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THE RADIATIVE MUON CAPTURE PROGRAM AT TRIUMF*

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We describe recent measurements of radiative muon capture on hydrogen, ^{3}He and ^{58,60,62}Ni using the RMC pair spectrometer at the TRIUMF cyclotron laboratory. Our determinations of the induced pseudoscalar coupling of the nucleon's weak current are discussed.

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The proton's weak axial current is governed by two coupling constants, the weak axial coupling g_a and the induced pseudoscalar coupling g_p. The values of g_a and g_p reflect the modification of the proton's weak interaction by its strong interaction. The approximate chiral symmetry of u/d quark interactions, and the resulting approximate conservation of the proton's axial current, relate these couplings to the pion mass m_π and decay constant f_π (which set the scales of explicit and spontaneous chiral symmetry breaking). For the free proton case, chiral perturbation theory (χPT) yields $g_p/\mathrm{g}_a = 6.52\pm0.07$ [1]. For the bound proton case, medium renormalizations of g_p could reflect medium modifications of such things as nucleon structure, the pion field, and chiral symmetry breaking.

Ordinary muon capture and radiative muon capture, OMC and RMC, are semi-leptonic weak interactions that compete with muon decay as disintegration channels of muonic atoms. The RMC branching ratio varies from $\sim10^{-8}(Z=1)$ to $\sim10^{-5}$ ($Z\geq12$) and the RMC photon spectrum comprises a broad continuum ranging from 0 to $\sim$100 MeV. The RMC branching ratio and photon energy spectrum are uniquely sensitive to the poorly known induced pseudoscalar coupling of the proton's weak axial current.

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At the TRIUMF cyclotron laboratory, using the RMC pair spectrometer, we have performed an extensive program of RMC experiments. The basic experimental difficulty is the low photon yield due to the small RMC branching ratio. Backgrounds include photons from pion capture (*e.g.* $\pi^- p \rightarrow \gamma n$ and $\pi^- p \rightarrow \pi^0 n$) and muon decay (*e.g.* external or internal bremsstrahlung), and cosmic and accelerator backgrounds. In the experiments negative muons are counted in a beam telescope and are stopped in the host material. Photons emerging from the target are converted in a cylindrical Pb converter, and e^+e^- pairs emerging from the converter are tracked in cylindrical tracking chambers. An axial magnetic field enables momentum analysis of the e^+e^- tracks, cylindrical trigger scintillator arrays enable fast identification of photon events, and cosmic ray counters enable rejection of cosmic ray and accelerator related backgrounds.

In our RMC on LH_2 experiment we stopped 3.6×10^{12} negative muons and recorded 279±26 RMC photons (in a six month cummulative running period). The resulting partial branching ratio for RMC on LH_2, with photon energies $k >60$ MeV and capture times $t >365$ ns, is $(2.10\pm0.21)\times10^{-8}$. The extraction of the weak pseudoscalar coupling from the partial branching ratio is dependent on the population of the μ^-p atomic and $p\mu^-p$ molecular states and, in particular, the ortho-to-para μ–molecular transition rate $\Lambda_{\rm op}$. In Fig. 1 we plot g_p *versus* $\Lambda_{\rm op}$ for our TRIUMF RMC experiment [2] and also the earlier SACLAY OMC experiment [3] (along with the current experimental and theoretical values of $\Lambda_{\rm op}$). The plot is intriguing: for $\Lambda_{\rm op}\sim0$ the RMC and OMC results for g_p agree with each other but not with χPT, for $\Lambda_{\rm op}=(4.1\pm1.4)\times10^4{\rm s}^{-1}$ (expt. [3]) the RMC result disagrees with, while the OMC result agrees with, χPT, and for $\Lambda_{\rm op}=(7.1\pm1.2)\times10^4{\rm s}^{-1}$ (theory [4]) neither RMC, OMC or the χPT results agree. The results in Fig. 1 have, consequently, motivated new experimental and theoretical efforts to investigate the puzzle (a remeasurement of $\Lambda_{\rm op}$ is underway [5]).

We have also measured RMC on ^{3}H in order to determine g_p. The ^{3}He nuclear wavefunctions are accurately determined, and the μ–molecular issues that plague the electrically neutral μ^-p system are absent for the positively charged $\mu^-{}^3$He system. During the summer '95 we performed a measuremnt of both exclusive and inclusive RMC on ^{3}He using the RMC pair spectrometer and a novel ^{3}He target. The pulse shape spectra of the UV scintillation light from the liquid ^{3}He target was digitized by CCDs to enable the identification of the recoil tritons, deuterons and protons. During the running period we accumulated a total of 7×10^{11} μ^- stops in liquid ^{3}He, and recorded a total of ∼400 photons from the exclusive $^3{\rm He}\rightarrow{}^3{\rm H}$ RMC process and ∼600 photons from the inclusive RMC process. The analysis is underway.

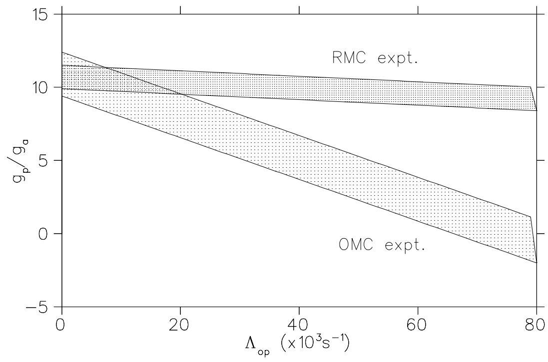

Fig. 1. g_p/g_a *versus* $\Lambda_{\rm op}$ for the TRIUMF RMC and the SACLAY OMC experiments. The current experimental and theoretical values of $\Lambda_{\rm op}$ are $4.1{\pm}1.4{\times}10^4$s^{-1} and $7.1{\pm}1.2{\times}10^4$s^{-1}, respectively.

Lastly, we have performed measuements of the isotope dependence of RMC on ^{58,60,62}Ni. Over recent years a large body of nuclear RMC data, accumulated at PSI and TRIUMF, has revealed a systematic decreasing RMC/OMC ratio with increasing atomic mass (A) or neutron excess (α). Some authors have claimed the decreasing RMC/OMC ratio is evidence for a large A dependence of g_p. Other authors have argued the decreasing RMC/OMC ratio is due to increasing Pauli blocking with increasing neutron excess. Our measurement of RMC on ^{58,60,62}Ni revealed, while the α dependence of the Ni RMC data is consistent with the earlier RMC data, the A dependence of the Ni RMC data is inconsistent with the earlier RMC data. Our Ni RMC data, therefore, strongly favor the "Pauli blocking" rather than "g_p renormalization" explanation for the nuclear RMC systematics.

In summary, we have reviewed several highlights of the RMC program at the TRIUMF laboratory. For the free proton case our results for g_p are both puzzling and intriguing. For the bound proton case our results do not favor the suggestions of a large atomic mass dependence of g_p.

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