SUMMARY AND CONCLUSIONS OF THE VIth MORIOND WORKSHOP

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After a short introduction I shall discuss, very briefly, the following topics:

Direct measurements of the neutrino mass (section 3)
Double beta decay and Majorans (section 4)
The solar neutrino issue (section 5)
The dark matter (section 6)
Nucleon Instability (section 7)
Exotic theory (section 8)
Exotic particles (section 9)
The mirror symmetries C, P and T (section 10)
Cosmic rays and Cygnus X-3 (section 11)

1. Preface

Just before leaving Stockholm, to come to this Workshop, I received a telex from Tran who asked me to present the summary talk at this Workshop. I should have said no, as I had no time to prepare anything in advance, but how could I say no ? Tran has been such a wonderful host at all the Moriond Meetings which I have attended and I am very pleased to be able to thank him at this occasion.

The topic of this Workshop has been "Searches of New and Exotic Phenomena". We have heard almost hundred talks and contributions on a large number of topics. Unfortunately, in this summary I can only treat very few topics. I feel uneasy that I must leave out some very interesting topics such as granule detectors, bolometric detectors, proposals for detection of dark matter, etc. After all, detectors are of crucial importance for our future.

2. New and exotic

The first question we must settle is what is meant by NEW and EXOTIC phenomena ? This is not so difficult because the standard framework may be defined to be the Standard Electroweak Model together with QCD and Einstein's theory of gravity. New (exotic) phenomena are those which are new (exotic) with respect to the standard framework.

The minimal electroweak model has 3 families of quarks and leptons, one physical Higgs and massless neutrinos. Of course it is trivial to extend it such that there would be more families and/or massive neutrinos. It is also easy to introduce several Higgs doublets into the model. However, triplets and higher - plets of Higgses will in general (but not always) destroy the phenomenological successes of the model. As was emphasized by Björkén[1], the Higgs sector of the model acts as a "new" force, which he referred to as the fifth force. We are not happy with the Higgs sector, of the minimal electroweak model, because it adds 15 arbitary parameters (masses, mixings, etc.) to the 2 fundamental gauge coupling constants (g and g'). If the neutrinos are massive (at least) 7 more arbitary parameters must originate from the Higgs sector. Unfortunately, in the Standard Model there is no prediction for the neutrino mass. Let me now turn to data presented at this Workshop.

3. Neutrino masses

The evidence for a nonvanishing neutrino mass, presented[2] by ITEP in 1983 Brighton Conference created a great deal of excitement. Lubimov presented a lower limit of 20 electronvalts with 95 % CL ! This is the reason why in 1987 some 20 experiments are in progress measuring the electron-neutrino mass directly. In this Workshop, Lubimov[3] presented the latest results from ITEP

$$m = (26 \pm 6)\text{eV}, \qquad 95\%\ \text{CL}$$

where m is the electron-neutrino mass. He also presented a "model independent" value

$$m = (17 - 40)\text{eV}, \qquad 95\%\ \text{CL}$$

where the crucial assumption is that the end point energy is (18580.9 ± 4)eV. This end point energy is the measured value obtained in the Soviet Union[3]. At this Workshop a new measurement of the beta decay spectrum of free molecular tritium at Los Alamos was presented by Bowles[4] who quoted

$$m < 26.8\ \text{eV} \qquad 95\%\ \text{CL}$$
$$m < 23.3\ \text{eV} \qquad 90\%\ \text{CL}$$

and the value 18582.8 ± 20.0 eV for the end point energy. The Los Alamos experiment is expected to be sensitive to 10 eV upper limit, in the future[5].

It is interesting to note that in Moriond 86[6] three groups presented results on the electron-neutrino mass

ITEP[7]	(30.1 ± 2) eV	
SIN[8]	< 18 eV	95% CL
INS[9]	< 34 eV	

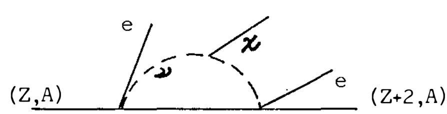
What is the conclusion to be drawn from the above results ? Clearly, the tritium experiment is a very difficult one and there is a clear clash between results presented by SIN and ITEP. All we can say is that, at the present, there is no convincing evidence for a nonzero neutrino mass and the upper limit is approximately 25 eV, for the electron neutrino mass.

4. Double beta decay and majorans

The two-neutrino double beta decay, $(Z, A) \to (Z+2, A) + 2e + 2\bar{\nu}$, was invented by Maria G Mayer more than 50 years ago. It has still not been seen in the laboratory. There is, however, some geochemical evidence for it from Se-Kr mother-daughter system. This process is expected to occur due to higher order charged current interactions.

The neutrinoless double beta decay, invented by Furry in 1939, goes via the diagram

where the virtual ν has to be its own antiparticle (Majorana particle) and massive. Otherwise the diagram gives a vanishing contribution. Finally a third possibility, double beta decay with Majoran emission, via diagram



has been much discussed recently.

If you ask the theorists who like Majorana neutrinos why do they do so they will tell you that their reasons are "emotional". Why should the neutrino mass be so small if it is a Dirac particle ? Other Dirac particles don't have small masses. Perhaps the smallness of the mass is due to neutrino having a different nature, i.e., its being a Majorana particle. This argument may turn out to be true but it is not convincing, at the present. The electron and the top quark are both Dirac particles and yet have vastly different masses. We don't understand masses. The Majorana neutrino is the simplest spin 1/2 object one could have. Why shouldn't Nature create such lovely creatures ?

Who wants Majorans ? Again, we don't understand lepton number conservation, seen so far in Nature. Perhaps the lepton number is not conserved but is spontaneously broken ? This is the assumption made in Majoran models[10]. In the Majoran models[10] one introduces appropriate scalar particles which carry lepton number. When the symmetry is spontaneously broken a Goldstone boson, called the Majoran, appears. The neutrino acquires its mass due to this spontaneous symmetry breaking and thus couples to the Majoran. As was discussed in detail by Caldwell[11] one may distinguish the 2-neutrino, neutrinoless and Majoran-induced double beta decays from their characteristic energy distributions, of the two electrons in the final state.

Two weeks ago there were rumors that the Majoran was discovered[12], in an experiment by Avignone et al, in Ge-Se transition. The reported half-life was 6×10^{20} yrs. At this Workshop we heard several contributions[11,13,14] on this topic and the results reported were

$$\tau_{1/2} > 10^{21} \text{ yrs} \qquad \text{Caldwell}^{11)}$$
$$> 5 \times 10^{20} \qquad \text{Fischer}^{13)}$$

Furthermore we were promised better limits very soon. I am very much impressed by how quickly the experimental groups can check each others results so that theorists don't go too much astray.

We heard from Boris Kayser[15] that if

$$\Gamma(\text{Ge} \to \text{Se} + e + e) = 1/\tau_o$$

would be found to be nonzero, then there will be a lower limit on the mass of (at least) one of the neutrinos. The limit reads

$$m > 1 \text{ eV} \sqrt{\frac{10^{24}}{\tau_o(\text{yr})}}$$

5. The solar neutrino issue[16]

At this Workshop there were several talks on the solar neutrino problem. The problem is that the flux of high energy neutrinos (energy above 0.8 Mev) from the sun is approximately 3 times smaller than expected. Although this issue is, by now, quite old it still triggers a great deal of attention. Several new solar neutrino experiments are planned. Among the possible explantions of the solar neutrino problem let me list

a) the experiment is wrong ?
b) the temperature in the solar core is 10% lower than conventionally expected ?
c) neutrino oscillations ?

In my opinion the first possibility (a) can not be excluded. In the past several excellent experiments were eventually found to have been wrong, e.g. the K_L puzzle turned out to be no puzzle at all. The experiment was wrong and yet no one could find anything wrong with it.

A possible mechanism for lowering the temperature of the solar core was discussed by Faulkner[17)]. The model assumes the existence of weakly interacting massive particles (WIMPs) with masses in the range 5 - 8 Gev and typical weak interaction cross sections. They can not be too heavy because otherwise they will not get out of the core and thus will not be able to cool it. If they are too light they will evaporate too quickly. The model also predicts some characteristic helioseismological effects which were discussed by Fröhlich[18)]. These effects, by which the sun radius oscillates in time, are of course very interesting on their own right. As far as the WIMPs are concerned, there are no such charged objects as they have not been found at the electron-positron colliders. Thus they are more like heavy stable "neutrinos". To exclude them we must use similar arguments as used in excluding heavy neutral objects.

The neutrino (vacuum) oscillations can easily reduce the flux of electron neutrinos from the sun. With 3 neutrino flavours and complete mixing the flux is expected to decrease by a factor of three, in agreement with Davis experiment. This possibility is not excluded because if the oscillation length is comparable with 8 light minutes the reactor and accelerator experiments done so far are not sensitive. With 3 neutrino families, the theoretical description of neutrino oscillations involves six unknown parameters (3 mixing angles and 1 phase in the lepton mixing matrix as well as 2 differences of the squares of the neutrino masses).

At this Workshop, Smirnov[19)] presented some new results on the so called matter oscillations which can be very effective in reducing the neutrino flux even if the mixing angles were small. The sun is made of ordinary matter which contains electrons (but not muons, etc.). The electron-neutrino thus interacts differently with matter than muon-neutrino and the tau-neutrino. As the "neutrino wave" propagates through the sun, the phase of the electron-neutrino component changes because of the index of refraction due to the forward scattering amplitude (generated by charged current interactions). This index of refraction is proportional to the density of the electrons in the sun. This density is largest at the core and falls to zero at the surface. One must diagonalize the neutrino "mass matrix" taking the density change into account. The amount of electron neutrino in the wave will depend on the unknown parameters mentioned before, the solar density and the traversed distance. The important point is that for certain range of parameters the matter oscillations can be very effective[19] in reducing the electron-neutrino flux.

One may be able to test the matter oscillation model in the near future. As we have heard, several solar neutrino detectors are now under construction[20]. Detectors with different neutrino energy thresholds will help. One may also be able to see[19] day/night and summer/winter effects. For example, if the matter oscillation length is comparable with the size of the earth, the electron-neutrinos may hit the detector only at night. Several scenarios are discussed, in detail, by Smirnov[19]

6. The dark matter

At this workshop, the present status of the missing light in the universe was discussed in detail by Lachièze-Rey[21] and also by Sikivie[22]
Definig

$$\Omega = \Omega(\text{vis}) + \Omega(\text{dark}),$$

where Ω is the density of the universe normalized to its critical density; the two terms in the above equation denote the contributions due to the luminous matter and the "missing" or "dark" matter respectively. Measurements give $\Omega(\text{vis}) < 0.02$ and $\Omega \approx 0.2$. The inflationary model of the universe requires $\Omega = 1$ which seems to be excluded. However, we were warned[21], that at very large scale Ω could be much larger. Last year, at this Workshop, Steigman[23] summarized the dark matter situation. The present status is very similar to that of last year. There could be ten times more dark matter, in the universe, than there is visible matter. Assumming that the dark matter is really there the immediate questions which it gives rise to are what does it consist of and how can one detect it. These questions were discussed in several talks[24] at this Workshop. Nobody seems to like baryonic dark matter candidates (such as Jupiters) however that possibility can not be excluded. Nonbaryonic dark matter can-

-didates are much more exciting because they might actually teach us new physics. My favorite candidates are axions or axion-like objects, i.e., particles which do something for us, in addition to making up the dark matter.

Several speakers[25], at this Workshop, addressed the question of granule and bolometric detectors, for the detection of the dark matter.

7. Nucleon instability[26]

The proton stability is a mystery, which we don't understand. In most models (such as grand unified theories and super symmetric models) it is so easy to draw diagrams through which the protons could decay in a fraction of a second. At this Workshop we heard the present status[26,27] of nucleon decay based on 10 kiloton yrs matter equivalent. The present limits typically read

$$\tau/B \; > 10^{31} - 3 \times 10^{32}$$

for a large number of final states. Here τ is the proton life time and B the branching ratio. For example, for the mode proton → positron + pi-zero the present limit, from the Kamiokande collaboration[26], is 10^{34}. The minimal SU(5) is excluded by the nucleon instability experiments. This is a pity, perhaps. The model has several attractive features (unification of electroweak interactions with QCD; quantization of charge, etc.) Of course, the 19 Higgses of SU(5) did not look very attractive and the model could not attack questions such as why are there (at least) three families.

I believe that the nucleon instability experiments have, nevertheless, been a great success. Not only have they improved the limit on the proton lifetime by several orders of magnitude, they have also given invaluable information on neutrino oscillations and cosmic rays. (The most spectacular success of these detectors is the observation of neutrinos from the supernova 1987 in the Magellanic Cloud which occured 3 weeks after the Conference.)

8. Exotic theory

The Higgs sector of the Standard Model may turn out to be much more exotic than expected. Experiment tells us that the Higgs mass is larger than about 11 - 14 MeV: this limit comes from looking for a Higgs-

-induced $0^+ - 0^+$ transition in ^{4}He. At this Workshop, Peccei [10] addressed the question of what would happen if the Higgs mass would be larger than say 10 TeV. His conclusion was that the Higgs will then become a σ -like object and will be very hard to establish. A gedanken experiment was presented by Björkén[1]. What would happen if we let the gauge coupling constants g and g' go to zero but keep the vacuum expectation value, v , of the Higgs field a constant ? This he called the gaugeless limit of the Standard Model which is useful for a better understanding of the fifth force (Higgs-mediated forces). The gauge bosons will be massless, their longitudinal components will behave as Goldstone bosons. The moral of the study was that the Higgs sector may turn out to be very complicated and the future experiments might have to face the difficult task of searching for a σ -like object.

Another topic which was discussed was search for deviations from the Standard Model in precision measurements. In the Standard Model there are no comparable precision tests to electron/muon g-2 or Lamb shift tests of QED. Nevertheless, as discussed by Peccei[10] and Langacker[28], the neutral current data and radiative corrections are very useful in providing limits, in a large number scenarios. From a global fit to the neutral current data, one finds[28]

$$\sin^2 \theta_W = 0.230 \pm 0.004 \equiv 1 - M_W^2 / M_Z^2 ,$$

and

$$\Delta r = 0.078 \pm 0.036.$$

Here Δr is the famous radiative correction in the formula for the W-mass. The dominant contribution to Δr comes from the vacuum polarization diagram. For example one obtains that[28]

$$m_t < 126 \text{ GeV} \qquad 90\% \text{ CL}$$

if there are three families. If there is an additional Z-boson one find[28] that the lower limit on its mass is 125 - 350 GeV. Of course, the limits depend on the specific assumptions made about the coupling constants. R. Cahn[29] gave a detailed analysis of signatures of the Higgs boson produced at SLC and LEP.

9. Exotic particles

The most exotic looking particle in recent times has been the Darmstadt 1.8 MeV object. At this Workshop the status of this 1.8 MeV "line" was extensively discussed by Bokemeyer[30]. The conclusion to be drawn is that the 1.8 MeV object is not a particle. The point was that a particle can not possibly always be produced at rest. The question is then what is it? The answer did not emerge from the discussions. Furthermore, a beam dump experiment[31] at SLAC has looked for a pseudoscalar particle coupling to an electron - positron pair. The mass range between 1.0 MeV and (2.2 - 3.2)MeV, could be excluded by the experiment. The uncertainity in the upper limit of the range originates[31] from the theoretical uncertainty in the electron g-2.

10. The mirror symmetries C, P and T

In the Standard Model parity and C violation are put in by hand when constructing the model. Thus we can not hope to "understand" these symmetries. CP-violation, however, requires the existence of at least 3 families. If the neutrinos are massless, there will be no CP-violation in the leptonic sector. Actually conditions for CP-violation in the Standard Model, with 3 families, are a bit more subtle than just stating that there is a phase in the quark mixing matrix. CP-violation prerequisities non- degenercy of the quarks with the same charge and $\theta_i \neq 0, \pi/2; \delta \neq 0, \pi$, i.e., altogether 14 conditions. These conditions are unified in a single relation stating that the determinant of the commutator of the mass matrices (for the charge 2/3 and charge -1/3 quarks) must be nonsingular. In the QCD sector we have the strong CP problem which manifests itself by the appearance of the so-called theta-term. From the most recent results, on the electric dipole moment of the neutron presented by Dubbers[32] at this Workshop we have $\theta < 5 \times 10^{-10}$. The θ-puzzle is then why is θ so small ? The axion is the most elegant solution to this problem, found so far.

At this Workshop we heard several theoretical contributions on mirror symmetries[33-37]. Several speakers emphasized the importance of looking for CP and T violation outside the K-$\bar{K}$ system. Furthermore, more accurate measurements in the K-system (e.g CP-violation in the decay $K \to 3\pi$) were requested by theorists.

On the experimental side [32,38] the limits 10^{-25} (neutron), 4×10^{-21} (proton) and 2×10^{-24} (electron), all in ecm were presented on the electric dipole moments of the particles indicated in the parenthesis. We heard from Raab[38] that much improvement of the upper limits on the electric dipole moments is expected from atomic measurements. As far as the neutron electric dipole moment is concerned the Standard Model predicts a value smaller than about 10^{-31} ecm. Thus deviations from the minimal Standard Model might show up if the next round of experiments would find an effect.

An important question, discussed at this Workshop[34-36], was whether the most recent measurement of the ratio ϵ'/ϵ is consistent with the predictions of the electroweak model with 3 families ? The 1987 value obtained by the Chicago-Saclay collaboration reads $+0.0035 \pm 0.003 \pm 0.002$. The answer was yes. However it was argued by Gérard[36] and also confirmed by Holstein[34] that if this ratio would be found to be less than 2×10^{-3} there will be need for new physics.

11. Cosmic rays and Cygnus X-3

For completeness, let me remind you that we heard several talks[39] on VHE (very high energy) gamma rays (100 GeV - 100 TeV) and UHE (ultra high energy) gamma rays (with energies beyond 100 TeV). A great deal of information has been accumulated by several collaborations. Unfortunately, I could not understand what was the most essential message from these observations and would like to refer the readers to the talks given[39].

The problem of Cygnus X-3 has been with us for sometime. See, e.g. the proceedings of the 19th Rencontre de Moriond in which gamma rays from Cygnus were discussed. In the last year's Moriond Meeting (21th Rencontre) several articles were devoted to the Cygnus. What is the present situation ? The situation can be summarized[40] by simply stating that there is no evidence for underground muons from Cygnus X-3. This is because the evidence deposited in the detectors Nusex[41] and Frejus[42] are contradictory. The same goes for the detectors Soudan-I and Baksan. Furthermore, the effect seen[43] in the IMB-detector is very marginal. As far I understood, there is no way to get rid of the above contradictions by arguments such as lack of simultaneous measurements, etc. My conclusion is that we have to be patient and hope that this very important issue will soon be resolved. Of course, it would have been wonderful to receive muons produced by particles coming all the way from the Cygnus.

12. Conclusions

This Workshop has been very exciting. Following the tradition started by Pauli, we have been discussing a large number of exotic and as yet nonexisting particles, with masses from zero (the graviton and the para-photon) all the way up to 10^{24} eV (magnetic monopoles). We have discussed how to look for the gravity waves, axions, the Higgs particle, susinos, new gauge bosons, new Higgses, WIMPs and the particles of the "Shadow World". This Workshop has also killed one particle (the Majoran), at least for the time being. Suppose none of these particles exist. Have we then wasted our time ? The answer is no. By considering such a large variety of particles and designing detectors for them at least we can be somewhat sure that our detectors will, most probably, be adaptable to cope with unforseen situations. Finally, I did not at all mention the papers presented on the other fifth forces, i. e., modification of gravity at intermediate distances. That subject is summarized by Alvaro de Rujula.

Acknowledgements

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