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THE LOS ALAMOS FREE ATOMIC TRITIUM BETA DECAY EXPERIMENT

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ABSTRACT

An apparatus is under construction at Los Alamos to measure the beta spectrum of free tritium atoms and molecules. The tritium atoms decay in a gaseous windowless source and are analyzed by a Tret'yakov type toroidal field beta spectrometer. The ultimate sensitivity of the experiment to electron antineutrino mass is expected to be <10 eV.

The technique of measuring the electron antineutrino mass using the endpoint of a beta spectrum was first proposed by Fermi[1]. Recently, a group at ITEP has carried out a highly sensitive experiment[2] of this type using tritium, and report a lower limit on the electron antineutrino mass of 9 eV. Since the mass of the neutrino is currently a quantity of considerable interest[3], this result has prompted a number of experiments to confirm or deny it.

Some concerns have arisen about the ITEP experiment. The most fundamental is that of the final states which result from the beta decay. For a free tritium atom decaying into a free $^3He^+$ ion, the energies of the final states and the branching ratios to them can be calculated using the "sudden approximation". These calculations have been shown to be correct to 0.1%[4]. Similar calculations have been done for the tritium molecule[5]. However, in the ITEP experiment the tritium atom is bound in a valine molecule. Kaplan *et al*[6] have calculated the energy levels and branching ratios for the two forms of tritiated valine, but the accuracy of these calculations is not known, and the structure of the molecules may have been altered by radiolysis. In an effort to avoid any final state problems, the ITEP group calculated a "model independent" neutrino mass by assuming that all the decays led to the ground state. This assumption leads to

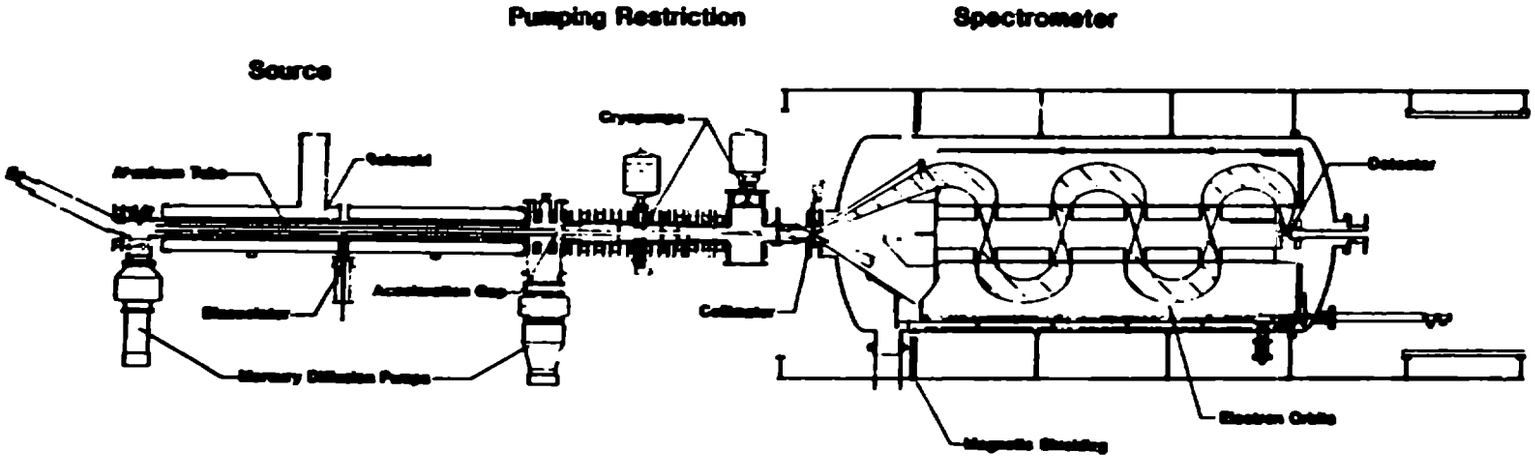

Fig. 1. Cross section of experimental apparatus. The overall length of the apparatus is 16 m.

a lower limit on neutrino mass if final state contributions are the only source of systematic error. However, some concerns about even this limit have been raised[7]. Therefore, we have decided that only free atomic or molecular sources can be treated with confidence.

A cross-sectional view of our apparatus is shown in Fig. 1. Beta particles originating in the source are extracted and focused to a collimator, and are then analyzed by a toroidal field magnetic spectrometer. Each of these sections will be discussed in more detail.

The basis for a practical source of atomic tritium was proposed to us by D. Kleppner. Atomic tritium is admitted into the center of a long tube pumped at both ends. If recombination does not occur too quickly within the tube, an equilibrium pressure of atomic tritium gas will exist in the tube. Since recombination ($2T \rightarrow T_2$) is mainly a three-body process, almost all of the

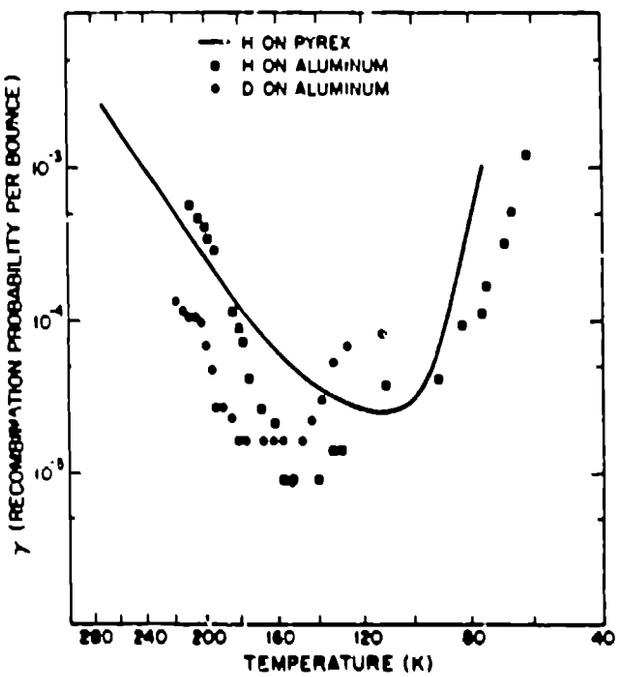

Fig. 2. Measured recombination probabilities for hydrogen and deuterium on an aluminum surface. The data for Pyrex were taken from Ref. 8.

recombination occurs on the walls of the tube. As the atoms diffuse from the center of the tube toward the ends, they bounce off the walls a number of times determined by the aspect ratio of the tube. It is known[8] that the recombination probabilities on quartz and Pyrex glass are very favorable, reaching a minimum of about 2.5×10^{-5} per bounce at 120 K. However, these materials were not acceptable for our source design since unknown charge buildup on the surfaces could change the source potential significantly. We conducted tests on a variety of tubes made of different materials, including Si, Ge, B , and Al. The best properties were exhibited by Al, owing probably to the native layer of Al_2O_3 on all Al surfaces. The measured recombination probabilities of hydrogen and deuterium on Al are shown in Fig. 2. Although the surface of the Al tubes is a thin insulator, charge buildup should not be a problem since the layer of Al_2O_3 is so thin that electrons tunnel through it easily.

An aluminum tube has been constructed based on these measurements. It is 4 m long and 3.8 cm in diameter, polished to 2 microinches. Atoms entering in the center will bounce about 4000 times down its length. The potential of the tube can be varied to 20 kV, and its temperature can be controlled. It is surrounded by a superconducting solenoid, which provides an axial field with a small gradient. Beta particles from decays in the tube are confined to spiral around the field lines. At one end of the tube a pinch coil reflects most of the betas emitted with a velocity component away from the spectrometer. The extraction efficiency from the source is about 93%.

An important feature of this experiment is that the source tube is biased at a negative potential. The effect of this bias is to shift the entire beta spectrum to a higher energy. As a result, tritium that decays anywhere in the apparatus except the source tube has an endpoint below that of the betas being measured, so it cannot appear as background. In addition, the spectrometer can be set at a constant field and the energy of the betas entering it can be varied by changing the potential. The price paid, of course, is that better resolving power in the spectrometer is required.

In order to achieve the necessary energy resolution, the source must be windowless. Therefore, after leaving the source and being accelerated, the beta particles are transported through a region which differentially pumps

the tritium gas to keep it from the spectrometer. In this same region, the beta particles are focused to a collimator. The magnetic focussing eliminates any beta particles that originate from decays either on or within scattering distance of the walls of the source tube, and the differential pumping keeps the contamination of the spectrometer volume down to about 2.5 millicuries per day. The efficiency of the extraction through this section of the apparatus was calculated to be approximately 25%. We measured it by putting a silicon surface barrier detector at the focus, and a ^{169}Yb source in the tank at the opposite end of the pumping restriction. The data, shown in Fig. 3, are in excellent agreement with ray-tracing calculations.

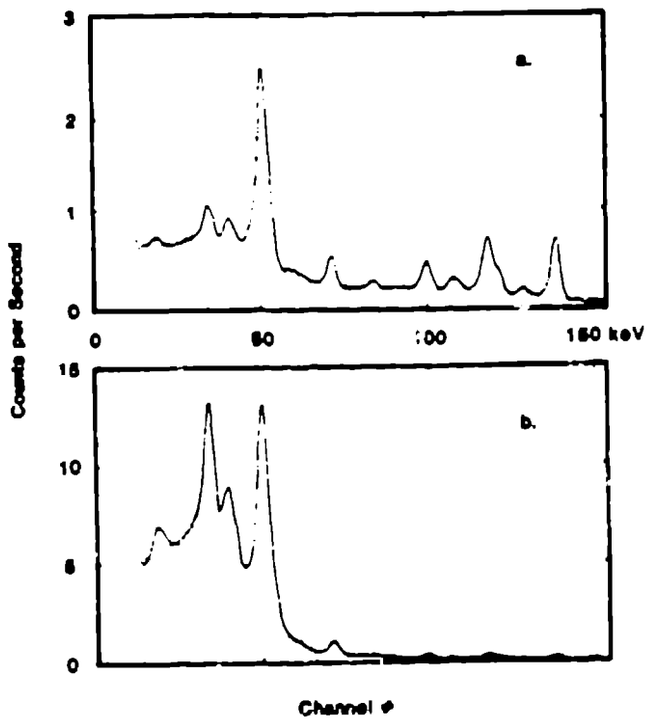

Fig. 3. Data taken with a solid state surface barrier detector. a.) Calibration data taken with source about 3 cm from detector, no field. b.) Data taken with source about 2.5 m from detector located at the focus of the extraction region. The measured extraction efficiency is 25% at 34 keV.

The design of the spectrometer is modeled after that of Tret'yakov[9]. The main modification to the Tret'yakov design is that the particles enter the spectrometer at angles between 20 and 30°, rather than between 85 and 95°. The conductors have been shaped at the entrance and exit so that the acceptance is maximized with a minimum effect on the resolution. In addition, the transmission has been improved by the use of very thin conductors at the points where the beta particles cross through the current planes. The background magnetic field in the active volume of the spectrometer is kept below about 10 milligauss by an active shielding system. The resolution of the spectrometer is determined mainly by source diameter and is calculated to be about 30 eV FWHM for 25 keV betas and a 1 cm diameter source, with detector position resolution taken into account.

The detector is a position and energy sensitive MWPC. The position sensitivity allows a fairly wide "slice" of the spectrum to be measured at once, which improves the data rate. The background in a prototype detector has been measured to be 1 count/600 sec., which we believe can be improved by the energy and position sensitivity of the final detector.

Several diagnostics are used to determine the performance of the apparatus. An electron gun can be aimed into the source to investigate the orbits of electrons, including those originating on the walls. A residual gas analyzer is used to determine the fraction of hydrogen contamination in the tritium gas. To measure the spectrometer resolution, a gaseous source of ^{83m}Kr will be used. This isotope can also be used to study the energy loss of electrons in the source. While the apparatus is running, the pressure of T_2 in the source can be determined by a UV laser tuned to the lowest wavelength molecular absorption line. In addition, the total source intensity will be monitored on-line by a solid state detector which detects electrons that originate in the guard region in the source, which is between the maximum radius that the spectrometer can accept and the wall. These last two diagnostics enable us to determine both the T and T_2 source intensities during each run.

Dissociation tests indicate that we can achieve a source intensity of about 10^{16} atoms per cm^2 in the source, which corresponds to a count rate in the detector of about 1 count/sec in the last 100 eV below the

endpoint. Based on this expected source intensity, we anticipate an ultimate sensitivity to neutrino mass better than 10 eV.

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