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PARITY-VIOLATING WEAK NEUTRAL CURRENT
EFFECTS IN ELASTIC $e^{-12}\text{C}$ SCATTERING

Progress Report

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ABSTRACT

As a means of investigating unified gauge theories of the electro-weak interaction we have been preparing an experiment for the Bates Electron Accelerator to determine the parity violating asymmetry $A = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L)$ for 30° elastic scattering by ^{12}C of 250 MeV longitudinally polarized electrons, where σ_R and σ_L are respectively the differential cross sections for electrons with right and left helicities. The asymmetry depends strictly on the isoscalar vector-hadronic coupling constant, γ , and in terms of the Weinberg-Salam model is predicted to have a value of $\sim 2 \times 10^{-6}$ for our choice of kinematics. Central to the success of the measurement of such a small quantity is the use of an intense, highly stable source of polarized electrons. The progress in the development of such a source, based upon photoemission from GaAs, is reviewed in this report.

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INTRODUCTION

Central to all unified gauge theories of the electro-weak interaction is the existence of a neutral weak current carried by one or more uncharged massive bosons. Although substantially weaker in influence than its neutral electromagnetic counterpart, the neutral weak current can be detected through its parity violating properties, most prominently revealed by interference effects between the weak and electromagnetic neutral currents. To this end we have been preparing an experiment at the Bates Electron Accelerator in which we will study the helicity dependence of elastic scattering of longitudinally polarized electrons by unpolarized ^{12}C nuclei, a process which depends upon the isoscalar vector-hadronic coupling constant $\tilde{\gamma}$.¹⁻³

For our choice of kinematics, an energy of 250 MeV and a scattering angle of 35° , the four-momentum transfer will be approximately 150 MeV/c, a value for which the standard Weinberg-Salam⁴⁻⁶ model predicts an asymmetry $A = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L) \sim 2 \times 10^{-6}$, where σ_L and σ_R are respectively the differential cross sections for the scattering of electrons with right and left helicities. Our experimental goal is the measurement of A to a precision of

$\sim 2 \times 10^{-7}$, as a consequence of which we have been developing an intense, stable source of polarized electrons with phase space characteristics that will remain largely invariant as a function of helicity. In order to meet the stringent requirements of our experiment, we have elected to use a GaAs photocathode⁷ illuminated by light from an electro-optically modulated beam of infrared radiation originating in a cw krypton-ion laser. This report details the progress that has been achieved to date in the development of the GaAs source.

SCIENTIFIC PROGRESS

More than ten sources of polarized electrons based upon photoemission from GaAs either are in use or are under development in laboratories around the world.⁸ All of these sources produce relatively intense beams of electrons with polarizations varying between approximately 0.35 and 0.45. The Bates source will also possess these characteristics, having as its design goals a peak intensity of ~ 20 mA in a 15- μ sec pulse, a repetition rate up to 1 kHz, and a polarization of ~ 0.4 . What distinguishes the Bates source from other GaAs sources in its planning, however, are its stability, its invariance of phase space under polarization reversal, and its ability to withstand high-gradient extraction.

In order to appreciate the need for such characteristics, consider that the determination of A to an accuracy of two parts in 10^7 will require for our experimental arrangement approximately 100 hours of beam time at a repetition rate of 650 Hz. Consequently, to avoid limitations of systematic errors, the intensity of the beam should remain constant at a level of $\sim 3 \times 10^{-3}$ on a pulse to pulse basis. Moreover since the fractional change in the differential cross section scales as 5 times the fractional change in the beam energy, the energy

of the beam should remain constant to within ~ 1 keV, a requirement that dictates not only stability of accelerator operation, but also that of source phase space and intensity in order to avoid changes in beam loading. The need for high-gradient extraction follows even more directly from the need for a high-current beam combined with the emittance requirements of the accelerator and the effects of space charge on the phase space of the beam.

Added to these conditions are the criteria of ~ 350 keV injection energy and long crystal lifetime. To meet these various demands, the source utilizes a three chamber design as illustrated in Fig. 1. All surface preparation of the crystal, including annealing, cesiation, and oxygenation, is performed in a preparation chamber, the details of which are shown in Fig. 2. A bakeable gate valve isolates this chamber from the gun region thus minimizing cesium contamination of the accelerator column and permitting high-gradient extraction of the polarized electrons. Transport of the crystal between the gun and preparation regions is achieved through the use of an ultra-high vacuum manipulator as indicated in Fig. 1. A similar manipulator permits the crystal to be transported from the preparation chamber past a second gate valve and into an airlock from which it can be retrieved for replacement. This three chamber design, with only the airlock being exposed to

FIG. 1. Schematic layout of Bates polarized electron source.

FIG. 2. Schematic diagram of preparation chamber.

atmosphere periodically, should permit the source to operate at the extremely low pressures required for long crystal lifetimes. In fact, the design goals for the vacuum are $\sim 5 \times 10^{-11}$ Torr in the gun region and $\sim 5 \times 10^{-10}$ Torr in the preparation chamber, conditions which can be met through the use of ion and Ti-sublimation pumping, judicious choice of materials, and 100-hour-long bakeouts at temperatures of $\sim 250^\circ\text{C}$ following initial pump down from atmosphere.

The lifetime of the crystal should be enhanced further by the use of liquid nitrogen cooling of the cathode and the first accelerating electrode, as shown in Fig. 3. Through this technique, desorption of cesium from the crystal surface will be limited and evolution of contaminants from the adjacent electrode will be retarded. However, the most serious threat to limited crystal lifetime is the danger of ion bombardment of the crystal surface caused either by ionization of the residual gas or by beam scraping of the extraction electrodes. Naturally the first of these processes cannot be avoided entirely but only can be minimized through the maintenance of extremely good vacuum. However, electrode scraping, a condition which seems to exist in the standard unpolarized Bates gun, should not be present at all in our polarized gun according to the results of extensive ray tracing computations, the details of which were presented in last years progress report (DOE/ER/40017-3).

FIG. 3 Scale drawing of gun region.

Insofar as stability of operation and constancy of phase space are concerned, the key lies in the design of the optical system. To this end, a cw krypton-ion laser is used with high-quality electro-optical modulation and sensitive beam intensity and profile monitors. It is difficult to assess the optical requirements quantitatively, however, as the coupling between phase space variation and accelerator performance is not known quantitatively. The design goal therefore is to achieve whatever optical stability state of the art permits, particularly as regards reversal of helicity.

During the last year, substantial progress was achieved in all phases of the source development, although the target of installation at Bates was not met. Two major problems precluded this achievement. First, the manpower committed to the project continued at an undesirably low level with only one graduate student, Gordon Cates, and one postdoctoral researcher, Reiner Schaefer, committed to full time experimental effort. This level should be contrasted with the original objective of the equivalent of two full time senior scientists and two graduate students devoted to the development of the source.

The second problem involved the operation of one of the ultra-high vacuum manipulators, in particular the one used for moving the crystal between the gun chamber and the preparation

chamber. Purchased as a stock item from Huntington Mechanical Laboratories, the manipulator (Model VF-169-18) repeatedly seized after bakeout and through apparent outgassing limited the vacuum in the preparation chamber to $>10^{-9}$ Torr. Two replacement units displayed the same behavior, and after more than four months of testing, an alternate approach was sought. In November, 1982, Vacuum Generators began to market an equivalent item, the first available model of which was obtained and tested successfully at Yale in mid-December. Size differences between the two manipulators required some mechanical changes in the gun region, which were undertaken at the close of the calendar year.

In spite of these problems, a number of major accomplishments were achieved. Extensive tests of crystal preparation were carried out, and eventually quantum yields of ~ 2.5 percent were obtained at the He-Ne wavelength of 632.8 nm with ~ 1.5 mW of cw incident light. If this figure holds at the krypton wavelengths of 752 nm and 799 nm, the design goal will have been met. Of equal importance, the lifetime of the crystal, as determined by a 50 percent reduction in the quantum yield, was found to exceed two days, far longer than that originally anticipated. Unfortunately both of these studies had to be carried out in the preparation chamber because the malfunctioning manipulator precluded transport of the crystal

into the gun chamber. Consequently, the lifetime measurements are not completely conclusive: the detrimental effects of high-current photoemission and ion backscattering could not be studied nor could the beneficial effects of liquid nitrogen cooling be determined. Nonetheless, the lifetime results do provide much cause for optimism.

With the new manipulator now installed and functioning properly and with the necessary modifications of the gun region completed, the pressure in the gun region has reached a level of $<8 \times 10^{-11}$ Torr following five days of baking at a temperature of $\sim 250^{\circ}\text{C}$. Final mechanical tests of the crystal transport system are being conducted preparatory to gun-region photoemission studies using the modulated Kr ion laser. These studies will comprise not only quantum yield measurements and the determination of true crystal lifetimes, but also electron polarization measurements and the investigation of the phase space properties of the circularly polarized incident krypton-ion laser beam. Barring unforeseen circumstances, these studies should be completed within three or four months.

FUTURE PLANS

Following the completion of tests at Yale University, the polarized electron source will be moved to Massachusetts, most probably in late spring. Installation of the source at Bates should take four to six months, in which case preliminary accelerator tests with the polarized beam could occur in the fall of this year. Dedicated experimental running would then ensue sometime after January 1, 1984. These predictions are relatively conservative and assume a level of manpower effort during the next year.

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