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Summary

This essay describes the results which have been obtained up to now in a discussion of the physical processes which should occur in a symmetric universe (containing as much matter as antimatter). They include the discovery of a separation mechanism between nucleons and antinucleons in thermal radiation at high temperature. Another new effect, which is related to the Leidenfrost mechanism concerns the hydrodynamical coalescent behavior of matter and antimatter. Quantitative applications to the problem of the origin of matter and galaxies are given. Other astrophysical applications still under investigation are sketched with a view to unequivocal experimental tests.

The possible existence of antimatter in the Universe could affect deeply many discussions about gravitation, together with several other important consequences. The present essay describes what results have been obtained in a systematic investigation of this question. It was assumed that matter (and antimatter) as we see it now, could originate from the elementary particles which existed in the early stages of the Universe according to the so-called "big-bang"theory. In practice we investigated new and important physical processes which should occur in the simplest model of the Universe, namely an isotropic model with zero total baryonic charge.

1) Our first point was to propose an actual mechanism for the initial separation of nucleons and antinucleons in thermal radiation. It was first shown that such a separation (which, from the point of view of thermodynamics would be a phase transition leading to a spontaneous breaking of the charge conjugation symmetry between particles and antiparticles) was a natural consequence of two hypotheses : (i) that mesons are bound states of nucleon-antinucleon pairs ; (ii) that the free energy of radiation is stationary with respect to a change in the number of mesons. From these two conditions, it results that precisely the separation between nucleons and antinucleons in thermal radiation is the simplest physical process of its own category, which may explain why it was never noticed previously.

A second stage in the investigation was to check whether or not the qualitative and quantitative conditions for the existence of such a phase transition were actually met. Using recent new developments in the foundations of statistical mechanics, we computed the first few virial coefficients in the expansion of the free energy for a gas of hadrons at high temperatures. These coefficients can be computed in terms of the scattering amplitudes which describe the collisions between elementary particles. The relevant amplitudes have been computed by using the mesonic theory of nuclear forces and this part of the work is by itself a significant contribution to particle physics. The result is that, at the level where the computations have been carried, the phase transition exists and its characteristics are rather stable (the critical temperature is found to be of the order of 350 MeV). In practice this is no proof of the existence of a phase transition because of the unavoidable approximations (no such proof in fact exists for any actual physical system) but that it is generally agreed that the argumentation is as strongly suggestive as it could be. Furthermore, the calculations have by now been carried as far as our present knowledge of elementary particle physics allows it.

To conclude the first part of the investigation one can therefore state that the existence of a phase transition in thermal radiation, leading to a separation between matter and antimatter at temperatures larger than 350 MeV is a probable effect which can be used as a good Ansätz for further research.

2) Another new physical effect was also considered which has to do with the hydrodynamical behavior of matter when it is directly in contact with antimatter. It is well known that the annihilation products exert a strong pressure upon the two sides of the boundary (this being called the Leidenfrost phenomenon). We have suggested that this annihilation pressure would produce hydrodynamical motions with the result of reducing the area of the boundary.

This suggestion was initially justified by arguments which were drawn from irreversible thermodynamics but, although strongly indicative, they did not constitute a completely satisfactory proof. Quite recently, this basic question has been solved using fluid mechanics and the following statement has been obtained : Turbulent motions are responsible for heat transfer in such a system. For any shape of the boundary, there exists a possible state of average equilibrium where thermal pressure compensates the annihilation background is also explained, the new contribution being a gamma-ray spectrum from π^0-decay, red-shifted by a factor 70 (corresponding to the time when the Universe became transparent to these gamma rays).

A more complete analysis of these astrophysical applications with a view to propose unequivocal experimental tests of the theory is now under investigation.

As a conclusion, the present essay describes a rather wide program with a view to discuss the simplest model for the Universe, which is compatible with the known laws of physics. It turned out that this model could show quite unexpected new features and was a better candidate than previously believed for describing the actual universe. Not all the parts of this program have been carried equally far. The first one (the separation effect) is as well established as it can be with our present knowledge of particle physics and statistical mechanics. The second one (coalescence) is reasonably well analyzed and it constitutes in any case a clear-cut physical problem. The third part (the origin of matter and galaxies) follows necessarily from the first two. Because of its fundamental importance, however, longer and harder work should still be done upon the two basic effects and the astrophysical consequences.

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Part of the work which is described here has already been published in

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- Physical Review
- Annales de Physique
- Astronomy and Astrophysics
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to which we refer for proper bibliographical references.

Biographical notice

Roland OMNES - French - Born in 1931. Studies at Ecole Normale Supérieure. After research done at CERN, Saclay and the Lawrence Radiation Laboratory in Berkeley, he is now professor at Paris University. Long a specialist in elementary particle physics (participant of the Solvay Meeting 1967, Nobel Symposium 1968) he is now working on the physical processes which are involved in cosmology.

Married - Four children.

Author of two books on elementary particle physics.