NEUTRINOS, PAST AND PRESENT

Talk at Stony Brook, October 11, 2002

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Identification of Beta-Rays with Atomic Electrons

M. GOLDHABER AND GERTRUDE SCHARFF-GOLDHABER
Department of Physics, University of Illinois, Urbana, Illinois
May 8, 1948

Reprinted from THE PHYSICAL REVIEW, Vol. 96, No. 4, 1157–1158, November 15, 1954
Printed in U. S. A.

Conservation of the Number of Nucleons*

F. REINES AND C. L. COWAN, JR., *University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico*

AND

M. GOLDHABER, *Brookhaven National Laboratory, Upton, New York*

(Received September 27, 1954)

overlay 3

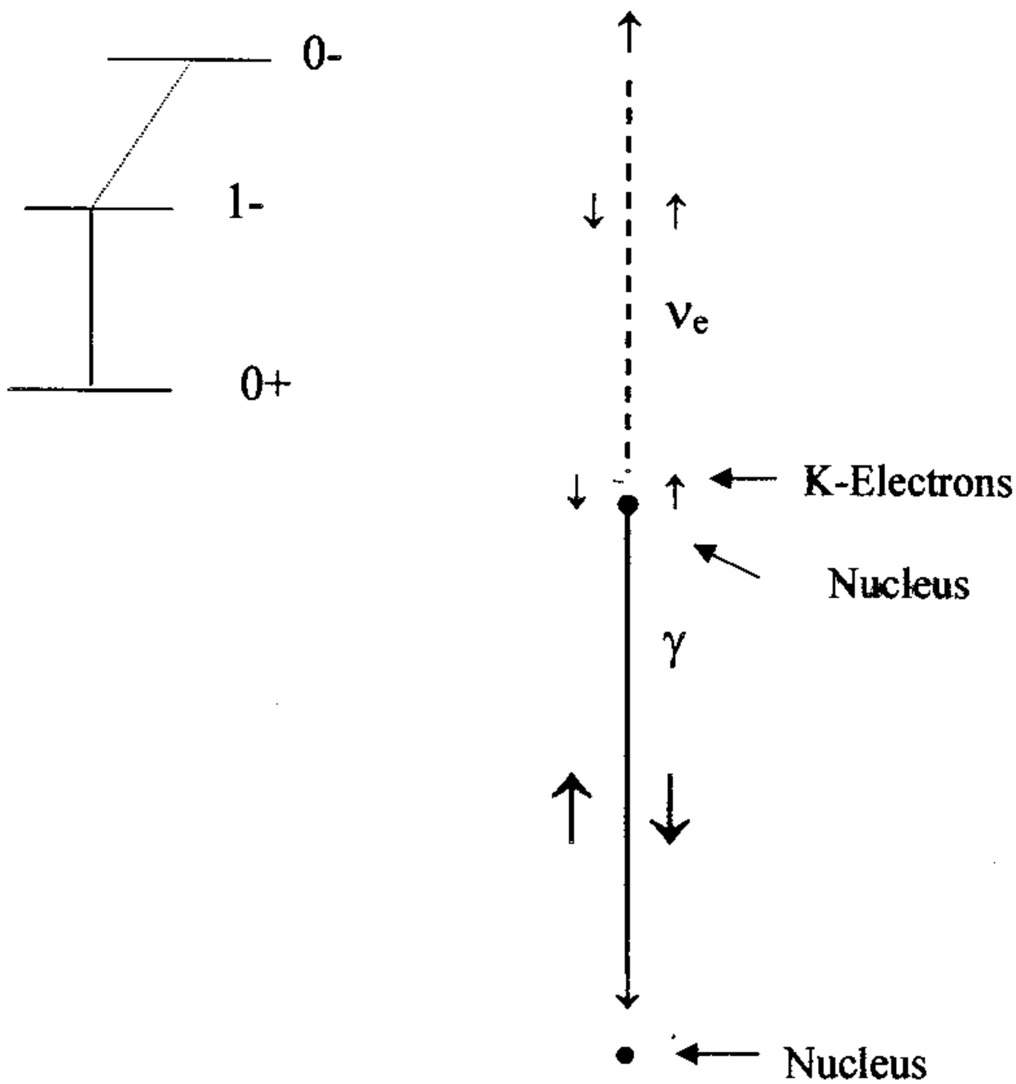
Reprinted from THE PHYSICAL REVIEW, Vol. 109, No. 3, 1015-1017, February 1, 1958
Printed in U. S. A.

Helicity of Neutrinos Emitted in Beta-Decay

~~Helicity of Neutrinos*~~

M. GOLDHABER, L. GRODZINS, AND A. W. SUNYAR
Brookhaven National Laboratory, Upton, New York
(Received December 11, 1957)

Overlay for Fig 3


0-
1-
0+
ν_e
K-Electrons
Nucleus
γ
Nucleus

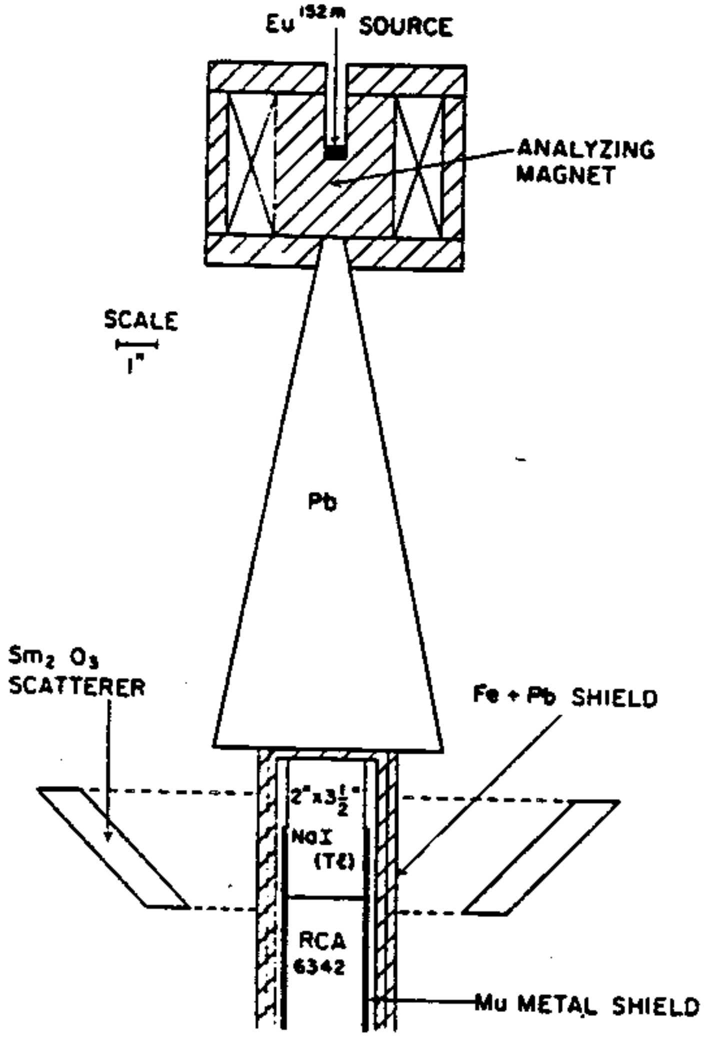


FIG. 1. Experimental arrangement for analyzing circular polarization of resonant scattered γ-rays. Weight of Sm_2O_3 scatterer: 1850 grams.

Estimate of the Neutrino Mass Eigenstates

In a recent paper,

M. Goldhaber, Proc. Nat. Acad. Sci., Vol. 99, 33 (2002)

A Closer Look at the Elementary Fermions

(With Minor Corrections – hep-ph/0201208),

it is emphasized that rules based on empirical data can be considered as *proto-theories* with predictive power, often pointing the way to final theories. You are probably aware of many past examples where such predictions, based on extrapolations, were confirmed by experiment and integrated into theories, not necessarily in that order!

THE THREE GENERATIONS OF ELEMENTARY FERMIONS

$$\begin{pmatrix} t & \tau \\ b & \nu_\tau \end{pmatrix} \qquad i = 3$$

$$\begin{pmatrix} c & \mu \\ s & \nu_\mu \end{pmatrix} \qquad i = 2$$

$$\begin{pmatrix} u & e \\ d & \nu_e \end{pmatrix} \qquad i = 1$$

Generalized to

$$\begin{pmatrix} u_i & e_i \\ d_i & \nu_i \end{pmatrix}$$

Elementary fermions of different generations have equal universal interactions and the same 'generational position', forming a 'family' to be referred to as f_i.

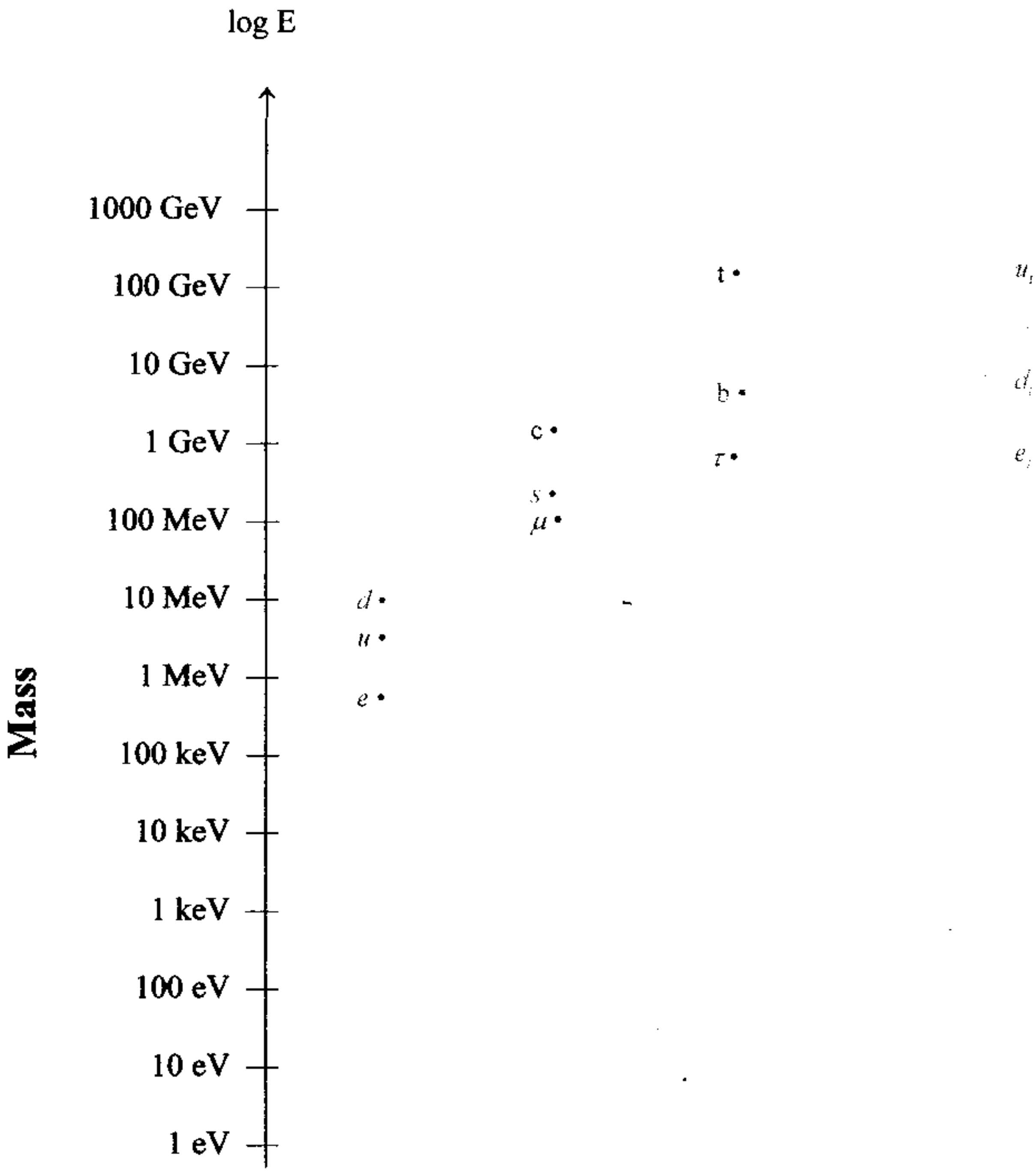

log E
1000 GeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 keV
10 keV
1 keV
100 eV
10 eV
1 eV
Mass
t
b
c
τ
s
μ
d
u
e

Figure 4

The definitive evidence for the existence of neutrino oscillations for atmospheric and solar neutrinos proves that neutrinos have finite masses. The Standard Model predicts zero masses for neutrinos, because of the assumption of chiral symmetry and leaves the 'heavy lifting' for other fermions to the Higgs. If we are guided by Rule 1, this should no longer be considered a mystery, because neutrinos, whose dominant interaction is the weak one, are then expected, to have finite, though small, masses.

RULE 1. *Within* each generation, the known masses of the elementary fermions are found to be correlated with the strength of *their* dominant interaction, thus with the hierarchy of the universal interactions. We shall call this the *first hierarchical mass relation*.

RULE 2. The known masses of those elementary fermions that have *equal* dominant interactions (f_i) increase as i increases – a *second hierarchical mass relation*, usually referred to as *the* hierarchical mass problem.

The masses of the elementary fermions with equal dominant interactions f_i, (Rule 2), allow us to express the following sub–rule:

$$\textbf{(Rule 2')}\quad m_{f_i}^{\,2} \ll m_{f_{i+1}}^{\,2}.$$

The question of whether neutrino-mass eigenstates are hierarchical or the reverse has been much discussed, but since there is no known exception from the hierarchical nature of the known masses of elementary fermions, it seems reasonable to assume that Rules 2 and 2' also hold for the neutrino mass eigenstates:

$$m_1 < m_2 < m_3$$

$$\text{and}\quad m_1^{\,2} \ll m_2^{\,2} \ll m_3^{\,2}.$$

It then follows from the Super-Kamiokande atmospheric neutrino results:

$$\Delta_{32} \equiv m_3^{\,2} - m_2^{\,2} \approx 2.5 \times 10^{-3}\ (\text{eV})^2,$$

and from the preferred SMW value found by SNO for solar neutrinos:

$$\Delta_{21} \equiv m_2^{\,2} - m_1^{\,2} \approx 5 \times 10^{-5}\ (\text{eV})^2.$$

and that according to Rule 2' we can neglect $m_i^{\,2}$ relative to $m_{i+1}^{\,2}$, that

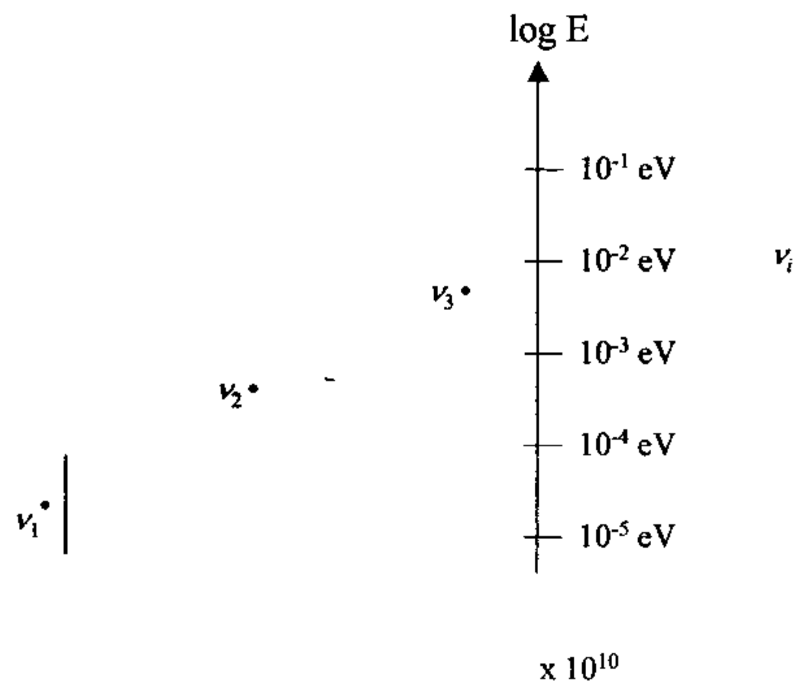
$$m_3 \approx \sqrt{\Delta_{32}} \approx 5 \times 10^{-2}\ \text{eV}$$

$$\text{and}\ m_2 \approx \sqrt{\Delta_{21}} \approx 7 \times 10^{-3}\ \text{eV}.$$

As the measurements improve, it may be possible to sharpen our arguments. If either the conclusion that the S-M-W effect plays a role for solar neutrinos in the Sun will be strengthened by the Kamland experiment, or the hints of the existence of a day-night effect for solar neutrinos will be confirmed, or both, $m_2>m_1$ would follow, confirming the hierarchical order of the neutrino mass eigenstates.

The estimated neutrino mass eigenstates are compared in the overlay for Figure 5 with the hierarchical masses known for the elementary fermions.

The large (near maximal) mixing found for the neutrino mass eigenstates may be due to the magnifying effect of any mixing interaction by the closeness of the mass eigenstates.



Overlay
to Figure ~~#~~ 3

~~Figure~~ 5

It may, therefore, be of interest to compare the ratios m_i/m_{i+1} for neutrinos with the ratios for the charged leptons with their well known masses, found to be intermediate between the other ratios (for u_i and d_i). We find that $m_2/m_3 \approx 1.4 \times 10^{-1}$ is ~2.2 times larger than the ratio $m_\mu/m_\tau = 5.9 \times 10^{-2}$.

For an estimate of m_1, we shall use as an approximate guide for the ratio m_1/m_2 the ratio $m_e/m_\mu = 4.8 \times 10^{-3}$, which yields

$$m_1 \approx 4.8 \times 10^{-3} \ m_2 \approx 2.4 \times 10^{-5} \text{ eV}.$$

We shall assume that this is also uncertain by a factor of ~2.2; in this case, however, it would be safer to assume that such a deviation could be in either direction, leading to an estimated range

$$m_1 \approx (2.4 - 7.4) \times 10^{-5} \text{ eV}.$$

As a further test we deduce m_1 differently by using the relation

$$m_1 = m_e/m_\tau \cdot m_3 = \frac{0.51}{1.777 \times 10^{3}} \cdot 5 \times 10^{-2} \text{ eV} = 1.44 \times 10^{-5} \text{ eV},$$

suggesting a probable range for m_1 of $(10^{-5} - 10^{-4})$ eV.