ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN/AE-92/28
11 Novembre 1992

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INFN - Istituto Nazionale di Fisica Nucleare
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ABSTRACT

We suggest "on line" detection of solar and other types of neutrinos by interactions on ^{81}Br leading to the excited state at 190.4 keV of ^{81}Kr. The signal for a monocromatic neutrino will consist of a delayed coincidence between an electron pulse corresponding to the neutrino energy decreased by 471 keV, and the 190.4 keV de-excitation pulse. The coincidence time (13.1 seconds in average) allows an efficient use of large thermal detectors operating at low temperature which have been proved to provide energy resolutions and stability comparable to those of Ge diodes.

A bolometer made by a crystal of one kilogram of NaBr is being constructed to be operated underground in order to investigate the thermal properties, the resolution and the background . If this first approach would be satisfactory we will suggest the construction of a pilot set-up of ten tons made by an array of these bolometers, to be also used to search for dark matter, as a fisrt step towards a 100 tons solar neutrino experiment. We also consider the alternative approach of an array of CsBr scintillators.

1. INTRODUCTION

Recent results on solar neutrinos [1-6] have stimulated the interest on more detailed experimental investigations on the different sources of production of these particles in the fusion chains [7] occurring in the Sun (fig.1) . In fact the radiochemical Homestake experiment [1], based on the ^{37}Cl - ^{37}Ar transition with an energy threshold of 813 keV, indicates a flux of only $(28 \pm 5)\%$ (with 1 sigma errors) with respect to the Standard Solar Model predictions of Bahcall and Ulrich [7]. This experiment is accessible mainly to ^{8}B and ^{7}Be neutrinos. The water Cherenkov experiment of Kamiokande, based on solar neutrino scattering on electrons, with a large energy threshold and accessible only to ^{8}B neutrinos, indicates a somewhat lower discrepancy , namely an experimental neutrino rate of $(49 \pm 5_{stat} \pm 6_{syst})$ % with respect to the theoretical predicted one. One has to point out however that predicted values of B and Be neutrino fluxes are strongly dependent on the central temperature of the Sun (T^{18} and T^{8}, respectively), while this dependance is much weaker for p-p neutrinos ($T^{-1.2}$) .

The low energy region of the solar neutrino flux has been recently explored by two radiochemical experiments based on the reaction ^{71}Ga - ^{71}Ge where, due to the low energy threshold (233 keV), about 54% of the signal is expected from the p-p chain . A preliminary result [3] by the Russian-American collaboration SAGE indicated no effect induced by solar neutrinos yielding a rate of $20\ ^{+15}_{-20}$ (stat) $\pm$ 32 (syst) SNU versus a value ranging from 125 to 132 SNU predicted by the SSM [7,8]. The Gallex Collaboration reported [4] a positive value of $83 \pm 19 \pm 8$ SNU, which has been recently [5] confirmed also by SAGE ($85\ ^{+22}_{-32}$ (stat) $\pm$ 20 (syst)). The Gallium experiments do not contradict the production of solar neutrinos from the p-p reaction with the full expected density. Before assuming new neutrino physics as a consequence of solar neutrino oscillations or decay it is essential to measure the various components of solar neutrino flux. A list of about one hundred nuclei which could be candidates for solar neutrino experiments has been suggested in [9] , and various new experiments, with different techniques have been recently designed [6,9]. Four of them , all based on the direct "on line" detection, have been, at least partially, approved: Borexino, Icarus, Superkamiokande and SNO. The signal in all of them is a continuous spectrum of electron energy. Only the first of these experiment, with an expected threshold of 250 keV, should be sensitive to ^{7}Be neutrinos.

As far as we know, the search proposed here , with the possible exception of the ^{115}I experiment [10], is the only one aimed to discriminate directly one or more solar neutrino sources in a sort of *solar neutrino spectroscopy* [11]. We are fully aware that the experiment considered here is extremely difficult and perhaps impossible, but we believe that its scientific interest is such to justify a feasibility study,which we

plan to carry out in the next year. We would like to stress that this type of neutrino spectroscopy can find important applications in other type of experiments performed with sources different from solar neutrinos.

2. THE PRINCIPLE OF THE EXPERIMENT

The experiment considered here aims to search for solar neutrino interactions on ^{81}Br leading to the $1/2^-$ excited state of ^{81}Kr [12] at 190.4 keV (Fig.2) and to detect its relatively long living decay. We would like to stress that this search is radically different from the experiment on the extraction of ^{81}Kr atoms proposed independently by R.D.Scott [13] and T.Kirsten and W.Hampel [14]. These and further proposals or discussions [15-24] are based on counting ^{81}Kr atoms either by geochemical methods of with Resonance Ionisation Spectroscopy [19] a technique suggested also to search for $\beta\beta$ decay of ^{82}Se [25]. Our approach is based on direct detection of the solar neutrino interaction by means of a delayed coincidence between the pulses produced by the electron and by the de-excitation of the first excited level of ^{81}Kr to its ground state.

As shown in Fig.1, ^{81}Br, whose atomic aboundance is 49.31%, has the peculiar property that neutrino production of ^{81}Kr in its ground state is forbidden . As a consequence most of the neutrino captures should lead to the first excited state at 190.4 keV via the allowed ($3/2^-$ - $1/2^-$) transition, similar to the one leading from ^{71}Ga to the ground state of ^{71}Ge.

The threshold for the neutrino interaction on ^{81}Br to produce the 190 keV excited level is 280.8+190.4= 471.2 keV definitely above the maximum energy of neutrinos from the p-p chain and the lower line (E_ν = 432 keV) of the dicromatic ^{7}Be neutrinos. Most of the signal will therefore be due to *monocromatic* neutrinos for the upper line of the doublet which is due to e-capture of ^{7}Be leading to the ground state of ^{7}Li. The unique signature of this reaction will therefore be the production of a 861-471=390 keV electron followed, with a lifetime of 13.1 seconds , by an internal transition or γ decay of 190 keV. The other source of monocromatic solar neutrinos , the p-e-p reaction (1.442 keV), would also lead to a monocromatic event where the electron energy would be 1442-471= 971 keV. We would like to stress that these signals can be produced *only by solar neutrino generated by ^{7}Be and p-e-p reactions* : this experiment could therefore constitute the first step for a *solar neutrino spectroscopy.*

We ignore in this first analysis the contribution of the $9/2^+$ level at 49.6 keV, but discuss solar neutrino interections involving excited states of ^{81}Kr above 190.4 keV on the basis of the present [26] limited nuclear information and on the various evaluations and measurements carried out so far [1,15-24]. ^{7}Be neutrinos could also

excite the upper level at 457 and 549 keV. Only the contribution of the former, whose quantum numbers are probably $5/2^-$, could be significant. It has in fact been pointed out [15] that a bromine experiment cannot be informative on ^{7}Be solar neutrinos in absence of a correct evaluation of the contribution of the 457 keV state. There are no detailed informations on the de-excitation branching ratios of this level which should mainly decay directly to the ground state without involving the characteristic delayed β - γ signature due to the contribution of the 190.4 keV state. De-excitation of the 457 keV level would follow immediately the signal due to the solar neutrino electron which in this case would have an energy of 123 keV. If the corresponding γ-ray is absorbed in a crystal different from the one where it was produced, we could detect in principle also this prompt "β - γ" coincidence. More in general, our experiment could allow to discriminate the contributions from the various levels of ^{81}Kr and could be therefore strongly selective for ^{7}Be neutrinos, unlike the other proposed ^{81}Br experiments [21].

Let us now discuss the p-e-p neutrinos which could excite with allowed transitions, in addition to the above mentioned 190 and 457 keV states, also those at 637, 701, 920, 994 and 1026 keV. The first three de-excite entirely to the 190.4 keV level, while the remaining two involve only partially this state. Even in this case we could therefore in principle discriminate the contributions of the different levels of ^{81}Kr with prompt and delayed "β - γ" coincidences.

We stress that the main aim of our experiment is detection of monocromatic solar neutrinos, whose rate can be well predicted with discrepancies in the literature which normally do not exceed 10%. We assume for the present study values of 10 and 1.2 SNU for the upper line of ^{7}Be and for the p-e-p neutrinos, respectively. Our experiment could however be capable, to search also for ^{8}B neutrinos, whose capture rate is however harder to be evaluated [7,24]. In fact previous calculations leading to values around 3 SNU, have been further modified when large Gamow-Teller strengths to highly excited levels of ^{81}Kr have been found in (p,n) measurements [21]. This yields capture rates about five times larger [7,24]. As discussed later our experiment would allow to discriminate this contribution from the "monocromatic" one due to ^{7}B and p-e-p.

3. EXPERIMENTAL APPROACH

We are considering and plan to test for this experiment the technique of thermal detection of particles suggested since 1984 [27,28] particularly to search for rare events [28-32]. This technique is based on the use of large diamagnetic and dielectric crystals whose specific heat at low temperature is given by:

$C = 1944\ (T/T_D)^3\ J\ K^{-1}\ mole^{-1}$

where T and T_D are the operating and Debye temperatures, respectively. At T of a few tens of millikelvin, easily reachable in dilution refrigerators, this heat capacity can be so low that even the tiny energy delivered by a single particle in the crystal can be revealed by the increase in temperature. Various detectors, based on this principle, have been constructed [33]. The most massive of them, a 340 g crystal of TeO_2 constructed by our group, is presently operating in a shielded and low intrinsic radioactivity dilution refrigerator installed in the Gran Sasso Underground Laboratory for a search on $\beta\beta$ decay [34,35]. The energy resolution of these bolometers for high energy γ-rays is already similar to that of Ge diodes, the best existing detectors for γ-ray spectroscopy . In addition their operation has shown excellent stability for long periods (more that 1400 hours of effective running time) , an essential requirement in all experiments on rare events.

Our speculation is based on an array of 10^5 crystals of NaBr of one kilogram each, operated at a temperature around 10 millikelvin. We are presently oriented towards this material due to :

a. reasonably large Debye temperature;

b. acceptably low solubility in water, about a third than NaI;

c. reasonable density ($3.2\ g\ cm^{-3}$) ;

d. reasonably low cross section for thermal and fast neutrons of the "companion atom" (Na) which ensures against a large neutron induced background, as it could be the case e.g. for LiBr.

The Debye temperature of NaBr is 224 K [36] from which a specific heat of $3.35 \times 10^{-3}\ J\ K^{-1}\ Kg^{-1}$ can be inferred. At 15 mK, the heat capacity of a 1 Kg crystal would be 1.1×10^{-8} J/K. The deposition of 190 keV in this crystal would determine a temperature rise of 2.8 μK. We consider this value rather reliable, since our experience with TeO2 shows that the temperature rise extracted from the amplitude of the voltage signal is always in reasonable agreement with that expected from the theoretical value of the heat capacity at the operating temperature. As temperature sensors we consider NTD Ge-thermistors [37] with masses of the order of 10 mg, like the ones we are employing now in the ^{130}Te $\beta\beta$ decay experiment. A resistance of the order of 100 Mohm and a sensitivity A (where A=dlogR/dlogT) around 10 is expected for such a device. The high power handling capability of the thermistor provided by its appreciable mass should allow to apply a voltage bias V around 20 mV across the thermistor itself (we have already reached this bias level in some of the TeO_2 detectors for $\beta\beta$ decay search). As the voltage signal is given by V x A x dT/T, a signal amplitude of 36 μV is expected for a temperature rise dT of 2.8 μV.

To predict the energy resolution, this signal should be compared with the noise level. To be realistic we will not consider the intrinsic noise of the bolometer, which would lead to a resolution of a few tens of eV [38], but the actual noise that we measure in the best conditions with our detectors in the Gran Sasso which is mainly due to spurious sources like microphonics and load resistors. This noise level is of the order of 1 μV r.m.s. in the typical signal bandwidth, which extends up to 100 Hz. Therefore, at the present stage of bolometer development, a signal to r.m.s.-noise ratio of 36:1 is expected at 190 keV, leading to a FWHM resolution around 12 keV at 190 keV. We would like to stress that this is just the status of art, and that large improvement margins are within the reach of the technique, essentially because much work is still to be done for the reduction of spurious noise sources.

The realization of 10^5 channels requires an excellent reproducibility of the sensor characteristics. As far as our experience is concerned, the choice of NTD Ge thermistors might be appropriate from this point of view [38] . We have observed that the doping uniformity achievable with this method makes the R-T curves of samples coming from the same crystal almost undistinguishable within the experimental errors. 10^5 sensors, 10 mg each, can be obtained by irradiating 1 Kg of germanium: the samples that we are using now come from crystals with masses of such order of magnitude. The technique to develop the NTD temperature sensors at least in medium quantity looks therefore firmly established.

Large amounts of NaBr are not presently available commercially. Bromine however, unlike Gallium, is rather abundant in nature, in particular in sea water. (~65 ppm). With a special production line it should be possible to realize a considerable amount of NaBr of good radioactive purity and crystallize it at a reasonable cost. Even this however has to be the subject of a specific chemical test.

On the basis of the above mentioned predictions we expect a rate of about 0.3 events per day on ^{81}Br due to ^{7}Be, with a signal due to p-e-p reaction about one order of magnitude weaker. These signals would appear as a pulse of a 390 or of a 971 keV electron, respectively, followed with a decay time of 13.1 seconds by a pulse at 190 keV. A Montecarlo analysis based on a large array of 1 kg cubic (side 6.78 cm) NaBr crystals has been carried out to study solar neutrino detection efficiencies and background effects due to radioactive contaminations of the crystals.

Let us first consider the efficiency for the case of ^{7}Be. The signal is mainly due to delayed concidences *in the same crystal* of the pulse due to the electron produced by the solar neutrino and de-excitation of ^{81}Kr (32.9% IC electron, 67.1% gamma). The corresponding efficiency (69.1%) is given by the sum of 32.9% (solar electron and IC electron) and 36.2% (solar electron and interaction in the crystal of the 190.4 γ-

ray) . In addition we consider the probability that the 190.4 γ-ray interacts in one of the contiguous crystals which amounts to 21% (probability for interaction in the further outside layers is only 1%). This corresponds to a further contribution of 14.1 % to the efficiency , yielding a total of 83.2%.

The calculation for p-e-p neutrinos is the same, but containment of the 971 keV electron is in this case of 95 %, while in the above mentioned case of the 390 keV electron is practically 100%. The total efficiency for the p-e-p reactions is therefore 79 %.

This simplified calculation is based on the hypothesis that the distance between crystals be negligible. More detailed calculations for a "practical" structure are in progress and could suggest coincidences also with the layer of crystals further outside.

We would like to stress, finally, that rise and decay times of massive thermal detectors are large. From analogy with our TeO_2 bolometer we expect that in our case these times should be of a few hundreds of milliseconds, which is appropriate to measure decay times of tens of seconds. On the other side, however, each single crystal will have to be tested in the Gran Sasso Underground Laboratory to avoid severe pile-up problems due to cosmic rays.

The set-up discussed here is made by an array of crystals of similar size and energy resolution as those of our thermal detector presently running in the Gran Sasso for a search on ββ decay of TeO_2. The number and mass of these detectors is only indicative and based on what seems to us *presently feasible* . It is possible that improvements in this technique and the preliminary feasibility tests which will be discussed later will allow to optimize a simpler and less expensive experiment.

The thermal detector approach appears at present very attractive, but could at the end result too difficult or too expensive. We are therefore considering in parallel a set-up made by scintillators. In this case the detector could be an array of cristals of CsBr(Tl). This scintillator has a density of 3.0 g cm^{-3} and an index of refraction of 1.6. Its main characteristics are [40]:

a. Efficiency relative to NaI = 17 %
b. τ_α (decay of light pulse for α particles) =1.9 μs
c. τ_β (decay of light pulse for β particles) =2.1 μs

From the NaI photon yield (Y_{ph}=4.3 x 10^4 photons/Mev) and assuming total collection of light and 20 % quantum efficiency for a photocathode, we expect that the 190.4 and 390 keV electrons loosing their energy in a CsBr cristal will produce pulses of the following amplitudes (in photoelectrons);

$H_{190} = 4.3 \times 10^4 \times 190/10^3 \times 0.17 \times 0.2 = 2.8 \times 10^2$ ph.e

$H_{390} = 4.3 \times 10^4 \times 390/10^3 \times 0.17 \times 0.2 = 5.7 \times 10^2$ ph. e

The corresponding "theoretical" resolutions would be 14 % and 10 % respectively. Practical resolutions of 20-30 % are more realistic.We are presently in contact with several laboratories and companies which could provide suitably doped CsBr(Tl) cristals and are also going to investigate the so far unknown scintillation properties of NaBr when activeted with Thallium. The possibility to detect simoultaneously scintillation and thermal pulses, successfully obtained with CaF_2 [41] is undoubtely very attractive, but probably too complicated in such a large set-up. The scintillation approach has the disadvantage of a definitely worse energy resolution, but the time resolution is much better and could help in the reduction of the background with the anticoincidence methods discussed later. Electronics will obviously be much simpler. This approach will be considered in the case that , after performing Step I of Chapter 6, the cryogenic method would result too difficult or expensive.

4. A FEW EXPERIMENTAL CONSIDERATIONS

We would like to discuss here in a very preliminary way some experimental details and difficulties.

4.1. Location and cryogenics

The experiment should be located in Hall D of the Gran Sasso Underground Laboratory which is going to be devoted to cryogenic experiments. Construction in a reasonable time (e.g.three years) of this Hall is an absolute condition for the realization of the experiment. In particular a system for helium recovery with an efficiency very near to 100% is absolutely needed to avoid excessive costs. Dilution refrigerators were already constructed to cool large masses to very low temperatures, a tipical example being the set-up to cool the 2200 kg gravitational antenna of the Rome group [42]. In our dilution refrigerator in the Gran Sasso we are presently cooling to temperatures below 8 mK masses up to 40 kg (the internal lead shield against local radioactivity) [35] and this mass is only limited by the mechanical properties of the refrigerator.The construction of a refrigerator able to cool a mass of 100 tons down to 10 mK is however a severe technological challenge, and will require the collaboration of an experienced cryogenic firm and of skillfull low temperature engineers. We can however anticipate some rough considerations which seem to show that the problem is, at least in principle, solvable.

The 10^5 crystals will require a copper heat sink at a temperature of about 10 mK. This heat sink, if properly constructed, could have a mass lower than 10% of the total mass of the crystals themselves. The whole mass to be cooled down would therefore be in any case of the order of 100 tons. This mass could be mechanically connected to a large heat bath at 1.5 K, obtained by pumping at a few torr a big liquid helium

reservoire. The heat conductance of the mechanical supports must obviously be minimized. The most trivial approach is to use stainless steel for the supports, even if there are surely more appropriate choices, like titanium (more expensive , but less radioactive) or perhaps some special non metallic materials. 100 tons can be held by 50 pillars of stainless steel, with a cross section of the order of 1 cm^2 each, or by an equivalent distribution of more pillars with smaller cross section.

If we imagine that these pillars are 2 m long and connect the 1.5 K bath to the 10 mK copper heat sink, a heat flow of about 100 microwatts is expected from the heat bath to the copper mass, as can be easily evaluated taking tabled values of the stainless steel thermal conductivity. We need therefore a dilution refrigerator with a cooling power of the order of 100 microwatts at 10 mK. This cryostat should be about 10 times more powerful than the refrigerator we are operating in the Gran Sasso for the $\beta\beta$ decay search: this means that 10 dilution units of that type, operated in parallel, should provide the necessary cooling power. The cryostat design we have pointed out is unavoidably naive at this stage: however, it seems to show that the required cooling power is within the reach of the present standard technology.

4.2 Electronics

There are in principle, two possible ways to readout the detector signal: reading every detector with a dedicated channel or using a matrix by grouping the signals of several detectors at the input of a single readout channel.

The first option is just an extension of the way the detectors are readout in our current experiments. It seems, at present, the most feasible way for signal readout although we are conscious that it is not possible to simply extrapolate the experience of a few channels experiments to the large number of the present case. Many questions are open, for instance the feasibility of fabricating 100.000 NTD Ge thermistors with reasonable matched characteristics has still to be demonstrated. So far, we have tested many units in our laboratories which have shown excellent performances in terms of sensitivity and reproducibility. This result makes us confident in getting larger quantities with satisfactory characteristics.

As indicated in chapter 3, the resistance at the estimated operating temperature of 10-15mK will be of the order of 100 MOhm and the signal level for the 190 keV signature, about 36 μV. The high impedance sensor must be readout with a voltage-sensitive low-noise preamplifier thermally clamped to the 1.5K bath or to the 4K main bath. Either the first amplifying stage or a complete cryogenic preamplifier will be used depending on the allowed power dissipation and the available space in the cryostat.

To improve the low noise performances of the readout preamplifiers used so far in the group [43], we are investigating different monolithic processes for designing low noise GaAs field effect transistors (MESFET's) for operation at 1K or 4K. A first chip consisting of a monolithic array of GaAs MESFETs was designed using ion implantation technology with TriQuint Semiconductors [44]. A second chip including also an array of MESFETs implemented in a specially cryogenic process is currently being performed in collaboration with other researchers. The first devices will be ready before the end of this year. After optimizing the design, a large number of devices can be manufactured.

The connection of the sensor to the preamplifier has to be done using a specially designed low-capacity and low thermal conductivity signal link. A high impedance sensor and link involves the risk of high microphonism that has to be cured and will most probably be the limit in the energy resolution as it happens in our present experiments.

As for the data processing we plan to proceed in the following way. The array of detectors will be functionally divided in say 500 subarrays of 200 units each. Two contiguous subarrays have at least one common layer that obliges to manage border conditions.

Once the signal of every channel is sent to the outside world, it will be splitted in two lines, one for the analog processing, the other for the logic. All the lines devoted to the logic will enter, after discrimination, into a logical pattern unit which will provide the trigger and the pattern of the fired channels in the subarray. This is done to perform a zero skipping on the analog side.

The analog lines, will be sequentially sampled using a multiplexer and a waveform digitizer with a sampling period of the order of 100 ns. As detector signals are slow, an efficient parallel to serial conversion of many channels is possible. In the given configuration each signal will be sampled every 20 μs, which is far above what is needed to have a good pulse reconstruction. Moreover, once the trigger is formed and the pattern of the event is available, the digitizer will continue to sample only the non-zero analog lines, which will be from this moment on the only processed and recorded signals. One pattern unit can drive even more than one "multiplexer + digitizer" unit. Final number of subarray and digitizers per subarray will be given by the real total counting rate of the full array.

An alternative to the one-preamp-per-channel approach is the use of a matrix readout. This new idea, still in its infancy, would be specially interesting in the case of relatively low counting rate. It allows to reduce the number of readout devices by conveniently grouping the signals of several detectors at the input of a single readout device. The number of signals to be "ORed" depends on the background rate. Events

particles coming from the ^{238}U and ^{232}Th chains (8 and 6 α's per Bq, respectively). The rate of these fake "e-γ" coincidences within 50 seconds would be ~4 per day on the entire apparatus, an order of magnitude more than the expected ^{8}B signal. Alpha particles would however be monocromatic and could therefore be subtracted from the spectrum and the remaining background could be similar or lower than the signal. Further discrimination could be provided by the characteristic 13.1 second decay time. Another possibility could be to apply to the "beta" signal a lower energy cut of 9 MeV, thus totally eliminating α-particles, but reducing the ^{8}B signal to ~40%. The background in this region should be due only to fast neutrons whose flux in the Gran Sasso Laboratory is reduced by about four orders of magnitude with respect to the surface [49] Most of these neutrons would interact in the outside layers of crystals and only there this background would be larger than the solar neutrino signal. With a suitable shield of water, detection of ^{8}B neutrinos seems, at least in principle, feasible. The effect due to cosmic ray muons, even if reduced by six orders of magnitude with respect to sea level [49] cannot be neglected, but we believe it can be safely eliminated by means of a suitable anticoincidence system.

We have also considered solar neutrino interactions on the other nuclei present in our target. Interactions on the $3/2^-$ ground level of ^{79}Br would mainly lead to the allowed transition to the $1/2^-$ ground state of ^{79}Kr (Fig.3), which decays with a lifetime of 35.0 hours [50] The main channel will be electron capture, very hard to detect in our experiment due to the low energy of the X-rays and the large lifetime which makes prohibitive the background. It would be on the contrary in principle conceivable to observe the positron decay of ^{79}Kr (branching ratio of 7%) via the contemporary detection of the two 511 keV γ-ray. It would perhaps be possible to search for neutrino interactions leading to highly excited levels of ^{79}Kr which then decay immediately to the $7/2^+$ state. This would then de-excite with an energy of 129.5 keV and a lifetime of 50 second, quite appropriate for a thermal detector. We would like to note however that, due to the large threshold (1.631 MeV), capture on ^{79}Br is only accessible to ^{8}B with a total rate of 1.2 SNU [15]. Barring unexpected enhancement factors, solar neutrino capture by ^{79}Br looks therefore very hard to be detected in the proposed experiment.

More promising looks the search for solar neutrino interactions on the $3/2^+$ ground state of ^{23}Na leading to the $3/2^+$ ground state of ^{23}Mg, which decays with emission of a positron [51] with a lifetime of 11.32 seconds (fig.4). Unfortunately the threshold is high (4.059 keV) and the cross section, obviously for ^{8}B neutrinos only, has never been calculated. The value of log $ft_{1/2}$ for e^+ decay from the $3/2^+$ ground state of ^{23}Mg to the $3/2^+$ ground state of ^{23}Na has been evaluated [52] to be 3.68. Using the relation between neutrino absorption cross section and electron energy reported in [7]

we obtain an absorption capture rate in ^{23}Na of about one SNU which yields one event every 15 days. This rate could be however strongly enhanced, as in the case of ^{81}Br, by the contributions of the high energy excited states of ^{23}Mg. The signal would appear as an "electron" pulse, followed with a lifetime of 11.32 seconds by two 511 keV pulses, if the two photons are absorbed in two different crystals. If absorption would occur in the same crystal, possibly the same where the electron was detected, there will be a single 1022 keV signal. Feasibility of this experiment is being investigated.

Neutrino electron scattering leads to considerable interaction rates : 144, 4, 60, 1, 6 and 8 events day^{-1} from the p-p, p-e-p, ^{7}Be, ^{8}B ^{13}N and ^{15}O, respectively, when a lower energy threshold of 50 keV is adopted. Since these reactions are however not accompanied by the characteristic de-excitation signal at 190.4 keV, we believe their detection is difficult in our experiment.

6.OTHER EXPERIMENTS WITH THIS DETECTOR

This detector, even in a small scale as conceived for the second step of chapter 7, can be usefully applied in other types of neutrino spectroscopy and in searches for dark matter. We would like only to suggest here a few examples for which more detailed calculations are in progress, also in order to ascertain the competitiveness of this method with respect to other techniques.

a. Measurements of neutrino cross sections

Intense artificial neutrino fluxes can be obtained from electron capture sources as those planned to calibrate gallium solar neutrino experiments [3-5]. Cross sections on ^{81}Br of 18.3 and 32.3 x 10^{-46} cm^2 have been calculated by J.N.Bahcall [15] for ^{51}Cr and ^{65}Zn. The former source provides a "doublet" of 751 keV (90%) and 431 keV (10%) neutrinos. Since the latter will be "sterile" we will be in presence , as for ^{7}Be neutrinos, of a monocromatic line. We would like to note that the energy of these neutrinos will be sufficient to excite also the 457 line. The electron energy will be however of 13 keV only and the probability much lower than for the 190 keV line unless some unforeseen nuclear enhancement factor are present.

A source of one Megacurie of ^{51}Cr, as foreseen for calibration of the Gallium experiments, placed inside a "pilot" ten ton detector would yield a well measurable signal of 0.7 delayed coincidence per day of a 280 keV electron and the 190 keV de-excitation pulse. This would provide valuable information not only for calibration of a larger solar neutrino detector, but also in general for neutrino physics.

b. Neutrino scattering on electrons

With the source of ^{51}Cr discussed before the rate of detectable neutrino electron scattering would be about 170 day^{-1} in a 10 ton detector. The possibility to detect these interactions as well as to reveal a possible neutrino magnetic moment with the source on- source off procedure is being investigated. Due to the low neutrino energy this set-up allows an experiment on neutrino oscillations which would be complementary to those with nuclear reactors (neutrinos instead of antineutrinos). The exclusion plots which could be obtained with the source placed at one meter from the detector for exposure times of one month and one year are compared in Fig.5 with those obtained at nuclear reactors [53].

c. Neutrino excitation of nuclear levels

Neutrinos and antineutrinos can excite nuclear levels by neutral current interactions. This process has been recently observed by the KARMEN collaboration at the ISIS spallation facility of Rutherford Appleton Laboratory with a pulsed beam containing electron and muon neutrinos and muon antineutrinos [54]. The overall averaged cross section for excitation of ^{12}C to the $(1^+,1)$ state at 15.11 MeV has been found to be $(10.8 \pm 5.1_{stat} \pm 1.1_{syst}) \times 10^{-42}$ cm^2. Let us now consider the nuclei present in a our "pilot" detector. ^{23}Na has many levels which could be excited by neutrinos or antineutrinos in allowed or superallowed neutral current interactions with the consequent emission of de-excitation γ-rays or IC electrons. Above the threshold of 4.059 MeV they could decay by allowed β transitions to the ground state of ^{23}Mg. In this case the β pulse induced by the neutrino beam would be followed with a lifetime of 11.3 seconds by the two 511 keV pulses from positron annihilation. Detection of this process, where suppression of the background could be strong, is possible only if the branching ratio for β-decay is not negligible with respect to de-excitation. The case of ^{79}Br (see fig.3) could be very interesting since neutrinos and antineutrinos could excite the $9/2^+$ state at 207 keV, which would then de-exite with a lifetime of 4.9 seconds. We would like to stess that due to its low energy this level could also be excited by antineutrinos from a pulsed nuclear reactor. Alternatively high energy neutrinos could excite levels of ^{79}Br above 1761 keV with quantum numbers such to selectively favour β-decay to the $7/2^+$ first excited level of ^{79}Kr. This state would then de-excite to the ground level with a lifetime of 50 seconds. Predictions of the possible rate for this process are difficult since the quantum numbers of the high energy levels of ^{79}Br are poorly known. The same is true for the levels of ^{81}Br above 471 keV which could selectively β-decay to the previously discussed 190.4 keV level. A severe constraint for these experiments is that they should be carried out underground in order to avoid excessive background and expecially "pile-up" in each detector.

d. Neutrino and antineutrino charged current interactions on ^{23}Na

Interactions of electron neutrinos and antineutrinos on ^{23}Na produce ^{23}Mg and ^{23}Ne, respectively, with thresholds of 4058 and 4376 keV. Both transitions are allowed ($3/2^+ - 3/2^+$ and $3/2^+ - 5/2^+$, respectively). ^{23}Mg decays by electron capture with a lifetime of 11.3 seconds, while ^{23}Ne β-decays with a lifetime of 37.2 seconds. With intense positive and negative beam dump sources as the one mentioned in the preceding paragraph one could carry on very interesting experiments on the cross section of neutrino and antineutrino interactions and on possible neutrino-antineutrino oscillations. This possibility is being studied.

e. Search for dark matter

An underground thermal detector as the one considered here, even in a configuration with a mass much reduced with respect to a solar neutrino experiment, could be very usefully employed to search for Weakly Interacting Massive Particles (WIMPS) [55-58]. The spin of all the nuclei in the detector (^{23}Na, ^{79}Br and ^{81}Br) is 3/2: this search would therefore be particularly suitable for spin dependent incoherent interactions of WIMPS. It would be somewhat similar to the experiments with NaI detectors being carried out by the Beijing-Rome-Saclay Collaboration[59]. The large mass would be of invaluable importance in detecting small effects induced by WIMPs on the counting rate in the low energy region taking advantage of the seasonal variation. This detector is mainly studied and optimized for neutrino physics, but a search for WIMPS already in the pilot set-up is probably the most interesting "subproduct".

7. DIFFICULTIES AND ATTEMPTS TO SOLVE THEM

We are fully aware of the various problems to be solved even before preparing a design study of the experiment. We would like to stress in particular:

a. cost and chemical methods to produce a large quantity of NaBr (electrolysis of sea water seems to as at present an interesting possibility);

b. cost and technical problems in constructing a cryogenic system for such a large crystal array;

c. cost and complexity of the read-out system;

d. possibility of an alternative detection methods (e.g. CsBr scintillators);

e. background.

We would like to add that available information on the values and quantum numbers of the various nuclear levels and particularly of those of the ^{81}Br-^{81}Kr doublet are still not sufficient in view of a full scale solar neutrino experiment.

We believe therefore that the work should proceed via three successive steps, where the second and third should be initiated only after successful completion of the previous one:

a. Step I : CONSTRUCTION AND OPERATION OF A NABR CRYSTAL OF 1 KG

We will start in a few weeks in Milano tests with a crystal of NaBr of about 100 grams. This will allow us to evaluate properly all thermal detection properties. Construction of a crystal of one chilogram would follow. It will be tested for a few months underground in the Gran Sasso Laboratory, due to pile-up problems at sea level. We would like to point out that the measurement in Gran Sasso will already constitute a reasonable first generation experiment on dark matter. This first step should last about one year, could be carried out by our group alone, and does not require additional finantial support. In the mean time we will stimulate further studies and possible new measurements.on the nuclear levels involved.

b. Step II: CONSTRUCTION OF A PILOT SET-UP (10 TONS)

If the results obtained in Step I would be satisfactory, after further tests with an array of crystals of intermediate dimensions, one could start the construction of a 10 ton detector to obtain already results of physical relevance. It would represent an excellent facility to search dark matter by its seasonal variation. It could be exposed to an artificial neutrino source: the one Megacurie ^{51}Cr source foreseen for the Gallex experiment would produce, as pointed out before, about one .event per day. An experiment on neutrino oscillations seems also possible. We would like to stress finally that, despite the poor mass, this detector could already give information on ^{7}Be solar neutrinos. In a year we could detect from 10 to 20 "characteristic" events fully distinguishable from the background.

This step undoubtely requires considerable funding, whose amount we will be able to evalute in a few months, and the collaboration with other national or international groups.

Step III: COSTRUCTION OF THE FINAL DETECTOR

As pointed out before, this is only a speculation on a possible solar neutrino experiment, based on a radically new technical approach. Optimization of the design of the final set-up and evaluation of the cost and of the feasibility of the experiment will require at least one year.

8. CONCLUSIONS

We would like to insist that the present is not a new proposal for a solar neutrino experiment, but only an attempt to show that detection of *monocromatic* solar neutrinos is in principle possible. We believe that the bolometric detection method could be indeed quite appropriate for this "on line" experiment, and that all difficulties can be in principle technically overcome. Even the problems of background seem to us in principle solvable and not particularly worse than in other solar neutrino experiments, due to the clear signature of the ^{7}Be and p-e-p neutrino interactions. It is however our experience that when searching for rare events unforeseen background sources always appear. They can sometime severely affect the experiment, and often require specific purification or shielding procedures. Therefore, despite our believe that the experiment is technically feasible, we are not sure at present that it is "possible" from a financial point of view. Even if this should not be the case, a detector of a reduced scale could be worth to be constructed for searches on dark matter and on monocromatic neutrinos.

On the basis of these hopes and of the interest in a detector for monocromatic neutrinos , we are presently starting a year long activity to construct an underground NaBr bolometer of a size similar to those to be used in the possible array for a solar neutrino experiment. We are also investigating the alternative possibility of an array of scintillators for detection of monocromatic neutrinos.

We aknowledge with pleasure discussions on this proposal with A.Allegretti, R.Barbieri, G.Benedek, P.Bortignon, R.Broglia, M.Lusignoli, L.Maiani , S.Pizzini, P.Pizzocchero and A.Pullia. Comments by other members of the scientific community will be greatly appreciated

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FIGURE CAPTIONS

Fig.1: Spectra of solar neutrinos;

Fig.2: Nuclear scheme of the ^{81}Br - ^{81}Kr doublet (all energies are in keV);

Fig.3: Nuclear scheme of the ^{79}Br - ^{79}Kr doublet (all energies are in keV);

Fig.4: Nuclear scheme of the ^{23}Na - ^{23}Mg doublet (all energies are in keV);

Fig.5: Sensitivity to neutrino oscillations of a ten ton detector exposed to a ^{51}Cr source of one MCi placed at one meter . The decay of the source with a 27.7 days lifetime has been taken into account. The present limit obtained on oscillations of antineutrinos from nuclear reactors is shown for comparison.

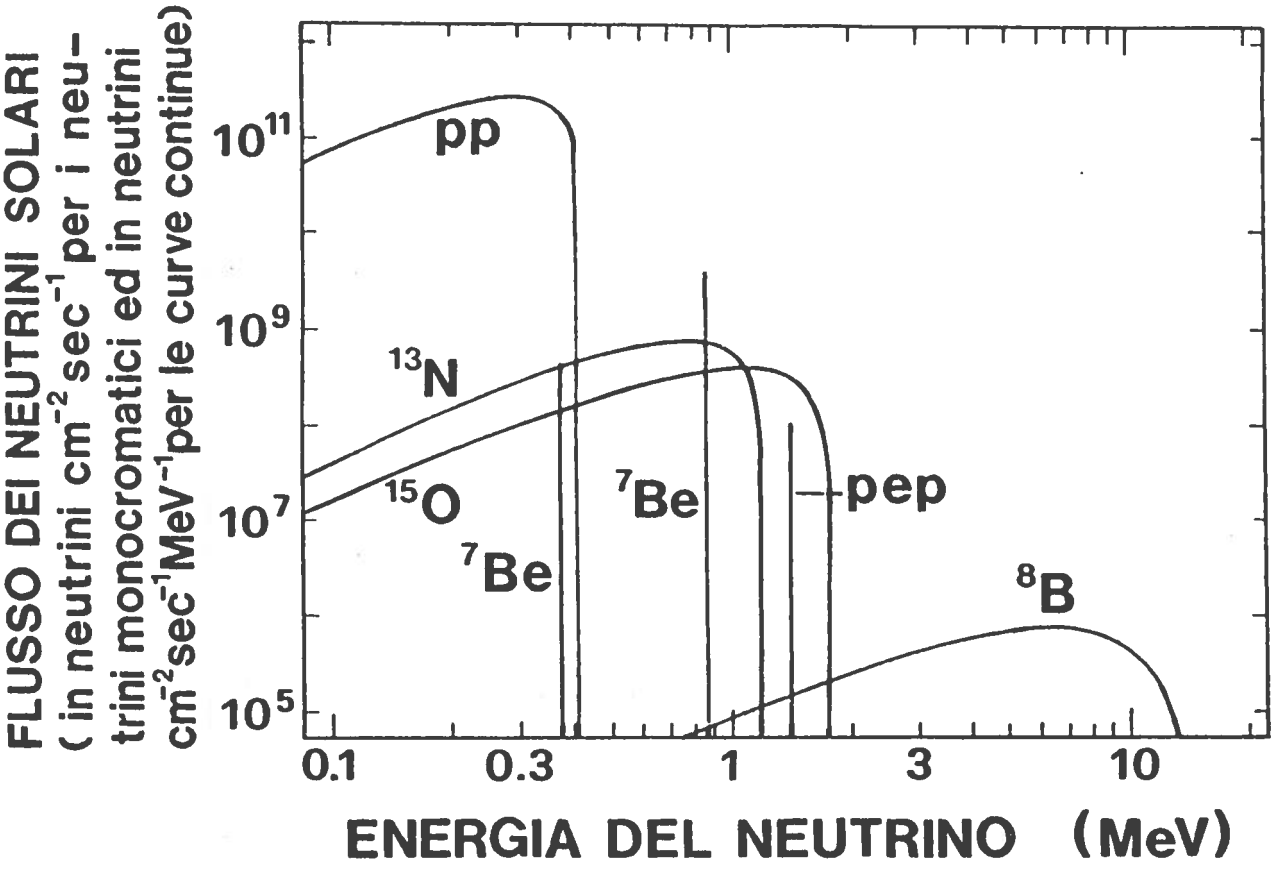
FLUSSO DEI NEUTRINI SOLARI
(in neutrini cm^{-2}sec^{-1} per i neutrini monocromatici ed in neutrini cm^{-2}sec^{-1}MeV^{-1}per le curve continue)
10^{11}
10^{9}
10^{7}
10^{5}
pp
^{13}N
^{15}O
^{7}Be
^{7}Be
pep
^{8}B
0.1
0.3
1
3
10
ENERGIA DEL NEUTRINO (MeV)

Figure 1

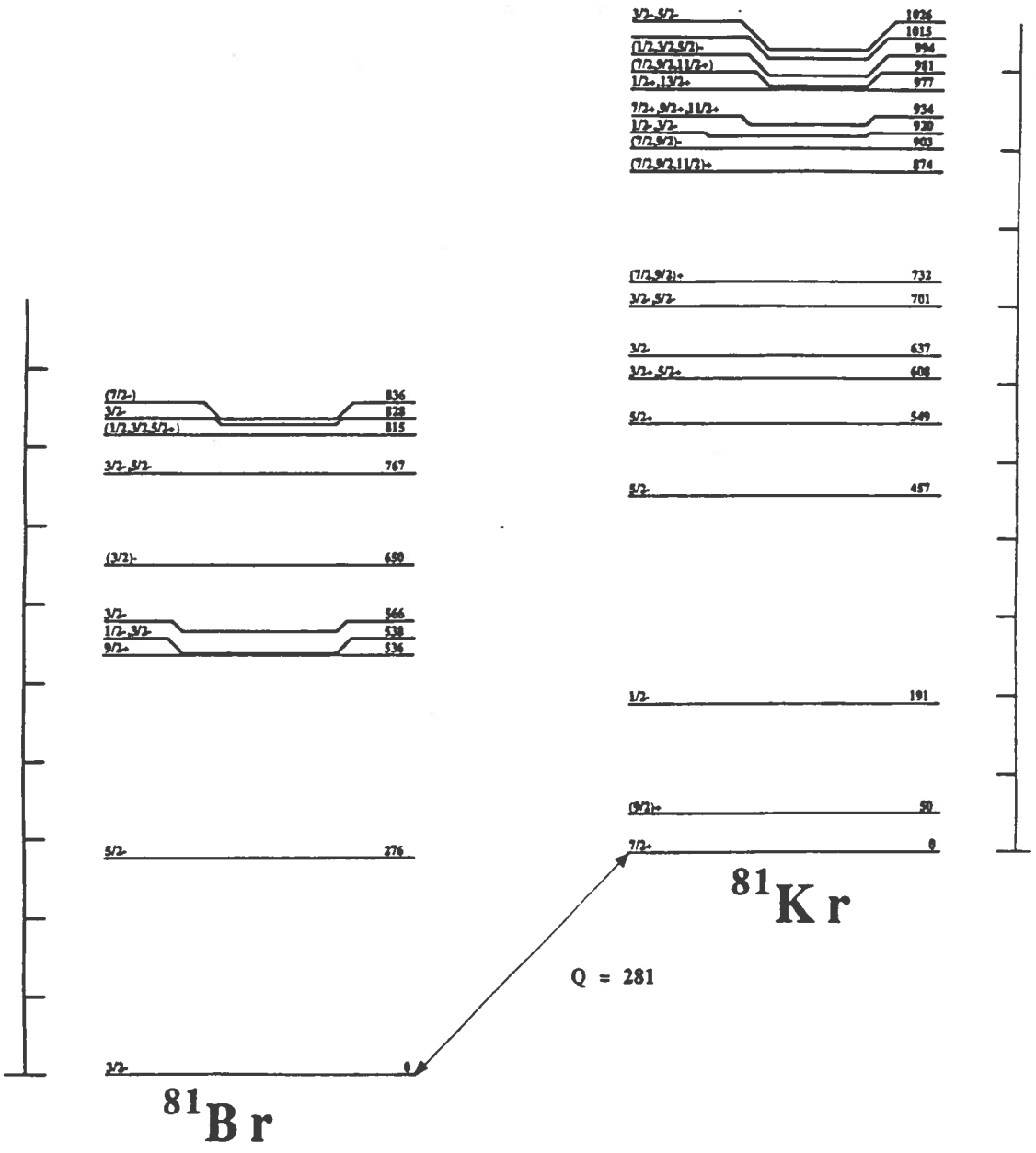
3/2-,5/2- 1026
1015
(1/2,3/2,5/2)- 994
(7/2,9/2,11/2+) 981
1/2+,13/2+ 977
7/2+,9/2+,11/2+ 934
1/2-,3/2- 930
(7/2,9/2)- 903
(7/2,9/2,11/2)+ 874
(7/2,9/2)+ 732
3/2-,5/2- 701
3/2- 637
3/2+,5/2+ 608
5/2+ 549
5/2- 457
1/2- 191
(9/2)+ 80
7/2+ 0
81Kr
(7/2-) 836
3/2- 828
(1/2,3/2,5/2+) 815
3/2-,5/2- 767
(3/2)- 650
3/2- 566
1/2-,3/2- 538
9/2+ 536
5/2- 276
3/2- 0
81Br
Q = 281

Figure 2

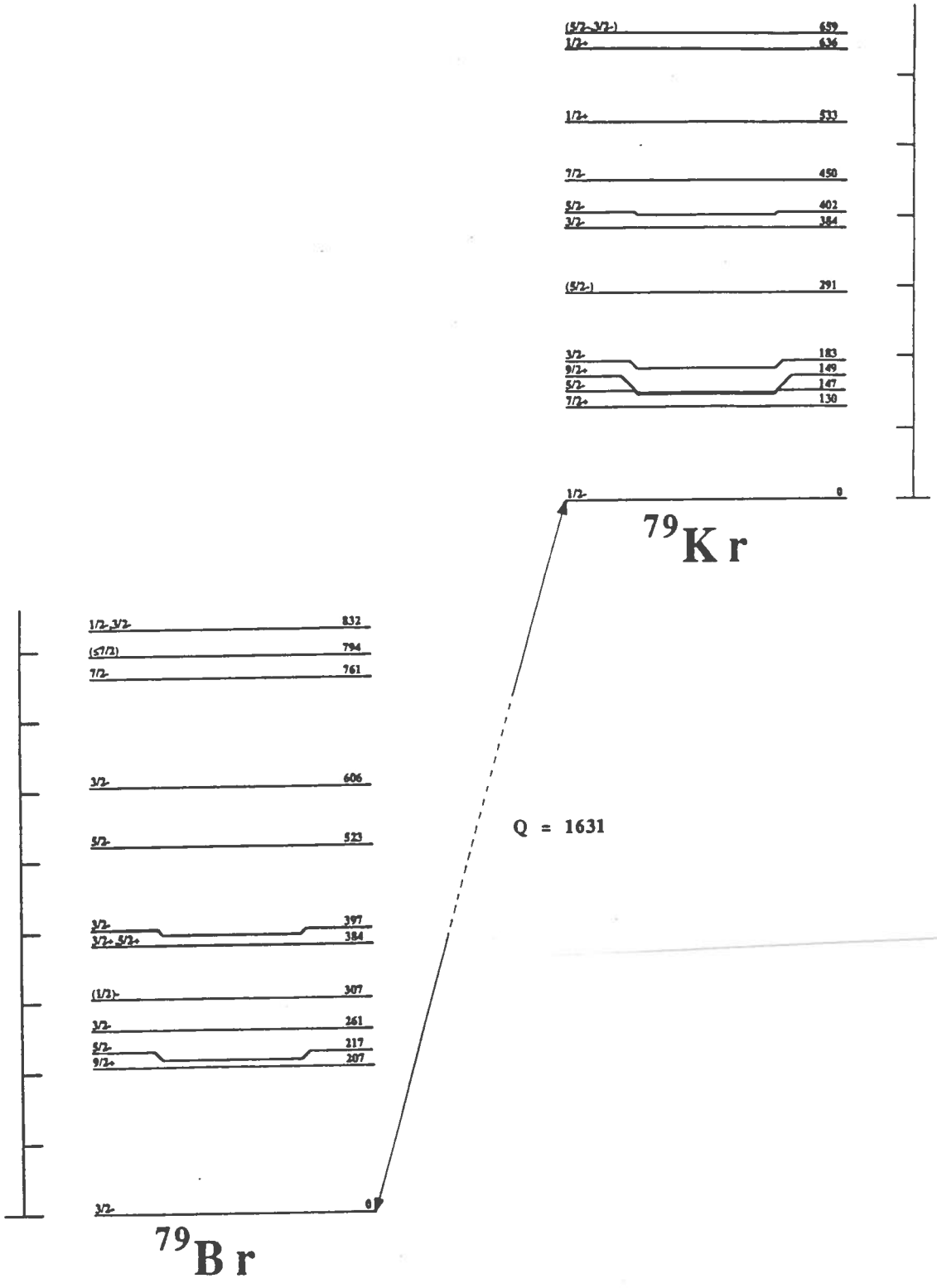
(5/2-,3/2-) 659
1/2+ 636
1/2+ 533
7/2- 450
5/2- 402
3/2- 384
(5/2-) 291
3/2- 183
9/2+ 149
5/2- 147
7/2+ 130
1/2- 0
79Kr
1/2-,3/2- 832
(≤7/2) 794
7/2- 761
3/2- 606
5/2- 523
3/2- 397
3/2-,5/2+ 384
(1/2)- 307
3/2- 261
5/2- 217
9/2+ 207
3/2- 0
79Br
Q = 1631

Figure 3

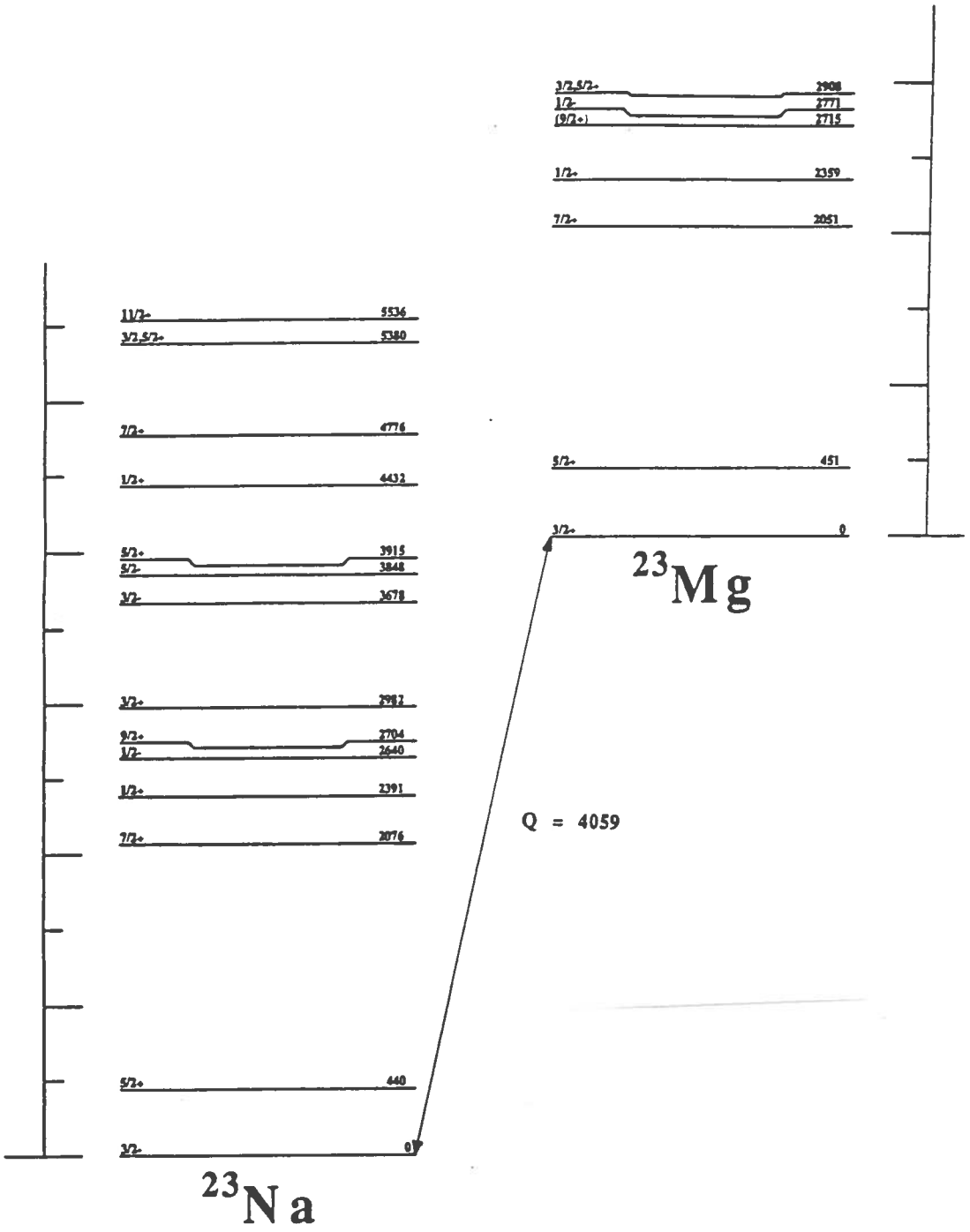
3/2,5/2+ 2908
1/2- 2771
(9/2+) 2715
1/2+ 2359
7/2+ 2051
5/2+ 451
3/2+ 0
23Mg
11/2- 5536
3/2,5/2+ 5380
7/2+ 4776
1/2+ 4432
5/2+ 3915
5/2- 3848
3/2- 3678
3/2+ 2982
9/2+ 2704
1/2- 2640
1/2+ 2391
7/2+ 2076
5/2+ 440
3/2+ 0
23Na
Q = 4059

Figure 4

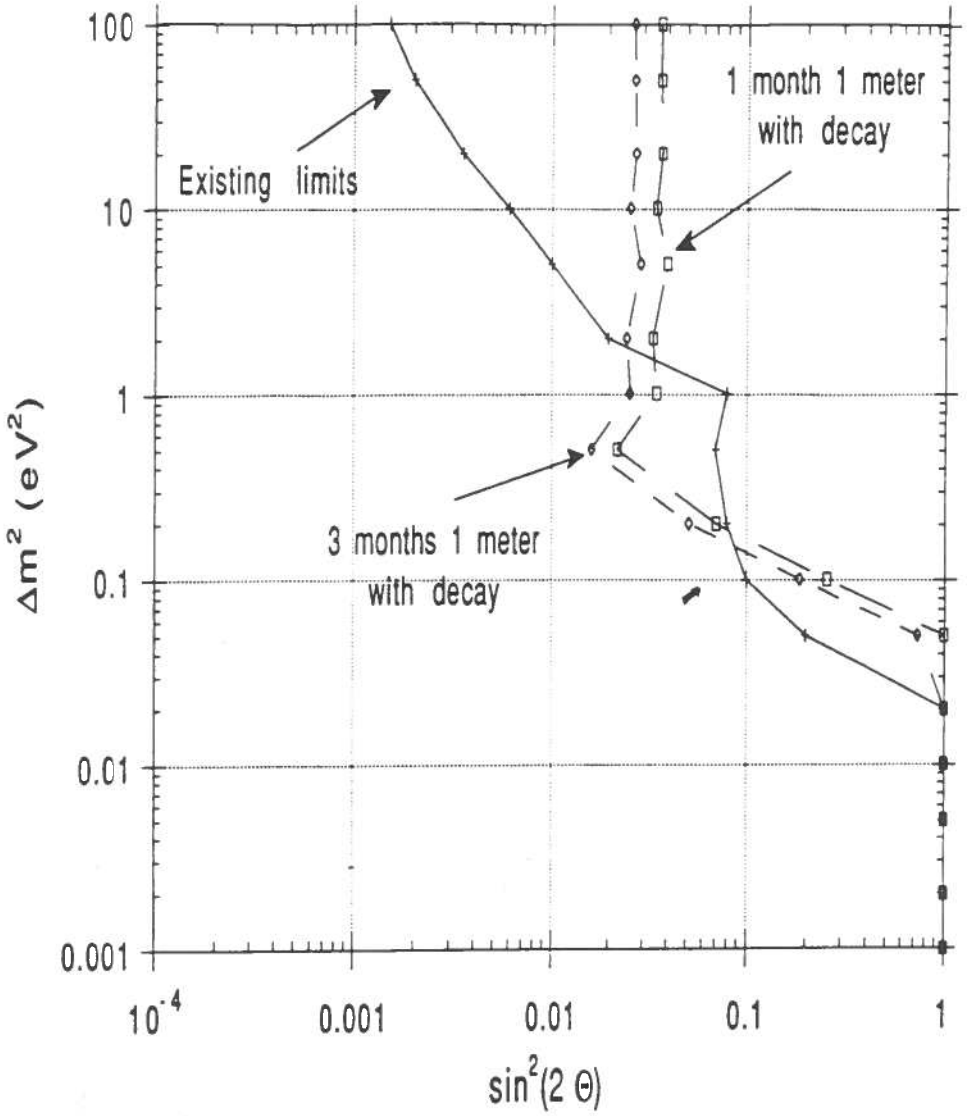
100
10
1
0.1
0.01
0.001
Δm^2 (eV^2)
10^{-4}
0.001
0.01
0.1
1
$\sin^2(2\,\Theta)$
Existing limits
1 month 1 meter
with decay
3 months 1 meter
with decay

Figure 5