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BOSONIC LEPTONS

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One of the most remarkable facts in the field of weak-interaction physics is the nonobservation of bosonic leptons (b.l.). In a recent paper dedicated to "crazy" particles, Okun'[1] discusses the possibility of the existence of bosonic leptons and baryons with leptonic and baryonic quantum numbers $n_L, n_B = 0,1$. Because of the conservation of n_L, n_B, and angular momentum, bosonic leptons and baryons with smallest mass must be stable. Up to the present no such particles have been detected and even if they existed, their masses should be very large.

It is the purpose of this Letter to suggest a more general possibility than that considered by Okun', regarding the existence of bosonic leptons, namely b.l. with $n_L > 1$. It will be shown that such particles could exist in a more accessible mass range. Moreover it is possible that they have already been observed, but, because of an accidental mass degeneracy,[2] the fact was not realized. We formulate a concrete model for b.l. and discuss its experimental implications. The result is that b.l., with the properties postulated below, may influence in a decisive manner certain weak-interaction processes and may also offer an explanation for the controversial π-μ asymmetry.

If b.l. have $n_L > 1$, they may decay into fermionic leptons. In particular if there are muonic bosonic leptons b_μ with $n_\mu = 2$, the decay $b_\mu \to \mu + \bar{\nu}_\mu$ is possible. Furthermore if $m_b \sim m_\pi$ or $m_b \sim m_K$, this decay would be masked by the decays $\pi \to \mu + \nu_\mu$ or $K \to \mu + \nu_\mu$. Thus, b_μ might appear as false pions or kaons.

In the following we shall limit our discussion to the case $n_\mu = 2$.

We will now distinguish between two variants: Variant I.—The lightest b_μ has $m_{b_\mu} \sim m_\pi$ $(\Delta m \equiv m_\pi - m_{b_\mu} > 0)$.

Present experimental data can be used to establish an upper limit for Δm. The most restrictive limitation is provided by the determination of the pionic mass in range measurements on muons emerging from stopped pions. An analysis of this type of determination, performed by Friedländer,[3] yields at a 99.7% confidence level for an admixture of 1% b_μ particles $(\Delta m)_{max} \sim 1.5$ MeV and for an admixture of 5% b_μ $(\Delta m)_{max} \sim 1$ MeV. The other methods for m_π determination lead to much larger values of $(\Delta m)_{max}$, as pointed out in Ref. 3.

Among others, the following weak decays are possible with b_μ:

$$K \to b_\mu + \nu_\mu + \nu_\mu, \tag{1}$$

$$K \to \bar{b}_\mu + \mu + \mu, \tag{2}$$

$$K \to b_\mu + \bar{b}_\mu + \pi, \tag{3}$$

$$\pi \to b_\mu + \nu_\mu + \nu_\mu, \tag{4}$$

and

$$b_\mu \to \mu + \bar{\nu}_\mu. \tag{5}$$

Decays (1), (3), and (5) might have been confused with decays $K \to \pi + 2\pi^0$ K_τ, and $\pi \to \mu + \nu_\mu$, respectively.

If the spin of b_μ is nonzero these particles could emerge longitudinally polarized in the weak decays (1)-(4) and the angular distribution of muons from (5) would be asymmetric. Because of the mass degeneray $m_{b_\mu} \sim m_\pi$, this effect could appear as an apparent asymmetry of muons from weekly produced pions. Possible evidence for such an effect might be considered the π-μ asymmetry in τ decay reported by Cvijanovich and Jeannet[4] although this result is still contested.[5]

The decay e_2 predicted by Cvijanovich, Jeannet, and Sudarshan[6] for "spinning pions" is rigorously forbidden in our model because of n_μ conservation. This is in accordance with experimental findings.[7] On the other hand, the agreement between the experimental and theoretical branching ratio $R=(\pi\rightarrow e+\nu)/(\pi\rightarrow\mu+\nu)$ could be invoked to get an upper limit for the branching ratio $\eta=(\pi\rightarrow b+2\nu)/(\pi\rightarrow\mu+\nu)$. Taking into account the experimental error of 2.2% in the determination[8] of R and the difference of ~1.2% between $R_{\rm exptl}$ and $R_{\rm theor}$, we get at a 99.7% confidence level $\eta_{\rm max}=5.4\%$.

Reaction (4) may lead also to a π-μ asymmetry observed for strongly produced pions.[9] In this case, however, to get with a mass difference $\Delta m<1.5$ MeV a branching ratio $(\pi\rightarrow b+\nu_\mu+\nu_\mu)/(\pi\rightarrow\mu+\nu_\mu)$ sufficiently large to explain the data of Ref. 9, the coupling strength of b_μ with pions should exceed the universal Fermi constant G, by several orders of magnitude.[10] This should occur only for pions and not for kaons where the mass difference $m_K-m_{b_\mu}$ is large enough. [For kaons the coupling strength cannot be much larger than G as this would yield an unobserved high probability for decays (1) and (2).] A less far-fetched explanation of the π-μ effect for strongly produced pions becomes possible in variant II (see below).

If the spin of b_μ should be odd, one might also expect the reaction

$$K_L^0\rightarrow b_\mu+\bar{b}_\mu \tag{6}$$

even if PC is conserved. The probability for this decay is limited by the observed[11,12] branching ratio $(K_L^0\rightarrow 2\pi)/(K_L^0\rightarrow 3\pi)$ [the possibility that the $K_L^0\rightarrow 2\pi$ effect might be due to Reaction (6) is ruled out by the observed interference between the PC-nonconserving and coherently regenerated amplitudes[13]]. We have the following:

$$\frac{K_L^0\rightarrow b+\bar{b}}{K_L^0\rightarrow \text{all decays}}\ll\frac{K_L^0\rightarrow 2\pi}{K_L^0\rightarrow\text{all decays}}\simeq 2\times10^{-3}. \tag{7}$$

Such a minute limit seems, however, difficult to reconcile with the magnitude of the π-μ asymmetry reported in Ref. 4. If we assume that this asymmetry is due to b.l. through Reaction (3), inequality (7) suggests that the spin of b_μ is even [Reaction (6) could then take place only through PC nonconservation].

The present model can be tested among others by searching for Reactions (1) and (2). This last reaction could be detected in an experiment designed to search for the neutral-current decay $K\rightarrow\pi+\mu+\bar{\mu}$. The present upper limit for this decay is given by[14] $(K\rightarrow\pi+\mu+\bar{\mu})/(K\rightarrow\text{all decays})\leq 3\times10^{-6}$.

Variant II.—There exist at least two bosonic leptons with $\eta_\mu=2$, a charged one with $m_{b_\mu}\sim m_\pi$ and a neutral one with $m_{b_\mu}\sim 0$ (bosonic neutrino ν_{b_μ}).

The following reactions could then take place, besides those of variant I:

$$K\rightarrow b_\mu+\nu_{b_\mu} \tag{8}$$

and

$$\pi\rightarrow b_\mu+\nu_{b_\mu}. \tag{9}$$

Decay (8) could have been confused with reaction $K\rightarrow\mu+\nu_\mu$, while decay (9) would hardly have been observed directly because of the small mass difference Δm.

This is of course a fortiori true for Reaction (4). Such a small mass difference is however sufficient to yield a considerable contamination of pion beams with b_μ particles even if the coupling constant $\pi b\nu_b$ is of the same order of magnitude as G.[15,10] If b_μ emerge longitudinally polarized, this could lead to an apparent spin for pions and to an apparent nonconservation of parity in strong interactions. Indeed, let us consider a reaction in which the initial particles are unpolarized and in which pions are generated at 0° or 180° with respect to the incident particles. Because of parity conservation in strong interactions, even if the meson had a nonvanishing spin, it could not emerge from this reaction polarized. However, if the π decays afterwards partially through the weak reaction $\pi\rightarrow b_\mu+\nu_{b_\mu}$, b_μ particles with $m_b\sim m_\pi$ and nonvanishing spin, generated in flight, may simulate longitudinally polarized pions and thus lead to the above mentioned conclusion. This effect could be tested by studying the angular distribution of muons resulting from b_μ generated in flight in pion beams (because of the smallness of Δm, b_μ particles emerging from stopped pions are practically in rest and therefore do not influence the angular distribution of muons; that is why this effect cannot be observed with stopped pions).

The challenging fact is that possible evidence for such paradoxal properties of "pions" exists already. In Ref. 9 a significant angular asymmetry and anisotropy of muons resulting from 0° pions generated in the reaction $p+p\to d+\pi$ was observed. Moreover, this effect was observed only with pions which had passed a filter representing about one interaction mean free path.[9,16] If this effect is due to bosonic leptons the role of the filter is easily interpreted. It enriches the beam in b_μ by a factor of about 4; and, taking into account the large statistical errors of the π-μ asymmetry measurements,[9,16] this factor might be decisive.[17] Recent results seem also to indicate that the π-μ anisotropy is larger for "pions" scattered through small angles than for those which undergo large-angle scattering.[18]

Finally, if there exists also a b_μ with $m_{b_\mu}\sim m_K$ one should expect an asymmetry in the angular distribution of decay products of kaons. This could possibly explain the recent findings of Osborne.[19] All these considerations on the K,π-μ effects, however, remain pure speculations as long as these effects do not receive unequivocal confirmation.[20-22].

To summarize: Experimental data are compatible with the existence of charged bosonic leptons with $n_\mu=2$ in the mass range $m_b\sim 0$, $m_b\sim m_\pi$, and $m_b\sim m_K$. Bosonic leptons can be filtered in the same way as muons, from which they can be separated, among other means, by their specific decay properties. It would be very interesting to apply this method for the search for b_μ in cosmic radiation where such a filtration process is automatically accomplished in the atmosphere or underground. To check the present model one should search among others for the decays (1), (2), (8), and (9). If the π-μ effect[4] is a genuine one and due to b.l. through Reaction (3), the following consequences are deduced:

(a) The spin of b_μ is probably even.

(b) The branching ratio $(K\to b+\bar{b}+\pi)/(K\to \text{all decays})$ should be several percent.

The π-μ effect for strongly produced pions[9] could also be due to b.l. through Reaction (4) or (9). In this case, (c) $\tau_{b_\mu}>\tau_\pi$ where τ_{b_μ} and τ_π are the lifetimes of b_μ and π, respectively.

(d) $\eta=(\pi\to b+2\nu)/(\pi\to\mu+\nu)$ and/or $(\pi\to b+\nu_b)/(\pi\to\mu+\nu)\geq 1.5\%$.

(e) The angular asymmetry in the decay of pions should increase with the path length of the beam and with the thickness of the filter.

(f) The apparent branching ratio $(\pi\to e+\nu)/(\pi\to\mu+\nu)$ should decrease with the enrichment of the pion beam in b_μ.

Some of these experiments are well within the limits of present experimental possibilities. Their performance is highly desirable given the important consequences which would emerge if the existence of bosonic leptons should be confirmed. Besides these new experiments, it is of utmost importance to repeat π-μ asymmetry measurements taking special precautions concerning possible depolarization factors.

The author has benefited from highly instructive discussions on the experimental aspects of these problems with E. M. Friedländer. My thanks are due to V. Rittenberg for his interest in this work and to S. Bernstein for help in improving the manuscript.

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[22]A different interpretation of the π-μ effect is given in a paper by L. Banyai, N. Marinescu, V. Rittenberg, and R. M. Weiner, to be published.

DYNAMICS OF SUPERNOVA EXPLOSION RESULTING FROM PAIR FORMATION

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The supernova explosion of a star is usually believed to result from a catastrophic implosion which reverses into an explosion. A mechanism for an instability which could lead to such a catastrophic implosion has long ago been suggested and investigated.[1,2] This instability is assumed to occur when the temperature of an iron core of a star rises to $(5\text{-}6)\times 10^9$ °K and the iron begins to dissociate into alpha particles and neutrons. Subsequently, it has been pointed out by Colgate[3] that the reversal of the motion of a strong implosion poses severe problems. In this paper we report on dynamical calculations of explosions triggered by an alternative mechanism, namely, the dynamical instability caused by pair formation. This instability occurs in heavy stars prior to the formation of any elements heavier than oxygen. The implosion caused by this mechanism is easily reversed by the oxygen burning. The explosion following the implosion disrupts the star, shedding out oxygen and its direct burning products (elements in the Mg-Si-S range) and all lighter elements which may be present in the envelope. No iron-peak elements are formed during this explosion.

The mechanism of pair formation has been considered by several authors[2,4] but was believed to be inadequate to result in any catastrophic event.

Evolutionary calculations have shown that stars heavier than $(20\text{-}30)M_\odot$ become dynamically unstable because of pair formation.[5] The instability sets in when the central temperature rises to $(1.5\text{-}2.2)\times 10^9$ °K, the lower temperature corresponding to the heavier stars. The evolutionary calculations of several models have been continued beyond the dynamical instability by detailed calculations of the stellar hydrodynamics. During evolution the star contracts slowly preserving hydrostatic equilibrium. After the occurence of the instability the contraction is accelerated. Since in the heavier stars oxygen is burning very slowly at the moment they become dynamically unstable, the contraction gathers sufficient momentum so that, before the motion is reversed, the rate of nuclear reactions increases by many orders of magnitude and an energy corresponding to the consumption of several solar masses of oxygen is released. This is despite the fact that during the collapse the unbalance between the gravitational forces and the thermal pressure gradients is only about 1% and thus induces very small accelerations.

The behavior of a stellar model of 40 solar masses composed of oxygen is shown in Figs. 1 and 2. The evolution was started with an isen-