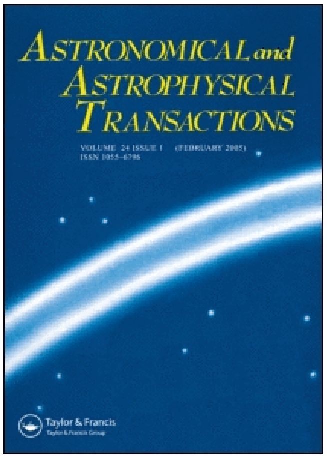

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GEORGE GAMOW'S UNIQUE STYLE

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We discuss some of the rich scientific legacy of George Gamov, an outstanding figure in physics and cosmology of the XXth century,whose talent has bridged the gap between East and West long before the decline of totalitarian system. Our analysis is based partly on Gamow's original scientific and popular papers, partly on the reminiscences of his colleagues and contemporaries (among other, R. A. Alpher, S. M. Ulam, A. A. Penzias, M. Delbruck). We discuss how these different facets of Gamow's rare talent are reflected in his transparent physical models and confront some of his predictions with the realities of contemporary extragalactic and observational cosmology.

For a historian of science George Gamow is a blessed figure. "Godfather" of the hot primordial universe model, one of the leading XXth century physicists and cosmologists who have shaped our modern views on physical nature of the universe and its constituents, a prolific popular writer, the author of nearly fifty popular books, monographs and several hundreds of scientific papers with their topics ranging from pure mathematics, micro- and macro-physics to astronomy, cosmology and even biology, his unusual charismatic character invariably attracted much attention of both professionals and general public through all his scientific career. Today, nearly a quarter of a century since his death in 1968, George Gamow's rich legacy is being constantly reassessed because recent spectacular achievements in space research and observational cosmology have brought about numerous confirmations of his prophetic forecasts.

When, three years after his death, a memorial conference had been convened in his honour, G. Gamow's spirit invisibly hovered by the scientific contributions presented there. Even a cursory glance at the materials collected in the memorial volume (Cosmology, Fusion & Other Matters, 1972) immediately reveals that practically the whole spectrum of the contemporary physical and astrophysical research pertinent to the problems of physical nature of the universe is represented there. In the retrospective it is remarkable to see how the original ideas put forward by G. Gamow have germinated and produced rich fruits 10–20 years after his death. Let us review here just some highlights of the most significant developments. The paramount importance of an isotropy of Cosmic Background Radiation (CMB) has been immediately recognized by both cosmologists and galactic investigators. The attempts to detect small imhomogeneities in the large scale distribution of neutral hydrogen at 21 cm wave been undertaken when G. Gamow was still alive. Soon it became clear that the radiation an extremely distant frame of reference, that of the matter which last scattered it (Partridge & Wilkinson, 1967). Thus an attractive idea originated to find an answer to the questions "Where are we going?" and "Where have we been?" by making very precise measurements of GMB radiation both on large scale and small scale respectively. The net velocity of Earth with respect to this frame should reveal an apparent excess of radiation in the direction of motion due to the Doppler shifts of photons. The idea of a new "cosmic ether" had inspired many at that time to study in great detail the overwhelming influence of the inverse Compton scattering in the early history of the universe (for instance, Sunayev–Zel'dovich effect of anisotropy of radiation scattered by the clusters of galaxies, Sunayev & Zel'dovich, 1980). At the other front, experimental efforts culminated in 1989 in launching the cosmic platform COBE (Cosmic Background Explorer) which measured the CMB temperature with an extremely high precision yielding the value $T = 2.726 \pm 0.01$ K and, as an additional bonus, discovered the quadrupole component in the distribution of CMB (Smoot *et al.*, 1972). Existence of CMB radiation was predicted by G. Gamow already in 1946 (Phys. Review, Vol. 70).

Another cosmic experiment, this time staged by nature itself, an explosion in 1987 of the Supernova in the Large Magellanic Cloud, has brought about a brilliant verification of another prediction made by G. Gamow, according to which a star exploding as a supernova would lose 99 per cent of its energy not in the spectacular optical flash but in a quiet URCA process which is accompanied by huge neutrino flux release (Gamow & Schoenberg, 1941). In fact, detection of the signal from this kind of event on the 23rd of February, 1987 with the neutrino telescope has been claimed by the Japanese team of scientists (Kamiokanda II) (Hirata, Kajita, Koshiba *et al.*, 1987) and later on independently confirmed by an American and a Soviet–Italian groups.

The theory of potential barrier penetration and theory of beta decay developed by G. Gamow jointly with E. Teller serve now in large measure as the foundations of our understanding why various radioactive elements have their characteristic lifetimes. These so-called *aeonglasses* constitute now a part of the flourishing branches of both stellar and galactic evolution as of the early history of the solar system.

The list of topics where G. Gamow's own accomplishments have figured prominently and had a profound impact on subsequent investigations would be far from complete without mentioning the early enigmatic results of Davis's experiments aimed at measuring the solar neutrino flux (Davis *et al.*, 1968) and the thermonuclear reaction theory.

If one tries to grasp the most essential and at the same time the most intriguing in George Gamow's character as a scientist, one tends to agree with Stanislav M. Ulam, a mathematician and a close associate of G. Gamow, who asserts that 'his overwhelming curiousity was directed towards the large lines of the theories which attempt to make us understand the *scheme* of things in the universe – the foundations of physics, the very set-up of the dimensions, and physical variables and the constants from which theoretical physics is built – the stage on which all phenomena take place, that is the nature of space and time the very small and in the universe at large' (Gamow and Mathematics, 1972, p. 272–273). This view is echoed by many others. Thus, according to R. A. Alpher and R. Herman (Reflections on Big Bang Cosmology, p. 11), in his paper "Any Physics Tomorrow" Gamow suggested that "the main job of theory was to express new empirical constants through existing constants of nature, namely, the velocity of light, Planck's constant, and a fundamental length for microphysics; Boltzman's constant in a special category; and the gravitational constant for macrophysics".

In the last chapter of his famous "collective portrait" of the 20th century's most outstanding physicists entitled "Thirty Years that Shook Physics" G. Gamow (1964) tries to catch a glimpse of future physics. Starting with a bitter and reproachful remark that "we are now dragging through the lean and infertile years in theoretical physics and looking for better luck in the years to come" and stating that "we have no crystal ball for predicting the future development" he again grasps at the straw of cosmonumerology and dimensionless analysis. He selects the velocity of light in vacuum and Planck's constant as the fundamental constants of nature and suggests that the third august quantity should be the classical electron radius. According to his view, every physical quantity can be expressed through these three ones. Even his popular book "Mr Tompkins in Wonderland" (1960) whose the little clerk of a big city bank, is transferred in his dreams into the imaginary worlds governed by quantum theory and the principles of relativity carries a subtitle "Stories of c, G, and h".

With his characteristic self-imposed censorship G. Gamow offered numerous excuses for this inclination and guards himself against an anonymous opponent, with the statements like "although one does not know the correct answer, one should not be blamed for speculating on this kind of problems" (Biography of Physics (1961), p. 324) etc. Or, describing sir A. Eddington's well-known efforts to interpret the number 137 (inverse fine structure constant) by building the matrix 16 x 16, G. Gamow writes ironically that "one can classify such kind of effort as 'numerology' which carries a bad connotation today" (*ibid.*, p. 325).

But one should not be misled by G. Gamow's ironical attitude. In fact, he treated the problem of cosmonumerology with an utmost seriousness and maintained the interest to the issue through all his scientific career. In view of all the above-mentioned an interesting question arises: Can one find a deep psychological motivation for what we would call G. Gamow's quest for the ultimate? As we see it, George Gamow himself provides an ample answer for an interested reader. In his "Biography of Physics" he describes in the chapter entitled "The Age of Electricity" first the notion of electrostatic units (esu) as defined by Coloumb law of electric attraction and repulsion, then the electromagnetic units (emu) defined by the Oersted's law of the action of electric current on a magnetic pole. Explaining then that two bodies charged by 1 emu each and placed 1 cm apart will repel one another with a force of 3×10^{10} dynes, he proceeds with the following: "Since in writing his equations, Maxwell had to use electrostatic units for electric fields, and electromagnetic units for magnetic fields, the factor 3×10^{10} crept into the formulas containing an electric field on one side of equation, and a magnetic field on the other". And the application of these equations for describing the propagating electromagnetic waves led to the conclusion that the propagation velocity is numerical equal to the ratio of the two units, i.e. 3×10^{10} cm per sec. And, lo and behold, this figure coincided exactly with the velocity of light in a vacuum which was measured by various methods long before Maxwell was born ! A-ha!, probably thought Maxwell, this must mean that light waves are actually electromagnetic waves of very short length, and this thought led to the development of an important branch of physics: the electromagnetic theory of light (bold face is mine I. P.) (Biography of Physics, (1961), p. 156), and somewhat later ending the chapter with summarizing statement: "The numerical coincidences between seemingly unconnected physical quantities such as the ratio of electrostatic and electromagnetic units on one side and the velocity of light on the other, often led to fundamental new discoveries and broad generalization in physics. Later in this book we will learn that another such coincidence between two physical constants, one pertaining to emission of light and heat waves by hot bodies, and another to emission of electrons from the surfaces illuminated by ultraviolet rays, turned out to be of paramount importance in the development of the quantum theory."(*ibid*, p. 157).

As we see it, the just quoted paragraph gives the key to G. Gamow's permanent, persistent interest to cosmonumerology: in it he reveals his own everlasting dream of unraveling the most fundamental laws of nature by the power of a sheer physical intuition, from the principles, without the necessity of being involved into lengthy mathematical analysis which he disliked.

According to M. M. Shapiro (George Gamow - An Appreciation, 1972, p. 301), "A dialogue with George Gamow was always animated by his insatiable appetite for exploring new ideas, and illuminated by his intuitive perception of the meaning underlying a new discovery". These features of his character perhaps give as well a key to his personal modesty and the apparent indifference to the issues of priority in scientific research. In his book "Thirty Years that Shook Physics" he makes a special footnote to explain a reader why he deviates from the academic habit to narrate some particularities of his life in the first person. His casual remarks about the notorious case of the two gentlemen, Carlisle and Nicholson of the Royal Society Publication, who shelved the manuscript with the results of Volta's famous experiments and committed thereby the act of scientific plagiarism, indicate that G. Gamow was oblivious to the problem. But he looks disinterested when it comes to the issue of priority of his own discoveries. Recalling the history of his interpretation of alpha particle decay with the aid of quantum mechanical approach to the penetration of the potential barrier, Gamow just mildly states that this discovery was given independently by him and by team of Ronald Gurney from Australia and Edward Kondon from USA. Disinterested as he may seem, G. Gamow should be stung when A. Penzias and D. Wilson in their first announcement of the measurements of the 3° K cosmic background radiation failed to mention G. Gamow's pioneering work on the hot primordial universe which led to the prediction of CMB.

In a letter to Dr. A. Penzias he thanked him for sending a copy of their paper and courteously stated that 'it is very nicely written, except that "early history" is not "quite complete", pointing to his own articles published in *Physical Review*, 70 in 1946 and *Nature*, 162, in the same year. But somewhat later, at the 4th Texas Symposium on relativistic astrophysics where G. Gamow was the chairman of the session on Microwave Background Radiation, he turned the whole issue into a joke: "He ended his remarks with a comment which to the best of my recollection went: "If I lose a nickel and someone finds a nickel, I can't prove that it's my nickel. Still I lost a nickel just where they found it". A. Penzias, "Cosmology and Microwave Astronomy", 1972, p. 41).

One of the most amazing features of his talent which brought G. Gamow public recognition is an extreme transparency, visuality of his physical models. According to the testimony of S. Ulam, "Gamow always tried to find even in most abstract theories, motivations or similes, i.e., analogies with precisely understood models". It looks as if this facet of his rare talent has something to do with G. Gamow's artistic abilities. Admittedly he made the most ingenious illustrations to several of his popular books. It may sound paradoxically, but the more complicated and abstract seemed to be the task he faced, the more eloquently manifested itself his artistic imagination. The long passage we shall reproduce below (taken from G. Gamow's Biography of Physics) exemplifies, in our view, in the best possible way visuality of his reasoning. Here he tries to introduce an uninitiated reader to one of the most tricky concepts of theoretical physics, Paul Dirac's relativistic wave equation. He explains how a "strange marriage" of relativity with quantum mechanics performed by P. Dirac immediately gives rise to a strange "negative" world challenging our imagination, where all objects have negative masses, which means that being pushed one way they will start to move in the opposite direction. By obvious analogy, he calls the electrons with negative masses "donkey" electrons. Next, in an attempt to indicate the fundamental difficulty facing Dirac's theory, G. Gamow draws the schematic picture of two energy continua, one for normal electrons and another one for "donkey" electrons and discusses the notorious problem: why electrons cannot overcome the abyss separating the two energy oceans?

Who knows, perhaps, on the bizarre properties of Dirac's antiworlds and looking at his drawing with dots as electrons resembling small fishes and transition arrow reminding fishing rod he recalled his childhood at the Black Sea shore in Odessa... A-ha, perhaps, thought G. Gamow at this point, now I have it. And he wrote: "The only way Dirac could handle that difficulty was to assume that all the states of negative energy are completely filled up by donkey electrons, and that the electrons from the positive energy states are prohibited from coming down by the Pauli exclusion principle. Of course, this mean that vacuum is not vacuum any more, but is thickly filled by donkey electrons moving in all possible directions with all possible velocities! In fact, each unit volume of vacuum must contain an *infinitenumber* of these self-contradictory particles! Why do we never notice them? The explanation is rather enigmatic. Imagine a deep-water fish which never comes to the surface of the ocean and therefore does not know that the water ends somewhere above it. If this fish is intelligent enough to speculate on its surroundings, it would not even think about water as a "medium", but would consider it as "free space". Similarly it can be argued that physicists do not perceive the presence of this infinitely dense herd of donkey electrons, because they are distributed quite uniformly through space.

Of course, this idea smelled of the old-fashoned world ether, but it was worth of investigating. Returning to our intelligent deep-water fish we can imagine that it formed the notion of gravity by observing empty beer bottles, other refuse and even whole ships coming down to the ocean bottom. But then one day some air trapped in a sunken ship's cabin was released, and our intelligent deep-water fish observed a school of glittering silvery bubbles rising up towards the surface of the ocean. The fish would be of course much surprised and, after due reflection, would come to the conclusion that these silvery spheres must have a negative mass. Indeed, how else can they move up when gravity pulls everything down?

Well Dirac had similar ideas about his ocean filled to capacity by electrons in the negative energy state. Suppose there is a bubble in Dirac's ocean, that is to say, one of the donkey electrons is missing. How would a physicist perceive that? Since the absence of a negative charge is equivalent to the presence of a positive charge, he would see it as a positively charged particle. Also, according to the bubble analogy, the sign of the mass will be reversed and the lack of negative mass will be perceived as the presence of positive mass. Could it be that such a bubble in Dirac's ocean is nothing else but an ordinary proton? It was a brilliant idea, but it did not work... The difficulties were augmented by the calculation of Pauli, who had shown that, if the proton really were a bubble in Dirac's ocean, the hydrogen atom could not exist for a negligibly small part of a second... Pauli proposed what is known as the "second Pauli principle", according to which any new idea formulated by a theoretical physicist becomes immediately applicable to all atoms forming his body. According to that principle, Dirac's body would be annihilated within a small fraction of one microsecond after he conceived that idea, and other theoretical physicists would be saved from hearing about it..."

What one can add to this? Perhaps, the most appropriate seems to be E. Teller's judgement: "George Gamow...was a physicist of excellent taste. Bethe, a man given to precision estimates that Gamow's popular books were 90 per cent correct. I suspect that a book which is 99.44 per cent correct may prove exceedingly dull". (E. Teller, Are the Constants Constant?, p. 60, 1972).

The choice of a jocular parody on Goethe's Faust as an epilogue to his book "Thirty Years that Shook Physics" is by no means incidental, in a sense it is symbolic. As G. Gamow explains it, the notion of massless and chargeless particle with the spin 1/2 was not so easy to swallow even for the outstanding physicists of the thirties. And then they seeked refuge in the world of art. But it seems to be only a part of the story. In fact, the book was completed four years before his death. The figure of doctor Faust and his tantalizing question "Where shall I clasp you, infinity of Nature?" was apparently appealing to George Gamow more and more in the epilogue of his life.

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