiment at Brookhaven National Laboratory in the United States. The results, published in *Physical Review Letters* [1], provide evidence that photons can directly produce matter (electron-positron pairs) in a single step through collisions, demonstrating the possibility of energy-to-matter conversion. Experimental physicists also verified that the photons produced during collisions exhibit characteristics of normal light particles, with affirmative results. This shows that matter and energy are not only equivalent but potentially convertible in both directions. This work opens new avenues for understanding deeper layers of nature, though significant challenges remain. Nevertheless, the first step has been taken. Just as with matter-to-energy conversion, which took decades to achieve, we have yet to discover experimental cases where high-Z elements completely or partially convert to energy, apart from hydrogen isotopes and radioactive materials.

Another question arises: Is it necessary to verify the constant term in the mass-energy equation? This constant may 预示 an inseparable relationship between mass-energy equivalence and the ubiquitous “photon” family throughout the universe. To fully comprehend the mass-energy equation and understand its deeper implications, we must turn our gaze to the vast cosmos, where more profound physical phenomena and cosmic laws may await discovery. The mass-energy equation demonstrates that fundamental physical laws and theorems, including energy conservation and mass conservation, hold true throughout the universe.

Black holes may provide a compelling example. From Einstein’s relativity predicting their existence to recent direct observations, nearly a century has elapsed. Current observations suggest that supermassive black holes may resemble the “singularity” described by Big Bang theory, but black holes are

not points. Their interiors or immediate vicinities likely represent the most promising venues for realizing the bidirectional mass-energy conversion implied by the equation. Accreted matter, including gas and photons (energy packets), is crushed and destroyed within the still-mysterious black hole interior. During transformation into lower-mass elements or pure energy, factors such as extremely strong magnetic fields, ultra-high temperatures, immense pressures, and violent collisions may facilitate the conversion of photons—existing as “energy packets”—into matter. As Breit-Wheeler theory predicts, not only high-energy photons but likely numerous low-energy photons could transform into matter within the specific environment of a black hole interior.

While these interior conditions may prove impossible to replicate in laboratories for the foreseeable future, observing and studying phenomena in the vicinity of black holes can help us understand and infer their internal mechanisms. The Breit-Wheeler theory proposed that colliding lasers composed of gamma-ray photons emitted within highly concentrated ion beams might directly convert photons to matter—an idea that could potentially be realized in laboratories, pending the invention of such lasers. When Breit and Wheeler proposed their theory, they recognized its impossibility under contemporary experimental conditions and therefore provided an alternative scheme. Even this alternative required nearly a century to achieve, demanding exceptional theoretical insight and, crucially, patience—experimentalists devoted nearly a decade of effort to its completion. Such experiments require not only patient researchers but also patient laboratory organizers.

Recent advances in observational capabilities and precision have dramatically enhanced our ability to study the cosmos, complementing experiments that prove difficult on Earth. Observations of supermassive black holes at galactic centers are particularly crucial, as they can deepen our understanding of many fundamental physical laws.

One promising example involves black hole jet phenomena. The origin of matter in jets near black holes has long fascinated researchers. A theoretical model proposed by scholars provides a potential example of energy-to-matter conversion [2]. This theory suggests that in the axial region of a rotating black hole, when a certain net charge exists, steady-state, axisymmetric solutions can make the sum of electric and Lorentz forces on electrons/positrons vanish. When perturbations alter the net charge, the electric field component parallel to magnetic field lines changes, disrupting the force balance. Electrons/positrons then experience a net electric force along magnetic field lines, accelerating them to extreme energies. These ultra-relativistic electrons/positrons collide with low-energy photons in the surrounding environment, producing high-energy gamma rays. These gamma rays subsequently collide with ambient low-energy photons, eventually converting into electron-positron pairs. The newly created particles are similarly accelerated, radiate high-energy photons, and collide with low-energy photons to produce additional pairs. This process requires the black hole’s spin to sustain the magnetic field, with the black hole’s rotational en-

ergy serving as the ultimate source for pair production. This model offers a plausible mechanism for energy-to-matter conversion, and we anticipate that the next-generation Event Horizon Telescope (EHT) international collaboration will provide crucial insights into this important question.

In summary, the physics community still lacks deep understanding of the profound implications of the mass-energy equation. This elegantly simple equation reveals the fundamental simplicity of the cosmos, as concise and graceful as the equation itself. As we gradually clarify its 内涵, we may uncover deeper mysteries of the universe!

The authors thank Dr. Yuan Feng of Shanghai Astronomical Observatory for pointing out the model regarding the origin of matter in jets from rotating black holes discussed in this paper.

References

- [1] Adam J, Adamczyk L, Adams J R, et al. Measurement of e+e- Momentum and Angular Distributions from Linearly Polarized Photon Collisions. *Phys Rev Lett.* 2021, 127: 2302
- [2] Hirotsu K, Okamoto L. *ApJ*, 1998, 497: 563

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv — Machine translation. Verify with original.