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AUTHOR(S): R.G.H. Robertson, T. J. Bowles, M. Maley, J. C. Browne, T. Burritt, J. Toevs, M. Stelts, J. Helfrick, D. Knapp, A. G. Ledebuhr

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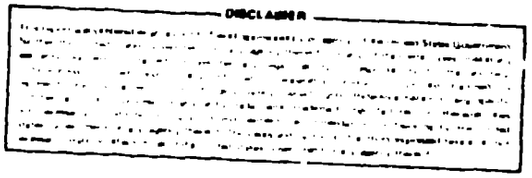

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545

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AN EXPERIMENT TO STUDY THE β-DECAY OF FREE ATOMIC AND MOLECULAR TRITIUM

R. G. H. Robertson, T. J. Bowles, M. Maley, J. C. Browne, T. Burritt, J. Toevs, M. Stelts, J. Helfrick,[a] D. Knapp,[b] A. G. Ledebuhr[c]

Los Alamos National Laboratory, Los Alamos, NM 87545, U. S. A.

An apparatus is described which will allow the measurement of the β-decay of free tritium atoms and molecules. It consists of an RF dissociator, a long cylindrical decay region open at both ends, a guide field, and a magnetic spectrometer.

There is some interest in determining whether the electron neutrino has mass. Recently, Lyubimov et al.[1] reported a measurement of the β-spectrum of ^{3}H which shows conclusive evidence for an antineutrino mass between 14 and 46 eV at the 99% confidence level. Despite careful study, no substantial flaw has been detected in their procedure. Nevertheless, many scientists would like to see a confirming experiment. Much of the concern revolves around the use of a solid source (tritiated valine, an amino acid) for which

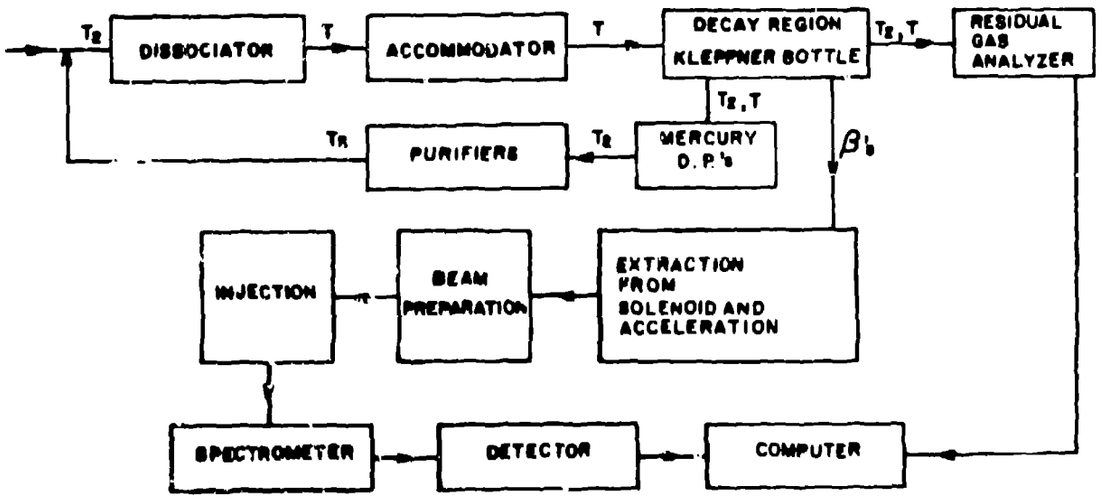


Fig. 1 Functional diagram of experiment.

one may not know the atomic and molecular final states of the ^{3}He daughter atom, the scattering and energy loss of β's in the source, and the shape of the background near the end-point as well as one would like.

The ideal source would be free tritium nuclei, but this turns out to be impractical owing to space charge limitations. The next best thing, free tritium atoms, may form the basis of a practical source for which detailed and accurate calculations of the atomic final states and electron energy losses can be performed. Recent advances in the production of dense gases of spin-polarized hydrogen encourage us to believe that a free-atom tritium source of adequate strength can be constructed. A functional plan of the experiment is shown in Fig. 1.

Molecular tritium at 300 mT pressure enters a Pyrex discharge tube cooled to 77° K (LN_2). The molecules are dissociated in an RF discharge and emerge through a small orifice into a transition region (also of Pyrex) in which the atoms are cooled (accommodated) to a temperature below 10° K. Because the adsorption energy for atomic H is lower than for H_2, the molecular component is "frozen out". In the pioneering work of Silvera and Walraven[2] a flux of 2.4×10^{16} atoms of H at 8.5° K was obtained, and simple modifications are expected to increase the output considerably. It is not yet known, however, to what extent tritium will behave differently from hydrogen. A test apparatus is now in operation at Los Alamos to explore this question.

Atoms emerging from the accommodator enter a cylindrical decay region ("Kleppner bottle[3]") whose walls are coated with a thin layer of Pyrex glass, which inhibits recombination. The maximum length of this decay region is set by the recombination rate, which is not known at present, and by the molecular fraction which can be tolerated, about 5%. An equilibrium density of atomic T is built up as established by the influx and the conductance of the tube. The equivalent source thickness integrated along the axis is conservatively estimated to be 5×10^{13} cm^{-2}, still a weak source by normal standards, but adequate for an experiment.

The Kleppner bottle is placed in a solenoidal magnetic field of about 1 kG with a small axial gradient. Betas ($B\rho$ < 463 Gauss-cm) spiral about the field lines. At one end of the solenoid a pinch coil with a peak field of about 4 kG reflects most of the β's that start with a velocity component

directe towards that end; as a result about 90% of the β's reach the weak-field end of the solenoid. There they are extracted and accelerated through a potential of 20 kV.

An important feature of our experiment is that this energy gain is never compensated by deceleration later in the apparatus: the entire decay region floats at -20 kV. There are two advantages in this; first, 18 keV electrons from the decay region are raised to 38 keV and are well above the energy of any β's from tritium that may find its way into the beam transport or spectrometer; and, second, the spatial component of phase space is reduced. Thus, not only is the background in the region of the shifted end point far lower than it would be at 18 keV, but the emittance of the beam is improved. We might also remark that this idea is equally applicable to solid sources. The price paid is, of course, that higher resolving power is required in the spectrometer.

One of the most interesting aspects of the problem is extraction of the β's from the solenoidal field into a field-free region at the object of the spectrometer. Given that in order to enter the spectrometer, all β's must pass through a collimator of radius r_c at an angle less than ψ_s, we find two general theorems: 1. There is a maximum radius in the solenoid, R_4, beyond which no β can originate and still enter the spectrometer and 2. The maximum fraction of rays originating within R_4 transmitted to the spectrometer is

$$\eta = \frac{x^2}{\left\{R_4 + \frac{R_4^2}{2\rho}\right\}^2} ,$$

where $x = \frac{r_c}{p} \frac{p'}{} \sin \psi_s$ and ρ is the (maximum) radius of orbits in the field. The electron momenta before and after acceleration are p and p', respectively. The first result follows from conservation of the canonical angular momentum and the second from application of the Poincaré invariant.

The significance of the first theorem is, of course, that any electrons originating from tritium adsorbed on the walls of the Kleppner bottle can be rejected absolutely, independent of aberrations or imperfections in the optical system. This is most important, because a monolayer of adsorbed tritium represents 6 orders of magnitude more activity than the gaseous source. A schematic diagram of the entire source is shown in Fig. 2.

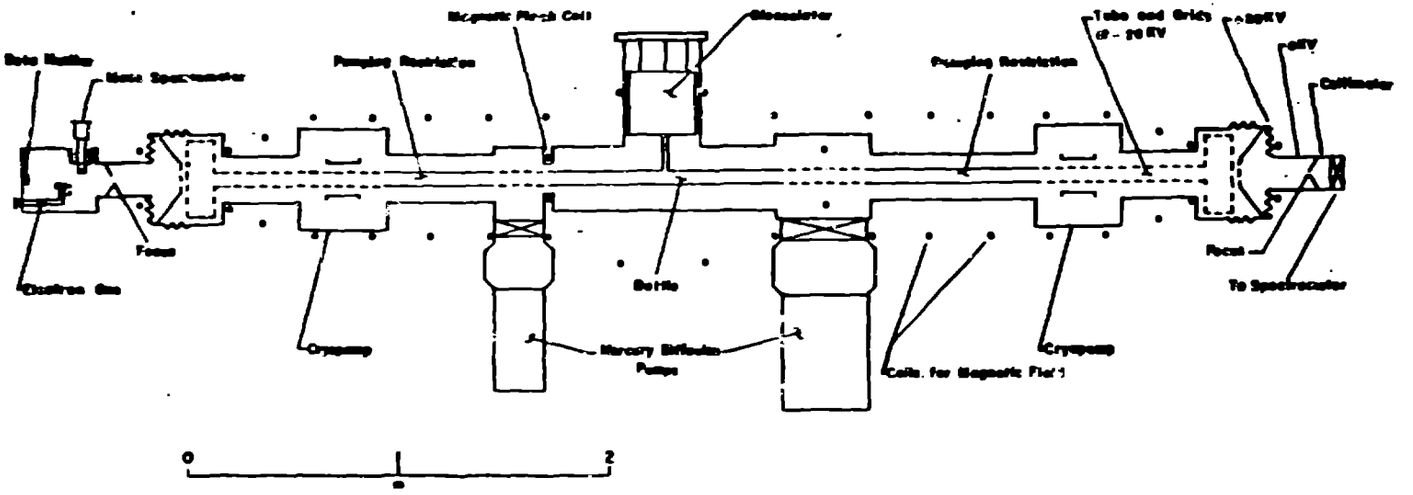


Fig. 2 Source and extraction system showing location of coils.

Acceleration and extraction is accomplished by grids and coils. Electrons are first accelerated through approximately 40 kV and then decelerated through 20 kV. This scheme has been adopted for a number of reasons. Spectrum distortion can result from tritium decaying in the acceleration region, and the volume is minimized by defining it with grids. In the present design, the fraction of detected decays occurring in the acceleration gap is of order 10^{-4}. Plane, parallel grids form a lens with infinite focal length which does not introduce the relativistic aberration. The deceleration region constitutes a short-focus Einzel lens (which does in principle possess relativistic aberration but operates with particles of fixed energy). Scanning the spectrum can be performed in several ways, but the preferred method is to vary the potential of the Kleppner bottle and maintain all other potentials and fields fixed. While this causes a (calculable) variation in extraction efficiency, the advantage of presenting the extraction lens, spectrometer and focal plane detector with fixed energy particles is considerable.

The spectrometer is modeled on the toroidal design of Tretyakov.[4] Not only does this design possess the highest luminosity of any β-spectrometer,

Table I

Spectrometer Design Parameters

Source - Image Distance	6.86 m
Orbit apogee	0.90 m
Inner cylinder radius	0.40 m
Entrance angle	$24 \pm 1.5^{\circ}$
Exit angle	$90 \pm 5^{\circ}$
Resolving power (base)	5×10^{-4}
Luminosity	0.023 cm^2
Object radius	0.83 cm
Image length (base)	0.4 cm

but it may be constructed entirely of straight conductors. The high performance is thus relatively simple to achieve. We have modified the design in two respects: The size of the spectrometer is approximately twice that of Tratyakov's, and particles enter the field at angles between 22.5° and 25.5° rather than between 85° and 95° to the axis. We find that the input profile of the coils can be straight lines at 125° to the axis (Fig. 3). Some price is paid in luminosity and in cancellation of high-order aberrations, but matching the atomic source to the spectrometer is greatly simplified. With the exception of fringing field effects, detailed calculations on the spectrometer have been carried out and Table I summarizes the important parameters.

The ion-optical characteristics of the system can be studied in several ways. A 40-kV electron gun is mounted at the opposite end of the source from the spectrometer and can be used to measure resolution, transmission and aberrations. A very convenient check on the general behavior of the Kleppner bottle, extraction system and spectrometer is to use 1.8-hr ^{83m}Kr, a daughter of 83-day ^{83}Rb. This isotope is gaseous, short-lived and emits a 17.8-keV conversion line. By appropriate variation of the temperature of the Kleppner bottle the ^{83m}Kr source can be made to roughly mimic the distribution of the tritium. At very low temperatures, the rejection of electrons originating at the wall can be investigated.

Construction and testing of the spectrometer is expected to be a lengthy project, and in the interim we shall make use of a Si(Li) detector at the

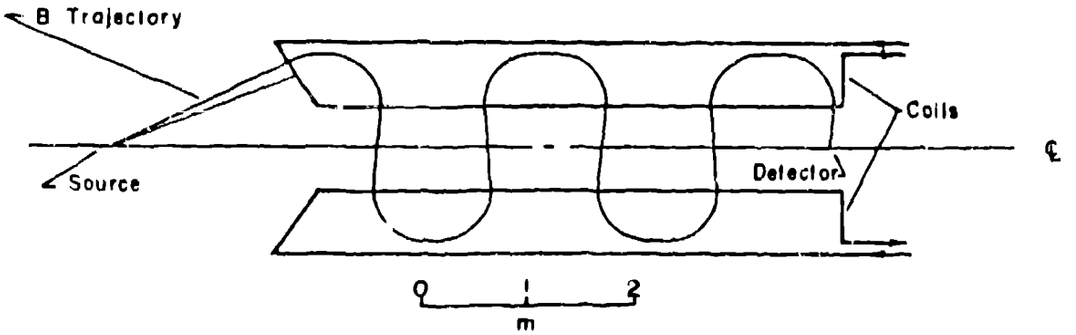


Fig. 3 Cross section of spectrometer showing coil profile and trajectory of β entering at maximum allowed angle.

focus of the extraction system. Its main function will be testing the system,but depending on how well its response can be understood, some consideration will be given to using it for a β-spectrum measurement.

In estimating the overall performance of the system we are hampered by lack of direct information about dissociation efficiencies and recombination rates for tritium. We have therefore taken data on H from the work of Walraven and Silvera[5] and arrive at focal plane count rates of approximately 1.3×10^{-3}/sec in the last 100 eV. Measured background rates in a prototype focal plane detector are of the same order, and Fig. 4 shows the limits that can be placed on $m_{\bar{\nu}_e}$ in about 2 weeks running. The counter-intuitive behavior of these curves (namely the increase in sensitivity with decrease in resolution) reflects the improved statistical accuracy obtainable at poor resolution. However, in practice, count rate will be sacrificed for the sake of reduced likelihood of systematic error, and data will probably be taken at 30 to 40 eV resolution. Should higher source intensities be available, the spectrometer is capable of substantially better resolution.

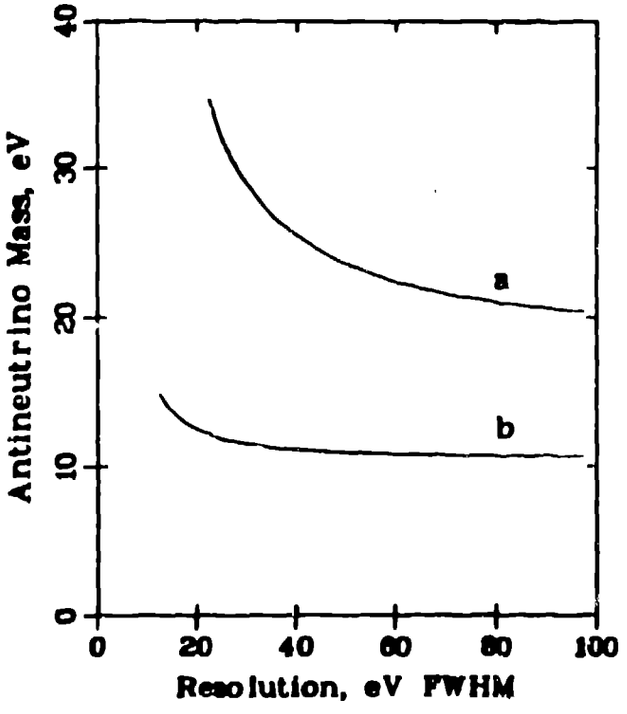


Fig. 4 Limits (2σ) on mass obtainable in 10^6 seconds running for a background rate of 2×10^{-3}/sec. a. source strength 5×10^{13} cm^{-2}. b. source strength 5×10^{14} cm^{-2}.

a. University of California at San Diego
b. Princeton University
c. Michigan State University

1. V. A. Lyubimov, E. G. Novikov, V. Z. Nozik, E. F. Tretyakov, and V. S. Kozik, Phys. Lett B94, 266 (1980).

2. I. F. Silvera and J. T. M. Walraven, Phys. Lett. 74A, 193 (1979).

3. This approach was suggested to us by D. Kleppner.

4. E. F. Tretyakov, Izv. Akad. Nauk. SSR. Ser. Fiz. 39, 583 (1975).

5. J. T. M. Walraven and I. F. Silvera (to be published).

COSMIC RAY INDUCED ERRORS

SOFT ERRORS

HARD ERRORS

A SINGLE COSMIC RAY MAY DEPOSIT ENOUGH ENERGY TO CAUSE TOTAL DOSE FAILURE IN A SMALL DEVICE

LOS ALAMOS' ROLE IN NATIONAL DEFENSE DICTATES THAT WE BE PARTICULARLY INTERESTED IN THE IMPACT OF THIS TECHNOLOGY BASE ON DOD MISSIONS/SYSTEMS

MATERIALS – PROCESSING

GENERAL SEMICONDUCTOR PROCESSING
- EPI, LASER ANNEALING, THIN FILM
- RADIATION HARD DEVICES

MATERIALS SCIENCE CENTER
- SURFACES

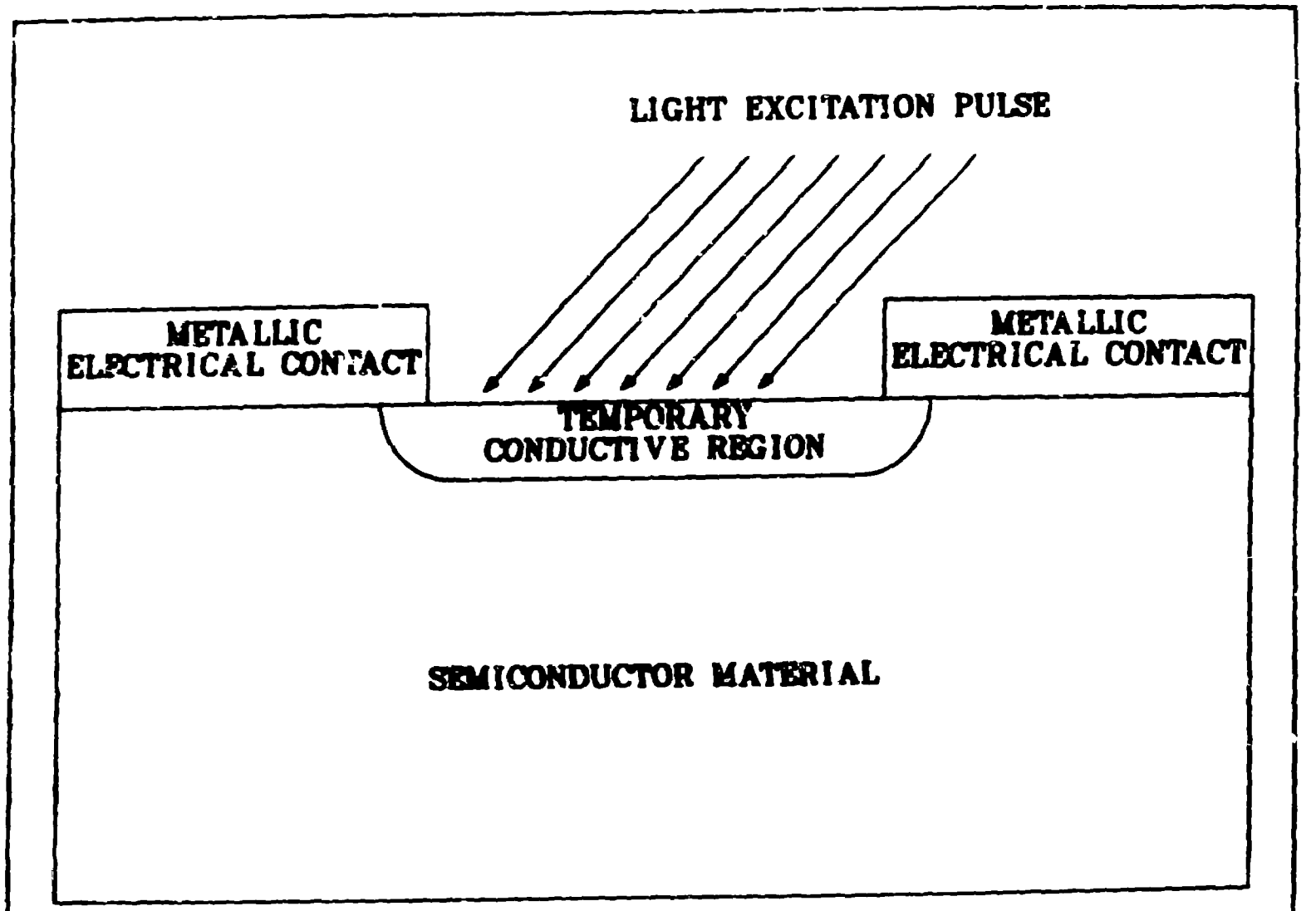
PROCESS CONTROL

ELECTROCHEMISTRY/CORROSION

ADVANCED LITHOGRAPHIES
- DEEP EXCIMER LIGHT SOURCES (2000 – 3000 Å, HIGH POWER)

ACCELERATOR TECHNOLOGY FOR E BEAMS

COOLING–PACKAGING QUESTIONS
- HEAT TRANSFER MODELING AND MATERIALS



PCE – METHOD OF OPERATION