DOE/ER/40342--4

DE91 007504

Technical Progress Report

Colorado School of Mines Low Energy Nuclear Physics Project

DE-FG02-87ER40342

Principal investigator

F. Edward Cecil

Professor of Physics

Colorado School of Mines

January 2, 1991

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Summary

This report summarizes the 1990 calendar year activities of the low energy nuclear physics project in the physics department at the Colorado School of Mines. This project is supported through the U. S. Department of Energy through research grant #DE-87ER-40342. A major accomplishment of this project in the past year is the completion of a fairly comprehensive paper describing the survey of radiative capture reactions of protons on light nuclei at low energies. In addition we have completed a preliminary set of measurements of $(d,p)/(d,\alpha)$ cross section ratios on the charge symmetric nuclei ${}^6\text{Li}$ and ${}^{10}\text{B}$ as a test of the Oppenheimer-Phillips effect. While the ${}^6\text{Li}$ data remain inconclusive, the ${}^{10}\text{B}$ data show solid evidence for the Oppenheimer-Phillips enhancement of the (d,p) reaction relative to the (d,α) reaction for deuteron bombarding energies below about 100 keV.

We have continued our investigation of fusion reaction products from deuterium-metal systems at room temperatures with the startling observation of intense bursts of energetic charged particles from deuterium gas loaded thin titanium foils subject to non-equilibrium thermal and electrical conditions.

We have completed two projects involving the application of the low energy particle accelerator to material science problems; firstly a study of the transformation of crystalline to amorphous Fe-Zr systems by proton irradiation and secondly the effects of ion bombardment on the critical temperature of YBCO high-temperature superconductors.

Finally we have made progress in several instrumentation projects which will be used in some of the up-coming measurements of nuclear cross sections at very low energies.

Table of Contents

1. Radiative capture of protons by light nuclei at low energies
2. Ratios of (d,p) and (d, α) reactions on ^6Li and ^{10}B at low energies
3. Fusion reaction products from deuterium-metal systems at room temperatures
4. Material sciences.
5. Instrumentation
6. Personnel
7. Theses
8. Bibliography of publications
9. Reprints and preprints of publications

1. Radiative capture of protons by light nuclei at low energies.

We have completed our survey of (p,γ) reactions on the nuclei ${}^6\text{Li}$, ${}^7\text{Li}$, ${}^9\text{Be}$ and ${}^{11}\text{B}$ at proton bombarding energies between about 30 and 170 keV. An important contribution to this effort was provided by J.A. McNeil of CSM and P.D. Kunz of CU who developed a distorted wave capture code for comparison with the measured cross sections. With the exception of ${}^6\text{Li}$, we find remarkable quantitative and qualitative agreement between the measured and calculated cross sections at low energies. The disagreement in the case of ${}^6\text{Li}$ is substantial and may be the result of the coupling of the capture process and the α - ${}^3\text{He}$ break-up channel. This possibility is under continuing investigation. The details of this project may be found in a preprint of a paper which we have completed and have submitted to Nuclear Physics for publication. A preprint of this paper is attached to this report. We feel that this work represents an important contribution to our understanding of nuclei and their interaction with protons. To quote from the concluding paragraph of our paper:

"...the results of this study close an important chapter in the field of nuclear physics. Together with earlier studies of proton capture reactions on the other light nuclei at low energies, the cross sections for all stable nuclei through C have now been measured at energies sufficiently low so as to allow extrapolation to zero energy."

2. Ratios of (d,p) and (d, α) reactions on ^6Li and ^{10}B at low energies

We have completed an initial set of measurements of the thick target yields of the (d,p) and (d, α) reactions on the charge symmetric nuclei ^6Li and ^{10}B at deuteron bombarding energies between 30 and 170 keV. The motivation for these measurements is to examine the viability of the Oppenheimer-Phillips (O-P) effect¹, in which (d,p) reactions are enhanced by virtue of the Coulomb distortion of the deuteron. This effect, although first proposed over fifty years ago, is still debated. Several years ago we measured the ratios of the reactions $^6\text{Li}(\text{d},\text{p}\gamma)^7\text{Li}$ and $^6\text{Li}(\text{d},\text{n}\gamma)^7\text{Be}$ between deuteron bombarding energies of 30 and 150 keV². We found an enhancement of the (d,p) versus (d,n) yields at the lowest energies as expected on the basis of the O-P effect. We noted that our interpretation was potentially clouded by the possibility of (n, γ) or (n,n' γ) reactions (from d-d reactions due to deuterium build up in the target) simulating the expected effect by virtue of production of the same gamma ray produced in the $^6\text{Li}(\text{d},\text{p}\gamma)^7\text{Li}$ reaction. More recently Paolo³ has argued that the O-P effect may play an important role in the claims of "cold fusion" by suppressing the neutron producing channels in the low energy d-d reactions. Koonin and Mukerjee⁴, on the other hand, have presented persuasive theoretical arguments that the O-P effect should influence the (d,p)/(d,n) ratio by no more than 10%.

The present set of measurements seeks to resolve these conflicting considerations. Specifically, the (d,p)/(d, α) ratio measurements should prove more sensitive than our earlier $^6\text{Li}(\text{d},\text{p}\gamma)^7\text{Li}/^6\text{Li}(\text{d},\text{n}\gamma)^7\text{Be}$ ratio measurements since neutron production from deuterium build up in the target will not directly affect the measurement and since the charged particle detectors used in these measurements are virtually background-free.

The ^6Li measurements were carried out with rolled metallic foils of 99.6% enriched ^6Li . A typical spectrum is shown in Figure 1. The relevant ratio is between the peaks labelled $^6\text{Li}(\text{d},\text{p}0)^7\text{Li}(\text{g.s.})$ and $^6\text{Li}(\text{d},\alpha)^4\text{He}$. The (d,p0)/(d, α) ratio is plotted in Figure 2.

We note a slight enhancement at the lowest energies, no more than about 10%. The large error bar at the lowest energy results from pile-up of the 3 MeV proton from the $d(d,p)t$ reaction, again due to deuterium build up in the target. At the higher energies our measured ratios agree with those of Elwyn et al⁵.

The ^{10}B measurements were carried out with pressed pellets of 90% enriched metallic B powder. A typical spectrum is shown in Figure 3. In this spectrum there are five levels of ^{11}B from the (d,p) reaction are evident up to an excitation energy of about 7 MeV as well the ground and broad first excited states of ^8Be from the (d,α) reaction. The ratios $(d,p2)/(d,\alpha1)$ and $(d,p0)/(d,\alpha1)$ are plotted in Figure 4 where a clear enhancement is seen at low energies. There have been no reported ^{10}B (d,p) and (d,α) cross section at low energies for comparison with the present work.

Further work is needed on the ^{10}B measurements to reduce the statistical uncertainties at low energies.

1. J.R. Oppenheimer and M. Phillips, Phys. Rev. 48, 500 (1935).
2. F.E. Cecil, R.J. Peterson and P.D. Kunz, Nucl. Phys. A441, 477 (1985).
3. P. Paolo, Nature 338, 301 (1989).
4. S.E. Koonin and M. Mukerjee, Phys. Rev. C 42, 1639 (1990).
5. A. Elwyn et al., Phys. Rev. C 16 1744 (1977).

Figure 1. Typical spectrum for the reaction $d + {}^6\text{Li}$.

Figure 2. Ratio of $(d,p)/(d,\alpha)$ reactions for ${}^6\text{Li}$.

Figure 3. Typical spectrum for the reaction $d + {}^{10}\text{B}$

Figure 4. Ratio of $(d,p)/(d,\alpha)$ reactions for ${}^{10}\text{B}$.

3. Fusion reaction products from deuterium-metal systems at room temperatures

We have continued our investigation of charged particle emission from deuterium loaded metals. The results of our original investigation, in which a deuteron beam from our accelerator was employed to load a thin foil of Pd and energetic charged particles subsequently measured, has been published. A copy of the publication is included in this report. Our subsequent work is supported in part by a research contract from the Electric Power Research Institute (EPRI) as well as the present DOE grant. Following this initial investigation, we modified the direction of our efforts to study the Ti alloy Ti662 (6% V, 6% Al, 2% Sn) following the reported successes of Menlove at LASL with his investigation of neutron emission from this alloy. We likewise substituted high temperature deuterium gas loading for the beam loading. The results have been astounding. Intense bursts, lasting in some cases more than an hour, of charged particles, with count rates in excess of a kHz and energies in excess of 10 MeV have been observed from thin (about 100 μm) $\text{Ti}_1\text{-D}_1$ foils. Every effort has been made to exclude electrical, mechanical and environmental artifact as possible sources of the observed signals. Details of these results may be found in a paper which has been submitted to Physical Review Letters. A preprint of this paper is attached to this report.

4. Materials sciences

The results of our investigation of the crystalline to amorphous transformation of Fe-Zr alloys by energetic proton bombardment has been published. A reprint of this publication is included in this report.

We have completed an investigation of the effect of light ion bombardment on the critical temperature of YBCO high temperature superconductor. In this work, the compositional, electronic and structural properties of six RF-sputtered YBCO thin films, deposited on MgO substrates and subjected to beams of H^+ , He^+ , C^+ , N^+ , O^+ and Ne^+ were investigated at an average bombarding energy of 150 keV and at dosages from 10^{13} to 10^{16} ions/cm². This work again illustrates the versatility of our accelerator, particularly in the flexibility of available beams. We found that the critical temperature decreased with increasing beam dosage in every case and that the films were amorphized. The results of this investigation will be published at a later date.

5. Instrumentation

We have devoted considerable effort to the development of instrumentation projects which will be used in upcoming measurements of nuclear cross sections. These include the production of TiD targets for the proposed measurement of the $D(\alpha, \gamma)^6Li$ cross section; the developments of a CAMAC system for the particle identification required for the measurement of the $^7Li(^3He, p)^9Be$ cross section and the completion of the beam profile monitor required of virtually all future studies.

6. Personnel

Ph. D.

F.E. Cecil

J.A. McNeil

P.D. Kunz (Nuclear Physics Lab, Univ. of Colo.)

C.S. Galovich (Univ. of Northern Colo.)

Graduate students

H. Liu

D. Beddingfield

H. He

J. Scorby

L. Greco

Undergraduate students

Ira Frosch

Mark Wassinger

Todd Kuhlman

7. Completed theses

Harry He, "A beam optics study of the general ionex model 1545 linear particle accelerator." M.S. December 1990. Advisor F.E. Cecil

Ira Frosch, "A Compton suppressed gamma ray scintillation spectrometer." B.S. May 1990. Advisor F.E. Cecil

Luigi Greco, "Ion irradiation studies of RF sputtered YBCO thin film superconductors" M.S. December 1990. Advisor J.U. Trefny

8. Bibliography of publications

1. F.E. Cecil and J.A. McNeil, "Coment on cluster impact fusion", Phys. Rev. Letters 64, 2210 (1990).
2. F.E. Cecil, D. Ferg, T.E. Furtak, C. Mader, J.A. McNeil and D.L. Williamson. "Study of energetic charged particles emitted from thin deuterated Palladium foils subject to high current densities", Journal of Fusion Energy 9, 195 (1990).
3. M. Kopcewicz, D.L. Williamson and F.E. Cecil, "Proton irradiation and solid-state reaction of Fe-Zr multilayer", Journal of Hyperfine Interactions 56, 1599 (1990).
4. F.E. Cecil, H. Liu, J.C. Scorby and S.S. Medley, "Prompt gamma ray diagnostics of advanced fuel fusion plasmas", Rev. Sci. Instruments 61, 3223 (1990).
5. S.S. Medley, S.D. Scott, A.L. Roquemore and F.E. Cecil, "Performance of the fusion gamma diagnostic on TFTR", Rev. Sci. Instruments 61 3226 (1990).
6. F.E. Cecil, H. Liu, D. Beddingfield and C.S. Galovich, "Observation of charged particle bursts from deuterium loaded thin Ti foils" Phys. Rev Letters, submitted 1990.
7. F.E. Cecil, D. Ferg, H. Liu, J.A. McNeil and P.D. Kunz, "Radiative capture of protons by light nuclei at low energies", Nucl. Physics A, submitted 1991.

Reprints and preprints removed

END

DATE FILMED

02 / 27 / 91