On the search for the $\mu \to e$ conversion process in a nucleus

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Among the most important problems of elementary-particle physics is the problem of searching for nonconservation of leptonic quantum numbers. In the $\mu \to e$ conversion process in a nucleus the muon and electron numbers are not conserved, and therefore this process does not occur in the standard electroweak theory. At the same time in a number of extensions of the minimal model[1] nonconvervation of lepton numbers is a natural property of the theory.

The signature of $\mu \to e$ conversion is the appearance of a single monochromatic electron with energy 105 MeV. At the present time an upper limit $4 \cdot 10^{-12}$ has been obtained for the relative probability of the $\mu \to e$ conversion process, and it is planned to reach the level $4 \cdot 10^{-14}$.[2,3] The main limitation to the achievable level of the process sought is the intensity of the negative-muon beam and the resolution of the detector in the energy of the conversion electrons. The low-energy negative-muon beams which exist in operating meson factories (the need for a low energy is due to the need for stopping the particles in a thin target which does not affect the monochromaticity of the electron produced in $\mu \to e$ conversion) apparently do not appreciably exceed in intensity 10^7 particles/sec under the condition of pulsed operation of the primary proton beam, which permits separation from the pion component and from the background of fast neutrons.

In the present work it is proposed to accomplish the formation of the muon beam, stopping of the muons in thin targets, and detection of the 105-MeV electrons produced as the result of $\mu \to e$ conversion, by means of an apparatus consisting of several superconducting solenoids (see Fig. 1). A proton beam is injected into the apparatus along the magnetic field of solenoid 2 with a field strength 1.6 T and is directed onto a target consisting of thin tungsten or molybdenum disks of small diameter (1 cm). Pions produced in the targets precess in vacuum along the magnetic field lines, are partially reflected from a magnetic stopper in the front part of the solenoid, and move backward with respect to the proton beam. In a length of a few meters most of the soft pions (with energy < 10 MeV) decay and the low-energy muons produced, whose trajectories are enclosed in a cylinder of comparatively small radius (15 cm), directly or after reflection from the magnetic stopper leave in the backward direction. As a result of the low average density of the targets and their well developed surface, it is possible to cool them by radiation up to an average proton current 100 μA. The meson-producing region is connected with the muon-target and detector region by a collimator, which is also located in the longitudinal field of a solenoid of smaller diameter.

The collimator diameter determines the efficiency of muon extraction and, as a specific calculation[4] shows, for a field of 1.2 T and a diameter of 30 cm the intensity of the stopped muons is at least $0.7 \cdot 10^{11}$ particles/sec for 100 μA of average proton current. The efficiency of the extraction is 10^{-4} per proton, in contrast to 10^{-8} for the usual schemes. The average kinetic energy of the extracted muons is 5 MeV. Most of the muons stop in thin targets located along the axis of the detector-region solenoid. Aluminum is considered to be the optimal target. The radius of the muon target is chosen to be smaller than the radius of the collimator, and since the targets are located in a high vacuum, the muons stop only in the targets. The optimal ratio of the orbit of a 105-MeV electron and the collimator radius is 2:1, and here the radius of the muon targets is half of the collimator radius. In this case in the field of the solenoid 8 the electrons from the decay $\mu \to e\nu\bar{\nu}$ are easily separated from the region of detection of the electrons from $\mu \to e$ conversion. Use of a magnetic field which falls off gradually over a length of several meters (1.4–0.9 T) permits complete preservation of the separation of the region of decay electrons from the peripheral part of the trajectories of the 105-MeV electrons as a result of the adiabatic nature of their motion and permits orientation of the plane of the chambers with respect to the direction of electron motion in the optimal way.

The problem of the experiment is to detect the monochromatic electrons of $\mu \to e$ conversion with the maximal resolution. Detection of them is possible by means of wire proportional chambers which are separated from the evacuated volume by a rather thin film, which requires a low pressure. The low sensitivity of such chambers to relativistic particles in turn makes the efficiency problem more important; this can be solved by use of the combination of a thin Čerenkov radiator and a photosensitive proportional chamber. This combination has a further advantage—a threshold sensitivity which permits appreciable suppression of the background of soft electrons and slow heavy particles emitted in capture of negative muons.

Separation of the events from capture of pions and muons must be carried out with use of a pulsed proton beam with a period of 1 μsec and a pulse of 0.2 μsec, so that during the period of detection of the $\mu \to e$ conversion process all pions decay or are absorbed. The required depth of modulation of the proton beam is 10^{10}. In addition to track detectors, it is possible to place also around the periphery a total-absorption scintillation detector which permits use of a more efficient trigger.

Modeling of the process in the apparatus discussed demonstrates the possibility of detection of $\mu \to e$ conversion at the level of a relative probability 10^{-16} of the capture probability under the condition that the energy resolution is 1%. The design of the superconducting system is within the range of existing technology. The most difficult part is the solenoid of the meson-production region. The diameter of this solenoid must be sufficient to place shielding from neutron radiation between the vacuum chamber and the solenoid cryostat. Calculations show that for a shield thickness of 0.5 m (copper, uranium oxide) the heat load on the cold part of the solenoid will be less than 10–15 W.

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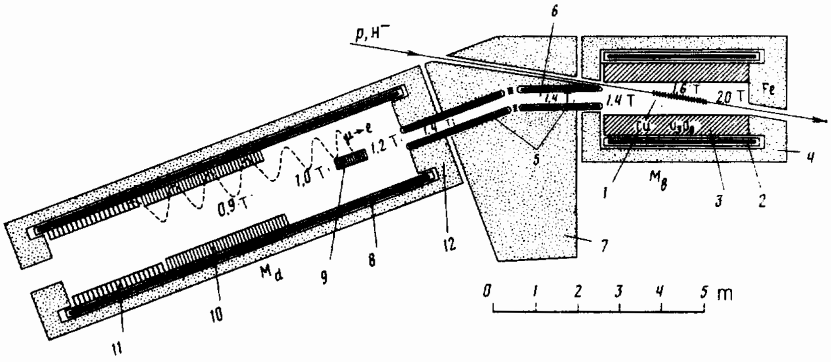

FIG. 1. Diagram of the apparatus: 1—meson-producing target (tungsten); 2—superconducting solenoid; 3—solenoid shield; 4—steel magnet yoke; 5—collimator solenoids; 6—collimator; 7—shielding (heavy iron); 8—detecting-system solenoid; 9—targets for stopping of muons; 10—detector (proportional chambers); 11—total-absorption scintillation spectrometer; 12—magnet yoke.

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