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# ELECTROMAGNETIC PROPERTIES OF A CHARGED VECTOR MESON INTERMEDIARY IN WEAK INTERACTIONS

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*(presented by S. A. Bludman)*

It has been argued that a charged vector meson mediating the weak interaction would, provided the two $\mu$ decay neutrinos can annihilate each other, allow the unobserved process $\mu \rightarrow e+\gamma$ in first order in the $\mu$ decay coupling constant. Lee and Yang have proposed searching for this $B$-meson by looking for the onset of the semi-weak process $\nu \rightarrow e+B$ with high-energy neutrinos. In this note we (1) show how the $\mu \rightarrow e+\gamma$ argument against the $B$-meson depends on its electromagnetic interaction and (2) suggest another experiment for the production of $B$-mesons, which does not require high energy neutrinos, and whose cross section is typically electromagnetic ($\sim 10^{-30}$ cm$^2$) instead of semi-weak ($10^{-35}$ cm$^2$).

The branching ratio between the unobserved $\mu \rightarrow e+\gamma$ and the normal $\mu \rightarrow e+\nu+\bar{\nu}$ decay is $\rho = 3\alpha N^2/8\pi$, where $N \sim 1$ if the intermediary vector meson has a "normal" magnetic moment of one magneton. This leads to $\rho \sim 10^{-3}$ which is 1000 times greater than the experimental upper limit.

There are two reasons, aside from the mild dependence on cut-off, why this calculation may not be, in a one-neutrino theory, entirely definitive evidence against the $B$-meson: (1) The localization of charge in a vector theory is ambiguous, so that a "normal" electromagnetic coupling is not defined by the principle of minimal electromagnetic coupling. (2) While the gauge invariance arguments suggesting the $B$-field would also suggest that its mass is zero, the $B$-meson if it exists must actually have a large mass. This also suggests a rather complicated structure for the $B$-meson so that a somewhat open mind should be retained as to its electromagnetic properties.

For these reasons, we have recalculated the effective $\mu e \gamma$ vertex as a function of the magnetic moment $(1+\lambda)\, e\hbar/2Mc$ and quadrupole moment $q$ that a spin one particle may, in general, possess. The formalism we have used is that in which the vector meson field is described by ten components $\phi_\mu$, $\phi_{\mu\nu}$ which obey first order equations of motion. For the electromagnetic coupling we chose the most general form invariant under Lorentz transformation and space-time reflections that can be formed from the undifferentiated meson field quantities. With this interaction we obtain, in collaboration with J. Young and Mrs. H. Hartmann, a result consistent with Ebel and Ernst and also Meyer and Salzman, who considered an anomalous moment but not a quadrapole moment nor the other $(\mu^2/M^2)$ terms of the same order. With the two parameters $\lambda$ and $q$ at our disposal the branching ratio can be made as small as we please. In particular $N$ can be made cut-off-independent and zero. Alternatively $\lambda$ and $q$ may be chosen to make the monopole and dipole factors both small enough so that the absence of both $\mu \rightarrow e+\gamma$ and the coherent $\mu+N \rightarrow e+N$ process need not exclude an intermediary vector meson nor compel us to a two-neutrino theory.

The choice of magnetic and quadrupole moments necessary to forbid these unobserved $\mu - e$ processes is certainly *ad hoc*. However, we know of no criterion fixing the form of electromagnetic coupling of a spin one meson, so that this explanation cannot be logically excluded. Actually, the most attractive way to forbid these processes is to say that $\mu$ and $e$ are obviously different leptons and that they must be accompanied by different neutrinos.

I would now like to propose briefly an experiment alternative to the neutrino experiments, to detect the intermediary boson if it exists. Lee and Yang and

Pontecorvo have proposed making $B$-mesons in the semi-weak process $\nu \rightarrow B + e$ which proceeds with a cross section, $\sigma \sim 10^{-35}$ cm$^2$ rather independently of boson mass and energy provided you are well above threshold. Since neutrinos are incapable of doing anything else semi-weakly, this is alright provided you have a high energy neutrino beam and can afford to wait for one count per day or hour. Now because they are charged, $B$-mesons can be photo-produced in pairs in the Coulomb field of a nucleus and the cross section for this is

$$\Phi = Z^2\alpha\left(\frac{e^2}{\mu_c^{\,2}}\right)^2 \sim 10^{-30}\ \mathrm{cm}^2$$

for $M \approx K$-mass. The cross section of course goes down as the square of the boson mass; on the other hand, since the particle has spin one, its cross section increases very rapidly with energy. This is a cross section that is a million times larger than the $10^{-35}$ cm$^2$ obtained with the neutrino beam. The problem is to distinguish the $B$'s that are produced from the background of other particles that are copiously produced. The $B$ decays promptly (in less than $10^{-17}$ seconds) into

$$B \rightarrow e + \nu\,,$$

$$B \rightarrow \mu + \nu\,,$$

$$B \rightarrow K + \gamma\,.$$

Quickly produced electrons or muons will be thrown well forwards, while the products of $B$-decay will be distributed at wider angles. We are chiefly concerned with muons or electrons originated from pions, that are also distributed at wide-angles. However, the large mass that the $B$ must have serves to distinguish its kinematics from that of other particles, and perhaps coincidence detection of $B^+$ and $B^-$ is possible. I also mention, for what it is worth, that the $\mu$ and $e$ from the weak $B$ decay will be partially polarized.

I am a theorist and so I should leave these "technical details" to my experimental colleagues. Some experimentalists, smarter than myself, who do not have a high energy neutrino beam, may be motivated to find a way to handle these background discrimination questions.

## DISCUSSION

BERNARDINI : I want to say that in CERN, using the high energy photons produced by the decay of the neutral pions (which are the by-products of the attempt to see the large angle muon pairs,) we also would like to see the $\mu$-$e$ pairs. When I mentioned this some time ago to Yang, he discouraged me, not from looking for the muon pairs, but in considering the $\mu$-$e$ pair clean evidence for the intermediate boson. I would now like him to tell them what he told me then.

YANG : My reasons were the reasons stated by Bludman : namely that for the experimentalists who do not have the high energy neutrino beam, this may be another way to detect intermediate bosons. It seems to me that if one has a neutrino beam it is better to do the neutrino experiment because then one would end up with no argument with other experimentalists or with theorists, but if you find something in the photon case you will end up arguing a long time because there are many pions produced which can also give rise to a muon and electron.

BERNARDINI : Certainly all these experiments are on the borderline of feasibility.

YANG : If one can possibly identify an intermediate boson, in whatever experiment, there are no objections. One experiment is just as good as another. But it seems much more difficult to do it this way than to do it with a neutrino beam.

BERNARDINI : I understand, but if one electron-muon pair would be found under kinematic conditions which would be automatically bound with the intermediate action of a heavy mass this will be as clean evidence as the neutrino experiments.

YANG : There will be two neutrinos coming out of the process also. How do you then get the mass?

BERNARDINI : I would like to establish at least a lower limit.

YANG : For example, if you do produce an $e$-$\mu$ pair experimentally, you have 2 counters which count a muon and an electron respectively. Then how do you prove that they have come from an intermediate boson pair?

BERNARDINI : From what else can they come?

YANG : Well, that is just where the argument is going to center. You cannot possibly identify them as positively coming from a pair of $B$'s. There is no unambiguous explanation unless you straighten out all the kinematics by measuring all the neutrinos too, but that would take a very ingenious device.

FEYNMAN : The experimental way to discover the $B$ that Bludman suggests should be part of a program. This experimental program, begun by Panofsky, involves the question of detecting, in a systematic way, all the possible particles which are charged. Just to give an illustration of the idea, suppose there exists an analogue to the muon : that the charged lepton spectrum is the electron, the muon, a new particle of mass 1200, etc. We are lucky that we can make the $\mu$ at all. We only make it easily because the $\pi$ decays. If it were heavier than the $\pi$, we would have no way to make it except by producing it in pairs with a gamma ray. So it is an interesting program to discover all the charged particles that exist. It gets harder and harder to do as the energy goes up. Therefore, it is a nice program. As you work harder and harder, you keep climbing up in the mass. We will pass the $B$ somewhere along the line and find it too.

BLUDMAN : The reason that I think you will pass the $B$ without finding it is that the $B$ is very, very short lived. Panofsky's program works for particles that live long enough to be seen in a magnetic field.

FEYNMAN : That is one way to detect particles directly, but if they are stable enough there are other obvious ways, such as looking for the wide angle electrons or the other particles which would be the disintegration products.

BERNARDINI : It is always difficult for me to tell if Feynman is speaking seriously or is joking. But anyway, I want to complete his program. We can even discover the magnetic monopole by this method. Do you agree?

FEYNMAN : If you are joking, yes.

GATTO : May I have some further comments about the statement that generating mesons from gauge invariances leads in general, to massless mesons?

BLUDMAN : I have no further comments on that. A naive look at gauge invariance arguments generally suggests that the $B$ field should be massless. I meant nothing much deeper than that. Note that I did not discuss the question of whether the $B$ field is a 3-component field or is a 4-component schizon.

YANG : There is a recent argument by Gürsey which gives very strong indications that one can prove that the $B$ field has mass zero. Gürsey pointed out that one can reduce the $B$ field mass problem to the photon mass problem.

PRIMAKOFF : Is a form factor effect included in your formula?

BLUDMAN : The figure $10^{-30}$ does not include a form factor effect. There is a form factor effect, an effect which in the Panofsky pair production of muons is a factor of 10, and which works against you near threshold. Once one gets away from threshold the form factor does not hurt you. There is also a quadratic energy dependence, for a spin one particle. That is working in your favor, and I have not put it in.