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Neutrino Studies in ^{100}Mo and MOON
-Mo Observatory Of Neutrinos-

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The MOON (Molybdenum Observatory Of Neutrinos) project is a hybrid $\beta\beta$ and solar ν experiment with ^{100}Mo. It aims at high sensitive studies of $\beta\beta$ decays with a sensitivity of $< m_\nu > \sim 0.03$ eV and real-time studies of *pp* and ^{7}Be solar ν's. The double β rays from ^{100}Mo are measured in prompt coincidence for the $0\nu\beta\beta$ studies, and the inverse β rays from solar-ν captures of ^{100}Mo are measured in delayed coincidence with the subsequent β decay of ^{100}Tc. Measurements with good position resolution enable one to select true signals by spatial and time correlations.

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1. NEUTRINO STUDIES IN ^{100}Mo MICRO LABORATORIES

The recent experimental data and theoretical analyses for ν oscillation experiments suggest effective Majorana ν masses of the order of 0.1 $\sim$ 0.01 eV if the neutrino is a Majorana particle and the mass spectrum is of the quasi-degenerate type or with inverted hierarchy. Thus it is of great interest to measure $\beta\beta$ decays with the sensitivity of the effective mass $< m_\nu >\sim$ 0.03 eV. Realtime studies of solar ν's have been made of the high energy component of ^{8}B ν's. It is now important to make realtime studies of the low energy solar ν's, which are the major component of the solar flux.

^{100}Mo is shown to have large responses for both the $\beta\beta$ decays and the low energy solar ν's [1] [2]. The MOON (Molybdenum Observatory Of Neutrinos) project is a "hybrid" $\beta\beta$ and solar ν experiment with $\sim$ 1 ton of ^{100}Mo. It aims at high sensitive studies of the $\beta\beta$ decays with sensitivity to Majorana mass of the order of $< m_\nu >\sim$0.03 eV and the charged-current neutrino spectroscopy of the major components of the pp and ^{7}Be solar ν's [3]. The oscillation survival probability is expected to exhibit a strong energy dependence below 1 MeV.

The unique features of MOON are as follows.

1. The β_1 and β_2 with the large energy sum of $E_1 + E_2$ are measured in coincidence for the $0\nu\beta\beta$ studies, while the inverse β-decay induced by the solar ν and the successive β decay are measured sequentially in an adequate time window for the low energy solar-ν studies. The isotope ^{100}Mo is the only one that satisfies the conditions for the $\beta\beta$-ν and the solar-ν studies.

2. The large Q value of $Q_{\beta\beta}$=3.034 MeV gives a large phase-space factor $G^{0\nu}$ to enhance the $0\nu\beta\beta$ rate and a large energy sum of $E_1 + E_2 = Q_{\beta\beta}$ to place the $0\nu\beta\beta$ energy signal well above most backgrounds (BG). The transition rate for the possible ν-mass of $< m_\nu >$ = 0.02$\sim$0.03 eV is of the same order of magnitude as the solar-ν capture rate.

3. The energy and angular correlations for the two β-rays identify the ν-mass term for the $0\nu\beta\beta$ decay.

4. Measurements of the $0\nu\beta\beta$ decays to both the ground and the 1.132 MeV excited 0^+ states in ^{100}Ru may complement each other since their experimental conditions are quite different. The $0\nu\beta\beta$ phase space for the excited state is smaller by one order of magnitude than that for the ground state, but the $2\nu\beta\beta$ transition rate is two orders of magnitude smaller. Thus the $2\nu\beta\beta$ tail in the $0\nu\beta\beta$ window is much less for the excited state. Nuclear matrix elements for the two $0\nu\beta\beta$ decays may be different.

5. The low threshold energy of 0.168 MeV and the large responses for the solar-ν absorption allow observation of low energy sources such as pp and ^{7}Be. The pp and ^{7}Be ν's are captured only into the ground state of ^{100}Tc, the capture rate of which can be obtained from the EC capture rate [4].

2. NUCLEAR RESPONSES OF ^{100}Mo FOR NEUTRINOS

The $\beta\beta$ transition rate for $< m_\nu > = 0.05$ eV is evaluated to be 31 per year(y) per one ton(t) of ^{100}Mo isotopes for the ground state transition. Here the nuclear matrix element, as calculated by RQRPA, is used [5]. This is one order of magnitude larger than the rate for ^{76}Ge. The rate for the excited state is expected to be around 4 per y t by using the same matrix element as for the ground state.

Table 1
Solar-ν capture rates in units of SNU [1] [2] [6]. The ν flux is based on the SSM without ν oscillations [6]

Nucleus	$-Q$ value(MeV)	pp	^{7}Be	^{13}N	pep	^{15}O	^{8}B	Total
^{2}H	1.442	0	0	0	0	-	6	6
^{37}Cl	0.814	0	1.1	0.1	0.2	0.3	6.1	7.9
^{40}Ar	>1.505	0	0	0	0	0	7.2	7.2
^{71}Ge	0.236	70.8	35	3.7	2.9	5.8	12.9	132
^{100}Mo	0.168	639	206	22	13	32	27	965
^{115}In	0.120	468	116	13.6	8.1	18.5	14.4	639
^{127}I	0.789	0	9.4	-	-	-	13	24.6

The charged current ν capture rates for individual solar ν sources are derived from the $B(GT)$ values measured by the charge exchange (^{3}He,t) reaction [2] at the RCNP cyclotron laboratory. Then the solar ν capture rates are deduced from the measured GT strengths as shown in Table 1 [1]. Here capture rates for other nuclei are also shown.

The raw count rates for the pp and ^{7}Be ν's are expected to be 121 and 39, respectively, without ν oscillations, and around 70 and 20 with the LMA oscillation.

3. MOON DETECTOR

MOON is based on the recent $\beta\beta$ studies of ^{100}Mo by ELEGANT V [7] and the solar ν studies by SNO [8]. In order to achieve adequate sensitivities for both the $0\nu\beta\beta$ decays and the low energy solar ν's, the MOON detector is required to have

1. ^{100}Mo isotopes of the order of 0.5 $\sim$ 1 ton.
2. Energy resolution of $\sigma = 0.03 \sim 0.04 /\sqrt{E(MeV)}$.
3. Position resolution corresponding to a subdivision of 10^{-9} to reduce $2\nu\beta\beta$ and radio isotope (RI) accidental coincident BG events.
4. RI impurities of the order or less than 10^{-3} Bq /ton (0.1 ppt of U and Th) to reduce correlated and accidental BG's.

Enriched ^{100}Mo isotopes with 85-90 % enrichment are obtained by centrifugal separation and/or laser separation methods in a reasonable time and cost. Purification of the source to the ppt level is realistic [9].

Since MOON detects two charged particles(β rays) for both the $\beta\beta$ and solar ν studies, the β-β event can be localized tightly in space and time windows in order to select the $\beta\beta$ and the solar ν signals.

Most of the natural and cosmogenic RI BG's are accompanied by γ rays. Then SSSC(Signal Selection by Spatial Correlation) is used to select two β signals and to reject all BG signals associated with γ rays.

Two β rays from the $\beta\beta$ decay are emitted simultaneously, while those from the solar ν capture followed by the successive β decay are emitted in the time interval of around 30 sec. On the other hand BG's from natural and cosmogenic RI's are mostly accompanied by pre- and/or post β - α decays in time intervals of hours $\sim$ days. Consequently the $\beta\beta$

and the solar ν signals are well separated from the BG ones by SSTC(Signal Selection by Time Correlation).

Research and development programs for solid and liquid scintillators are in progress. A possible option for the solid scintillator is a supermodule of hybrid plate and fiber scintillators. One module consists of a plate scintillator and two sets of X-Y fiber/wave length shifter (WLS) scintillator planes, between which a thin ^{100}Mo film is interleaved. The fiber/WLS scintillators coupled with multi-anode photomultiplier tubes (PMT's) enable one to get the necessary position resolution of $\sim 10^{-9}$ and the scintillator plate (X-Y plane) with multi PMT's at both X and Y sides provides an adequate energy resolution to satisfy the physics goals.

^{100}Mo with the low threshold energy for the ν capture has been shown to have large charged-current responses for supernova ν's. Thus MOON can be used to study the low energy ν_e spectrum and the $\nu_x \rightarrow \nu_e$ oscillation by using thick ^{n}Mo plates of $\sim$ 100 tons in place of thin Mo foils [10].

MOON, where the $\beta\beta$ source and the detector isotopes are different, may be used to study other $\beta\beta$ isotopes such as ^{150}Nd and ^{116}Cd as well by replacing Mo isotopes with other isotopes.

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