Reports

Speculations on Cosmogony

The recently reported conclusive evidence for the existence of the antiproton (*1*) encourages me to publish a speculation in which I attempt to extend to cosmogony a fundamental symmetry idea which has proved to be a valuable guide in the study of elementary particles—namely, the particle-antiparticle conjugation symmetry (*2*). This symmetry implies that, as far as the general laws of nature are concerned, neither a particle nor its antiparticle can have a preferred position. However, the part of the universe of which we have direct observational knowledge appears to consist essentially of only one kind of matter (nucleons and electrons). If it also contained a comparable amount of "antimatter" (antinucleons and positrons)—for example, in different stars of one galaxy, or in different galaxies, we would expect to notice effects of the large release of energy from the mutual annihilation of matter and antimatter (*3*) (in the form of light or of radio noise), since the stars within a galaxy, and probably also the different galaxies, are "in touch" with each other through an all-pervading, though tenuous, hydrogen atmosphere.

Some of the current theories of the origin of matter tacitly, or explicitly, assume an asymmetry in the process of "creation"—that is, the creation of nucleons, but not of antinucleons. According to the theory developed by Gamow, Alpher, and Herman (*4*) the present world originated from a dense neutron-rich atmosphere, the "ylem," which existed about 4.5×10^9 years ago and was transformed rapidly, by successive neutron capture and β-decay processes, into the elements which make up our cosmos. This theory makes the unsatisfactory tacit assumption that during some period the asymmetric "act of creation" of nucleons, in preference to antinucleons, took place an extremely large number of times (equal to the number of nucleons in the universe), and that it then stopped.

A similar tacit assumption of an asymmetry in creation underlies the "polyneutron" theory developed by Mayer and Teller (*5*) and Peierls, Singwi, and Wroe (*6*), which followed Lemaître's (*7*) original proposal of a "primeval atom," supposed to have contained all the nucleons of the universe (*8*). The hypothesis of the steady-state universe, developed by Bondi, Gold, and Hoyle (*9*), also assumes an asymmetry—namely, the continuous creation throughout all space of hydrogen atoms (consisting of protons and electrons), but not of their counterparts (consisting of antiprotons and positrons).

While initial conditions may have been asymmetrical, we may nevertheless ask ourselves: What would be the logical structure of a theory of the origin of the universe which attempts to preserve symmetry between nucleons and antinucleons? Should we simply assume that nucleons and antinucleons were originally created in pairs, that most nucleons and antinucleons later annihilated each other, and that "our" cosmos is a part of the universe where nucleons prevailed over antinucleons, the result of a very large statistical fluctuation, compensated by an opposite situation elsewhere? Could this statistical separation be so complete that we should not be able to detect occasional collisions of galaxies and "antigalaxies" with spectacular results, or considerable "background" radio noise from the voids in which hydrogen atoms meet "antihydrogen" atoms?

While these questions deserve further theoretical and experimental investigation, I should like to put forward here a speculation about a possible quite different preceding state of the universe which preserves symmetry in the initial conditions, but leads nevertheless to an apparent present asymmetry of matter in "our" cosmos.

If we want to preserve the particle-antiparticle conjugation symmetry at creation without assumption of a purely statistical separation of matter and antimatter, we have to consider models in which the cosmos and its possible counterpart, the "anticosmos," are somehow separated from the very beginning of their existence. Remembering the law of the conservation of nucleon number, such a "pair creation" might be achieved, perhaps in the simplest way, by the following modification of Lemaître's model (*7*).

We shall assume that there existed "at first" a single particle, containing the mass of the whole universe, which we shall call here the "universon." For reasons of symmetry we shall assume that it is a self-conjugate particle. We shall further assume that at a time $t = t_0$, unknown at present, the universon divided into a particle and its antiparticle which we shall call the "cosmon" and the "anticosmon," each possessing a large "nucleonic charge," but of opposite sign (where nucleonic charge is defined as $+1$ for a nucleon and -1 for an antinucleon). This division may be considered analogous to the spontaneous decay of a fundamental particle into a particle and antiparticle, such as one finds in the decay of $\theta^0 \rightarrow \pi^+ + \pi^-$, which takes place with a considerable release of kinetic energy, equivalent to approximately three-fourths of the rest mass of the two π mesons (*10*). The cosmon and anticosmon may have similarly flown apart with a large relative velocity (*11*). After the separation, the cosmon which replaces here Lemaître's primeval atom, and must therefore be assumed to be the particle of positive nucleonic charge, "decayed" at a time $t = t_1$, possibly through many intermediate steps, into nucleons, which in turn formed our present expanding cosmos.

Early stages of the cosmos may have resembled the "polyneutron" or "ylem," and the time t_1 may be close to the time at which our elements were formed, about 4.5×10^9 years ago. The anticosmon may or may not have decayed by now, since spontaneous decay is a process governed by a statistical law. If it did decay (forming an "anticosmos"), any antinucleons which are shot out with sufficient velocity to reach our cosmos will annihilate some part of it, possibly establishing a deviation from spherical symmetry in the distribution of matter in our cosmos.

These speculations suggest many questions, some of which are similar to questions raised earlier (*4, 7, 9, 12*). Some are of a philosophic nature; others may ultimately prove answerable by observation. The following may be mentioned.

1) Is the direction in space defined by the line connecting the centers of the cosmos and anticosmos detectable—for example, through detailed studies of the large-scale mass distribution in our cosmos, or of the large-scale average of the angular momenta of the galaxies?

2) Is the anticosmos itself detectable? How far away is it, and is it still receding from us?

3) If only a single universon existed, is it meaningful, even if only in principle, to ask any question involving a time preceding $t = t_0$?

4) Is it reasonable to assume the existence of particles of very large nucleonic charge (cosmon and anticosmon) in view

of the fact that the only particles known at present have a nucleonic charge of 0 or ±1; and why should the decay of the universon into particles of large nucleonic charge be a preferred mode?

It remains to be seen whether these speculations, which are most easily visualized in a Newtonian universe, can be formulated in a way that is compatible with the ideas of the general theory of relativity.

M. GOLDHABER
Brookhaven National Laboratory, Upton, New York

References and Notes

1. O. Chamberlain *et al.*, *Phys. Rev.* **100**, 947 (1955); J. M. Brabant *et al.*, *Phys. Rev.* **101**, 498 (1956); O. Chamberlain *et al.*, *Univ. Calif. Radiation Lab. Rept. No. 3325* and *Phys. Rev.* **102**, 921 (1956).
2. I should like to thank R. Schlegel for useful comments.
3. In a sufficiently dense environment, the total energy released in the mutual annihilation of electrons and positrons (1 Mev in the form of γ-rays) may be transformed into heat; up to about one-half the energy released in the mutual annihilation of nucleons and antinucleons (1876 Mev in the form of π-mesons, charged and uncharged) may be transformed into heat, the remainder being carried away by neutrinos, resulting from decay of the charged mesons. The decay modes of the π mesons are $\pi^0 \to 2\gamma$; $\pi^{\pm} \to \mu^{\pm} + \nu$; $\mu^{\pm} \to e^{\pm} + 2\nu$.
4. R. A. Alpher and R. C. Herman, *Ann. Rev. Nuclear Sci.* **2**, 1 (1953); G. Gamow, *Creation of the Universe* (Viking, New York, 1952).
5. M. G. Mayer and E. Teller, *Phys. Rev.* **76**, 1226 (1949).
6. R. E. Peierls, K. S. Singwi, D. Wroe, *ibid.* **87**, 46 (1952).
7. G. Lemaître, *The Primeval Atom* (Van Nostrand, New York, 1950).
8. Gamow (see *4*) suggests that one may escape discussion of the creation of the "ylem" or "polyneutron" if the "beginning," $\backsim 4.5 \times 10^9$ years ago, was only the latest beginning of an expansion of the universe which may ultimately be followed by a contraction and a new expansion, in endless cycles.
9. H. Bondi, *Cosmology* (Cambridge Univ. Press, Cambridge, 1952); F. Hoyle, *The Nature of the Universe* (Harper, New York, 1951).
10. See, for example, B. Rossi, *Nuovo cimento* **2**, Suppl. 1, 163 (1955).
11. Other forms of pair-creation of cosmon and anticosmon, as well as processes leading to more than two particles, might be considered, as long as the essential assumption of the existence of particles of large mass and large nucleonic charge is maintained.
12. W. H. McCrea, *Repts. Progr. Phys.* **16**, 321 (1953).

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Mechanism of Sound Production in the Sculpin

Definite information on the sound-producing mechanisms of many fishes has been obtained, especially on those of species possessing swimbladders and associated intrinsic or extrinsic muscles (*1, 2*). In many other species, including either those without swimbladder muscles or those entirely without swimbladders, this mechanism is less fully understood. For example, in marine sculpins, which are fishes lacking swimbladders, Fish (*2*) suggests a possible mechanism in *Myoxocephalus octodecimspinosus* Mitchill which involves pectoral-pelvic girdle vibration, and she describes two other mechanisms proposed by earlier investigators (*1, 3*).

In the experiments reported here (*4*), muscles considered to be primarily involved in sound production in the longhorn sculpin, *M. octodecimspinosus*, have been identified by use of electrophysiological techniques. These experiments suggest that a different mechanism is involved. Muscle-action potentials that were coincident with each burst of sound were detected by a cotton-wick electrode and a capacitor-coupled preamplifier that provided a gain of 44 db. The output was aurally monitored by a separate audio amplifier-loudspeaker circuit, displayed on a 5-in. oscilloscope, and recorded on magnetic tape by a Magnecord PT63 at 7.5 in./sec for detailed analysis and photorecording.

The action-potential pulses could be picked up from all parts of the body surface, increasing in amplitude in the vicinity of the gill chamber. The point of maximum amplitude (2 to 3 mv) was the posterior, dorso-lateral corner of the gill chamber on each side of the body near the junction of the posterior edge of the operculum with the dorsal body wall.

Careful dissection revealed the presence in that location of two muscles, one superficial to the other. Both muscles insert on the anterior edge of the cleithrum near the point of articulation of the latter bone with the supraclavicle. Both have their origin from the ventral surface of the skull, the deep muscle from the posterior region of the otic capsule just lateral to the midline and the superficial muscle from a more lateral region. Their contraction would thus produce adduction of the pectoral girdle relative to the skull. The homology of these muscles has not been determined with certainty. In some respects, they resemble either cephaloclavicularis or cucullaris muscles, but the deep muscle, at least, is innervated by branches of the first two spinal nerves rather than the vagus (*5*).

Electrophysiological recording directly from the surface of the exposed muscles indicated the deep muscle to be the source of the action potentials. That it is the only source is indicated by the fact that the superficial muscle could be completely removed without altering the nature of the spikes, and no other muscle site was found to yield such action potentials.

The relationship between the action potentials and the sound-producing vibrations was determined by comparing both separate and simultaneous oscillographic records of the two phenomena. The vibrations were detected by a crystal phonograph cartridge holding a stiff wire which rested near the coracoid

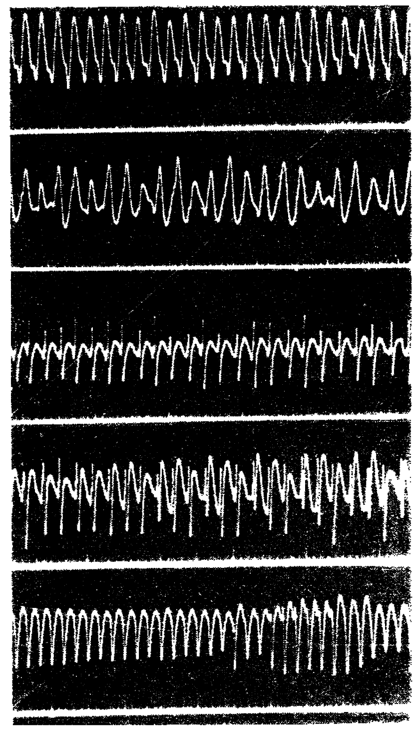

Fig. 1. Mechanical and electric events occurring during sonic activity in the longhorn sculpin. The top four records are from the same animal. Top to bottom: underwater sounds, pectoral-girdle vibrations, action potentials, simultaneous action-potential and pectoral-girdle vibrations, contractions of the deep cephaloclavicularis muscle. Time marks occur every 10, 50, and 100 msec.

symphysis, where maximum vibration could be felt. The crystal output was connected directly to the oscilloscope input. For simultaneous recording, the two potentials were first combined in a two-channel audio mixer that had separate volume controls for amplitude equalization. Contractions of the deep muscle from one side of the body were recorded separately during sound production by tying the severed insertion of the muscle to the crystal pickup.

The following facts are evident from examination of the oscillograms. Typical examples are shown in Fig. 1. (i) Except for minor differences in records made at different times, the repetition frequencies of the muscle-action potentials, underwater sounds recorded by hydrophone, and pectoral-girdle vibrations are identical. (ii) The pectoral-girdle vibrations occur in phase with the muscle-action potentials. (iii) The deep-muscle contractions during sound production consist of a series of separate twitches, of which the repetition rate is similar to that of the phenomena reported here. The frequency difference that is visible in Fig. 1 between the bottom record and the preceding ones is apparently an individual variation.

Therefore, it is concluded that the