ON THE POSSIBLE TYPES OF ELEMENTARY PARTICLES

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The possibility of existence in nature of particles with unusual combinations of baryon and lepton numbers and spins is discussed both for particles possessing and not possessing strong interaction. Some such particles could not have been observed in experiments carried out so far.

THE known elementary particles are characterized by a set of conserved charges: electric charge Q, baryon number n_B, and lepton number n_L. There are many essential differences between these charges. Thus, the electric charge is not only a conserved quantity but also the source of electromagnetic interactions. It is possible that the baryon number is the source of strong interactions; this role is attributed to it in several schemes [1]. As regards the lepton number, it is apparently not the source of weak interactions, since weak interactions can occur also without the participation of leptons, either real or virtual, as happens in the case of hadronic decays of strange particles [1)]. The available experimental data also indicate the existence of another difference between Q, on the one hand, and n_B and n_L, on the other. Electric charge can be possessed both by bosons and fermions, both by strongly interacting particles and by particles that do not interact strongly. In contradistinction to this: 1) only strongly interacting fermions carry a baryon number, 2) only weakly interacting fermions carry a lepton number, and 3) particles with $n_B = n_L = 0$ necessarily possess integral spin.

It is the purpose of the present paper to investigate to what degree the assertions 1)—3) are proved experimentally. There is another question connected with this problem: to what extent has it been proved that there do not exist in nature interactions which do not reduce to one of the four known types of interactions: strong, weak, electromagnetic, and gravitational.[2)]

If one considers all possible combinations of three quantum numbers that characterize elementary particles—the baryon number (n_B = 0, 1), the lepton number (n_L = 0, 1), and the spin J (integral and half-integral)—one obtains the 10 possible types of particles enumerated in Table I.

Table I

Name	Symbol	Quantum numbers n_B	n_L	J
Baryons	B	1	0	$n+1/2$
	b	1	0	n
Leptons	L	0	1	$n+1/2$
	l	0	1	n
Mesons	M	0	0	n
	m	0	0	$n+1/2$
Baroleptons	H*	1	+1	n
	h	1	+1	$n+1/2$
	G	1	−1	n
	g	1	−1	$n+1/2$

*The symbol H has been chosen because of the fact that the baroleptons have the same values of n_B and n_L as the hydrogen atom.

Adding as a characteristic of a particle its ability to interact strongly, each type will include two kinds of particles: strongly interacting particles (we shall label them with the subscript s, e.g. B_s) and particles which do not interact strongly (without any additional subscripts, e.g. B). It is understood that within each kind, the particles can be further subdivided according to other quantum numbers, as for instance, electric charge, isospin, strangeness, muonic charge[2)]. We emphasize the fact that the definition of baryons, leptons, and mesons given in Table I, as particles characterized by definite values of n_B and n_L, differs from the generally accepted definition.

The particles presently known are of the follow-

[1)]Cf. the note added in proof.

[2)]It is known, that the selection rules which are explained by invoking muonic charge can be explained in terms of conservation of the lepton number and helicity, if one assumes the existence of a single four-component neutrino. It is interesting to mention yet another possibility: μ and ν_μ are mesons of the type m with $n_B = n_L = 0$. Then the conservation of lepton number would forbid transitions of the type $\mu \to e\gamma$ and $\mu \to 3e$. This possibility differs from the generally accepted one by the fact that it would allow, in principle, the occurence of reactions of the type $2\pi^+ \to 2\mu^+$, $p + p \to 2n + 2\mu^+$ etc.

ing four kinds:

1. B_S (nucleons, hyperons, baryon resonances) are "baryons" in the generally accepted terminology;

2. L (μ, e, ν) are "leptons" in the generally accepted terminology;

3. M_S (the η, π and K mesons and the meson resonances) are "mesons" in the generally accepted terminology;

4. M (the photon, the graviton and the so far undiscovered W-boson).

The other sixteen kinds of particles have not been observed. The "discovered" particles have no theoretical advantages over the "undiscovered" particles. We do not need these undiscovered particles to explain any known phenomenon, in the sense in which the pion was necessary in order to explain nuclear forces. But we already know one example of an "unnecessary" particle, viz. the muon. It is then natural to raise the question: is not by any chance the assertion that baryons must be strongly interacting particles an assertion of the same type as the famed statement that baryons must posses half-integral isospin, which was accepted before the discovery of strangeness? Only experiment can answer the question whether there exist, for example, 1) baryons which do not interact strongly, 2) strongly interacting leptons, 3) baryons and leptons with integral spin, 4) mesons with half-integral spin, 5) baroleptons, and 6) weakly interacting leptons which are heavier than the muon.

Let us analyze in more detail the problem of existence of particles of the types B, L, M, H, and G with normal spin and which do not interact strongly. Some possible production and decay reactions for such particles are listed in Table II.

Table II

Particle	Examples of possible production reactions	Examples of possible decays
B	$\nu n \to \mu^- B^+$	$B^+ \to \pi^+ n$, $B^+ \to n\mu^+\nu$
L	$\left\{ \begin{array}{c} \nu n \to L^- p,\ \nu n \to L^0 n, \\ \nu n \to L^- B^+ \\ \gamma Z \to L^- L^+ Z,\ \mu^- p \to L^0 n \end{array} \right.$	$L^- \to \pi^- \nu$, $L^- \to \mu^- \nu\bar{\nu}$ $L^0 \to \pi^0 \nu$, $L^0 \to \pi^+\mu^-$, $L^0 \to \mu^+\mu^-\nu$
M	$\left\{ \begin{array}{c} \gamma Z \to M^+ M^- Z \\ \nu Z \to M^+ \mu^- Z \end{array} \right.$	$M^+ \to \mu^+\nu$ $M^+ \to e^+\nu$
H	$\left\{ \begin{array}{c} \nu p \to H^+ \to \mu^-\pi^+ p \\ \nu n \to H^0 \to \mu^- p \end{array} \right.$	$H^+ \to \mu^-\pi^+ p$ $H^+ \to \nu p$, $H^0 \to \mu^- p$
G	$\bar{\nu} p \to G^+ \to \mu^+ n$, $\tilde{\nu} p \to G^+\gamma$	$G^+ \to \mu^+ n$

If the mass of the B-particle is larger than the masses of the known hyperons, so that decays of the type $\gamma \to \pi + B$ are forbidden, then the observation of B should be very difficult. Owing to the large background, the observation of B in high-energy collisions of strongly interacting particles should be practically impossible. It should be relatively easy to observe the particle B in a neutrino experiment. However, should the lifetime of B be $\tau_B \lesssim 10^{-12}$ sec, a very thorough kinematic analysis would be required for its detection.

Searches for charged leptons heavier than the muon have been proposed in [1-3]. For a mass of approximately 1 BeV, such a heavy lepton would decay weakly within a time on the order of 10^{-12} sec. We note that if L^- interacts weakly only in combination with L^0 (in the same manner as μ^- appears with ν_μ), no heavy L-leptons will be produced in a neutrino beam. In this case the best method of searching for heavy L leptons should be by photoproduction of L pairs.

One of the representatives of the class of M mesons is the W boson, which is responsible for weak interactions. The existence of other M mesons is also possible. In order that the existence of such virtual M mesons should not manifest itself in the weak V-A interaction, their interactions with ordinary leptons and baryons (L and B_S) should be weaker than that of the W boson. If however such M mesons interact only with B_S or only with leptons (e.g. with μ and ν_μ) then their coupling constant may also be larger than the coupling constant of the W boson[4].

Baroleptons H have been considered by Wentzel [5] (cf. also [6-8]) as early as in 1936 as intermediate particles in beta-decay, assuming that the interaction of these particles is semi-weak. In the light of the present-day universal V—A theory the existence of an H barolepton responsible for the weak interaction between baryons and leptons seems extremely unlikely. It is not impossible, however, that such particles exist and lead to an interaction of a nature which differs from the weak interaction. The existence of H could show up as a resonance in reactions of the type $\nu n \to H^0 \to \mu^- p$, or $e^- p \to H^0 \to e^- p$. A search for resonances of this kind is being presently carried out at CERN [9] and in other laboratories [10-12].

Let us consider now particles with anomalous spin, which we will call "wild" particles: b[3)], l, m, h, g. It is easy to see that those among this

3)A baryon field with integral spin, the so-called B-field, has been discussed in the papers of the Nagoya group (cf. e. g.[13]) and also by the translator of the present paper [M. E. Mayer, Nuovo cimento 17, 802 (1960)] – Tr.

group with minimal mass must be stable, owing to the conservation of n_B, n_L, and of the angular momentum. Such particles should not be absorbed in interactions with matter, but only scattered. This is also true of the corresponding antiparticles. Wild particles would be produced only in pairs. When a heavier wild particle decays another wild particle is necessarily created. Baryons and baroleptons with integral spin could play an essential role at ultrahigh densities (in some stars), since they obey Bose-Einstein statistics (transitions of the type $pp \rightarrow bb$). Interactions in which wild particles could be generated, e.g., $\nu n \rightarrow b^+ l^-$ or $\pi p \rightarrow bm$, would of course be interactions of a completely new type.

One can raise the following objections against the existence in nature of stable particles, other than the electron and proton.

1. Such particles should have survived in noticeable quantities since the time of the formation of our part of the universe.

2. Such particles should be generated by high-energy cosmic rays and accumulate on the earth.

3. Such particles should be observable in investigations of high-energy collisions in cosmic rays or in accelerators.

The first objection is quite serious, especially as regards charged stable particles. However, our present understanding of cosmogonic processes is not so exhaustive as to consider this objection as decisive. We remark that if the hypothetical stable particles are neutral and their nuclear forces (if existent) are repulsive, then such particles should accumulate under the action of gravitation in the center of the Earth and other massive objects, undergoing there interactions with each other.

The second objection is not very serious, since the concentration of such particles would be extraordinarily small. Indeed, even if one assumes that one such particle is generated in each process of interaction with an energy larger than 30 BeV, and if one takes into account that one particle with energy $\gtrsim 30$ BeV hits 1 cm^2 once every 100 sec, then over the time of existence of the earth the concentration of anomalous stable particles in the atmosphere would be of the order of 10^{-10}. It is clear that this number is an upper limit. If the stable wild particles are positively charged, they could form a heavy "wild" hydrogen. If they are negatively charged, they would be captured by nuclei into Bohr orbits. It would be interesting to carry out a special mass-spectroscopic analysis of the air with the aim of detecting such "wild" isotopes.

As regards the third objection, it is clear that sufficiently massive stable particles (mass ~ 2 BeV and even smaller) could not have been observed in experiments carried out so far, if they were not due to strong interactions. In some cases the observation of such particles might be more difficult if they did possess strong interactions. In particular, if their mass were close to the mass of the deuteron or the triton, it would be difficult to observe them.

In conclusion we note that the existence of strongly interacting unstable particles, of a completely different nature than the known baryon and meson resonances, can not be excluded. An argument in favor of this assertion is the fact that the majority of the resonances has been observed over the past two years and that very recently the Ω hyperon has been discovered.

Summarizing, we can say that increasing the energy of accelerators and perfecting experimental techniques, as well as carrying out special experiments with existing techniques and at presently accessible energies, may lead to the discovery of new types of elementary particles.

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Note added in proof (September 22, 1964). The lepton number could be considered as the source of weak interactions if one assumes that both leptons and baryons have nonvanishing lepton number. In this case the known baryons should be referred to particles of type h or g according to the classification of Table I. This possibility was pointed out to the author by V. B. Berestetskiĭ.

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