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PROGRESS REPORT

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Submitted by

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University of Arizona

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PROGRESS REPORT

January 1, 1970 - December 31, 1970

A. FACILITIES

1. The 5.5 MV CN Van de Graaff

The CN Van de Graaff was used 3430 hours during this report period. Approximately 80% of this time was utilized for nuclear physics research under this contract. The remaining time was used by Dr. S. Bashkin's atomic physics group. The tank was removed 20 times during the year. Nine of the openings were in connection with the polarized source. The machine ran well with no major repairs necessary. The 2 MV machine was not used for nuclear physics research during the past year.

2. Additional Beam Line

A third beam line in the nuclear physics target room will soon be installed. Parts have been ordered to construct an additional 20 ft. beam line to the west of the two existing lines. This will allow us to have three experiments semi-permanently lined up and ready to go.

B. WORK COMPLETED

1. Mean Lives and Angular Correlations in ^{57}Co with the $^{54}\text{Fe}(\alpha, p\gamma)^{57}\text{Co}$ Reaction (Burton and McIntyre)

The reaction $^{54}\text{Fe}(\alpha, p\gamma)^{57}\text{Co}$ with incident α -particle energies of 9 and 10 MeV has been used to investigate the properties of ^{57}Co levels below 3 MeV in excitation. Using the Doppler-shift attenuation method,

mean lives were obtained for eleven excited levels. These results are as follows: $\tau(1.22 \text{ MeV}) = 0.084 \pm 0.018$, $\tau(1.68 \text{ MeV}) = 0.26 \begin{smallmatrix} + 0.12 \\ - 0.09 \end{smallmatrix}$, $\tau(1.76 \text{ MeV}) = 0.36 \pm 0.07$, $\tau(1.89 \text{ MeV}) = 0.12 \pm 0.03$, $\tau(1.92 \text{ MeV}) = 0.03 \pm 0.02$, $\tau(2.31 \text{ MeV}) = 0.32 \pm 0.09$, $\tau(2.48 \text{ MeV}) = 0.036 \begin{smallmatrix} + 0.014 \\ - 0.011 \end{smallmatrix}$, $\tau(2.60 \text{ MeV}) = 0.11 \pm 0.03$, $\tau(2.73 \text{ MeV}) = 0.11 \pm 0.03$, $\tau(2.80 \text{ MeV}) = 0.04 \pm 0.02$, and $\tau(2.87 \text{ MeV}) = 0.05 \pm 0.02$, all in picoseconds. In addition multipole mixing ratios were obtained for several transitions. Arguments are given for a spin assignment of $J = \frac{7}{2}$ to the 2.31 MeV level.

2. Mean Lives and Angular Correlations in ^{35}S with the $^{34}\text{S}(d,py)^{35}\text{S}$ Reaction (Burton and McIntyre)

The $^{34}\text{S}(d,py)^{35}\text{S}$ reaction at incident energies between 2 and 3.25 MeV has been used to investigate the properties of the first three excited states in ^{35}S . The Doppler-shift attenuation method of measuring mean lives gives the following results for the levels at 1.57, 1.99 and 2.35 MeV: $\tau \cong 1.8 \text{ ps}$, $\tau \cong 4.5 \text{ ps}$, and $\tau = 0.8 \pm 0.2 \text{ ps}$, respectively. Angular correlation measurements were also performed using a collinear geometry. The 2.35 MeV level is found to have $J^\pi = \frac{3}{2}^-$.

3. Mean Lives of Some States in ^{33}S (Cummings and Donahue)

The mean lives of the 0.84, 1.97, 2.31, 2.94 and 3.22 MeV levels were studied using the Doppler-shift attenuation method (DSAM). The $^{32}\text{S}(d,p)^{33}\text{S}$ reaction was used with deuteron energies ranging from 1.86 to 2.50 MeV to populate the excited levels of ^{33}S . The directions of the recoiling nuclei were determined by detecting γ rays in coincidence with protons. Mean lives of $\tau_m = 0.9 \begin{smallmatrix} + 0.5 \\ - 0.4 \end{smallmatrix}$, 0.15 ± 0.03 , 0.14 ± 0.04 , > 1.4 and $0.04 \begin{smallmatrix} + 0.02 \\ - 0.01 \end{smallmatrix} \text{ ps}$ were found for the levels at $E_x = 0.84, 1.97, 2.31$,

2.94 and 3.22 MeV, respectively. Where applicable, the results are compared to predictions of the strong-coupling rotational model.

4. Mean Life Measurements in ^{29}P (Cummings and Donahue)

The Doppler-shift attenuation method was used to obtain the mean lives of the first two excited states in ^{29}P : $\tau(1.38 \text{ MeV}) = (2.1 \pm 0.6) \times 10^{-13} \text{ sec}$ and $\tau(1.95 \text{ MeV}) = (3.2^{+1.5}_{-1.1}) \times 10^{-13} \text{ sec}$. The excited states were populated by the reaction $^{28}\text{Si}(d,n)^{29}\text{P}$ using deuteron energies ranging from 2.93 to 3.50 MeV. Pulse-shape discrimination was employed for the neutron- γ -ray coincidence measurements. The results are compared with those in ^{29}Si and with the predictions of the strong-coupling rotational model.

5. Electromagnetic Transitions in $^{51}_{23}\text{V}$ and $^{53}_{25}\text{Mn}$ (Goodman and Donahue)

The nucleus $^{51}_{23}\text{V}$ has three protons in the $f_{7/2}$ shell and $^{53}_{25}\text{Mn}$ has three proton holes in that shell. These measurements were undertaken in order to compare transitions in the two nuclei with one another and with the general predictions of the shell model. The reactions $\text{Ti}^{48}(\alpha,p)\text{V}^{51*}$ and $\text{Cr}^{50}(\alpha,p)\text{Mn}^{53*}$ with 10 MeV alpha particles were used to produce the two nuclei. The Doppler-shift attenuation method was used to measure mean lives of five states in ^{51}V and eight states in ^{53}Mn . In addition, angular correlation measurements were made on several states in ^{53}Mn in order to determine multipole mixtures of the transitions. This work is completed and has been written as the dissertation of A. S. Goodman. A publication containing the results is in preparation. The mean lives measured for the two nuclei are listed in the table.

Table I. Mean lives in V^{51} and Mn^{53}

V^{51}		Mn^{53}	
Level (MeV)	τ (psec)	Level (MeV)	τ (psec)
1.61	0.63 ± 0.12	1.29	0.8 ± 0.3
1.81	0.70 ± 0.14	1.44	0.81 ± 0.25
2.4	< 0.05	1.62	0.66 ± 0.20
2.67	0.90 ± 0.24	2.28	0.47 ± 0.13
2.70	> 1.1	2.41	0.17 ± 0.05
		2.58	0.07 ± 0.03
		2.69	0.06 ± 0.02
		2.71	1.1 ± 0.3

6. Stopping Power of Havar for 2.5 to 7.0 MeV Deuterons (Porter, McIntyre, and Haerberli)

Energy losses of 2.5 to 7.0 MeV deuterons in thin Havar foils have been measured. The results are fitted by means of the Bichsel energy loss computer code with fixed shell correction parameters common to the major constituent elements and a variable mean excitation energy. The best fit value of the mean excitation energy is 15% lower than the value calculated from an assumed additivity of stopping effects.

7. $Sc^{42} \rightarrow Ca^{42*}$ β -decay Branching Ratio (Kennedy and McCullen)

Last year's report discussed early problems with this experiment. The experiment was completed this summer, and a preliminary report was submitted to the Nuclear Divisional meeting in Houston this fall. The data are now in the last stages of analysis. A letter will be submitted

to Phys. Rev. Letters in the very near future. A brief description follows.

The experiment consisted of exciting the Sc^{42} ground state through the $\text{K}^{39}(\alpha, n)$ reaction, and measuring the γ rays in singles which resulted from the decay. Two targets were used: one was enriched isotopically to 99.9% K^{39} , but was chemically not as pure as reagent grade potassium iodide. The other was ultra-pure KI, with chemical impurities in general less than 0.001%, but with natural isotopic composition. Each target had spurious gamma radiation following the bombardment. By comparing the yield from the two targets we could identify all the foreign peaks.

Using the most useful target, the isotopically pure one, 190 hours of data were collected. The identification of the β -decay from Sc^{42} to the excited 0^+ state in Ca^{42} depended on the observation of the 1.52 MeV gamma ray in its de-excitation. No such gamma ray was seen. The additional analysis now being done is an attempt to obtain the best upper bound on its existence. However, it is safe to say that the branch is less than 3×10^{-4} per ground state decay.

8. Ti(p,ny)V Reactions (Rickel and McCullen)

In addition to the work quoted in last year's report, some lifetime estimates of several of the states were obtained. This work is now being written by Rickel as a Ph.D. thesis.

C. WORK IN PROGRESS

1. Coulomb Stripping Using the (d,p) Reaction on Isotopes of Tin (Carson and McIntyre)

This experiment has proven fruitful and is near completion. We have measured the angular distribution of the differential cross-section

for the (d,p) reaction on ^{118}Sn , ^{122}Sn , and ^{124}Sn for several energies between 4.5 and 5.5 MeV. In addition we have measured the energy dependence of the cross section in the case of ^{118}Sn over the range 4.4 to 5.4 MeV in 100 keV steps. Using cooled Si surface barrier detectors we obtained typical energy resolution of 20 keV. We are in the process of extracting absolute cross sections from the data. We are also in the process of obtaining spectroscopic factors for many individual states using the DWBA code DWUCK.

2. The $^{40}\text{Ca}(\alpha,\gamma)^{44}\text{Ti}$ Reaction (Barker and McIntyre)

The measurement of the cross-section for this alpha-capture reaction is of great interest to astrophysicists since it plays a role in nucleosynthesis. Our original efforts toward this goal consisted of bombarding a ^{40}Ca target with 4 MeV alpha particles and then attempting to count the 43 year half-life ^{44}Ti using a low-background β - γ coincidence scheme. We now believe a better way to do this is the detection of the prompt high-energy gammas from ^{44}Ti . Investigations along this line are continuing.

3. Doppler Shifts of Gamma Rays from Fe^{56} (Hershberger and Donahue)

This work is nearly complete and has been written as part of the Ph. D. dissertation of R. L. Hershberger. Mean lives or limits thereto have been obtained for eleven states in Fe^{56} and have been compared to calculations of several models. In particular, calculations of Lerner (Phys. Rev. 2-C, 522 (1970)) agree quite well with the measurements. Publication of these results is being held up because the Doppler shifts of the four lowest levels, which are nearly zero when the Fe^{56} nuclei recoil in a solid, are being measured with gas backings.

4. Doppler Shifts with Gas Backings (Hershberger, Ceccon, and Donahue)

A technique for measuring mean lives of nuclear states which are longer than about 5×10^{-12} seconds has been developed. Two targets are bombarded simultaneously. Excited nuclei from one target recoil in a solid and stop before decaying, while those from the other recoil in gas. The difference in γ -ray energies is related to the mean life of the decaying state and the slowing down properties of the gas. We have performed a series of experiments to investigate the method using the 0.871-MeV state in O^{17} . The mean life of this state has been measured by other methods with a precision of $\pm 1.6\%$. Two results of interest from these experiments are:

a) A variation in beam current of a factor of ten (from 2 namps to 20 namps) caused no observable change (less than 1.7%) in the measured Doppler-shift attenuation factor.

b) Using electronic and nuclear stopping powers of Lindhard, Scharff and Schiott (Kgl. Danske V. Selskab, Mat. Fys. Medd. 33, No. 14, 1963) the mean life which we obtain for the 0.871-MeV state is within five percent of the precise result of Becker and Wilkinson (Phys. Rev. 134, B1200, (1964)). The conclusion from this result is that within the precision of our measurement (5%) the slowing down of O^{17} ions recoiling in krypton with speeds from 0.8% to 0.1% of the speed of light, is correctly predicted by theory.

Measurements with gas backings have also been made for states in Mg^{25} and Fe^{55} .

5. Transition Probabilities in the $f_{7/2}$ Shell (Rickel and McCullen)

Using the program discussed last year, which calculates M1 and E2 transition probabilities between states with wave functions described by

the McCullen, Bayman, and Zamick model, an extensive list of calculations has been performed. Using wave functions generated by a better Sc^{42} spectrum, the magnetic and quadrupole moments of isotopes in the shell have been recomputed and new fits to the effective moments and charges have been made. Particularly interesting have been the quadrupole calculations. The effective charges which seem to be most useful are $e_p = 1.7 e$, $e_n = 1.0 e$. These are not least squares values. One would have to be rather selective in choosing least-squares fitting parameters, because it is clear that some data (e.g., the $B(E2) 2_1^+ \rightarrow 0_1^+$ in Ca^{42}) are heavily influenced by core excitation. Except for some glaring exceptions such as that just quoted, however, the electric quadrupole matrix elements are rather well reproduced by the model.

Most of the calculations will not be separately published, but will appear in the review article. One set, on M1 transitions in Ti^{47} , was calculated for L. Meier-Shutzmeister at Argonne, and will appear in an article by her. The results are rather interesting in that the decay of the state in Ti^{47} which is the isobaric analogue to the Sc^{47} ground state is well reproduced.

6. Review (Bayman, Zamick, Hintz, and McCullen)

Two developments have recently appeared on this subject. One, a review by Ricci and Maurenzig, in *Rivista Nuovo Cimento* 1, 291 (1969) surveys primarily the lower part of the shell, and is far from conclusive. The other is the publication in *Nuclear Data*, by several authors, of compilations of data from $A = 45$ to $A = 61$. Neither of these developments renders our review unacceptable, since our approach is different and our

point of view more theoretical. It has, however, required some changes in scope, and the work has been delayed. The final meeting (hopefully) of the group is scheduled for February 3-5 at Rutgers. Publication will be some time this year.

7. Polarized Ion Source (Tipton, Smith and McCullen)

The source was mounted on the Van de Graaff this summer. The first installation was primarily to check that all space, electric, and cooling requirements were met, and the tank was not closed. All seemed adequate. A remark may be made about cooling, since other labs have had mixed experience. The source is cooled with Freon, pumped to the top of the Van de Graaff through heavy-walled polyvinyl chloride pipe. Teflon pipe was tried, but suffered spark damage. The PVC pipe has worked well.

In August the source was remounted, and a beam of 2 namp of protons was deflected through the bending magnet and onto the control slits. The beam at the viewing port at the bottom of the Van de Graaff was seen to be of very poor quality. At least 10 times this much beam was present, but could not be focussed. This indicated that the primitive injection from the ion source into the accelerator was insufficient and needed refinement.

In addition, some annoying but probably curable difficulties developed. Chief among these was the problem of micro leaks through the seals in the source at elevated external pressure. The degree to which these bothered the operation varied from run to run. At times the full tank pressure (225 psi) could be used; at other times the pressure in the tank had to be reduced to 120 psi. The other major annoyance was that the system to reduce the hydrogen pressure from its storage value of

2000 psi to the dissociator pressure of 250 μ Hg had leak problems. The pressure regulators leak slightly, and over a period of 24 - 48 hours build up enough back pressure on the solenoidal valves (used to shut off the hydrogen flow) so that they won't open. A new high flow rate thermo-mechanical leak is now available, and this problem should be cured.

Work over the past two months has concentrated on design and laboratory testing of a lens system for injection. This is now completed. The source will be remounted on February 8, and if the lens fulfills its promise, experiment can begin.

D. PERSONNEL

Faculty members directly participating in the nuclear physics program are: D. J. Donahue, J. D. McCullen, and L. C. McIntyre, Jr. Three nuclear theorists, Sigurd Köhler, A. Sherwood, and Bruce Barrett are also members of the physics department and are available for consultation. Professor B. Bayman visited the department from January to March, 1970.

Students working in the program:

D. Barker	J. Cummings [†]	D. Rickel [*]
K. Burton [†]	A. Goodman [*]	W. Smith [†]
P. Carson [*]	R. Hershberger [†]	J. Tipton [*]
C. Ceccon	J. Kennedy [*]	

[†]Received Ph. D. degree during period of this report.

^{*}Expected to fulfill requirement for Ph. D. degree by summer, 1971.

A secretary and a technician are associated full time with the Van de Graaff and receive partial support from this contract.

E. PUBLICATIONS

Articles Published January - December 1970

1. J. E. Cummings and D. J. Donahue, Mean Lives of Some States in ^{33}S , Nucl. Phys. A142, 609 (1970).
2. M. J. Wozniak, Jr. and D. J. Donahue, Mean Lives of Some States in Si^{31} below 3.54 MeV, Phys. Rev. C 1, 601 (1970).
3. J. E. Cummings and D. J. Donahue, $^{30}\text{Si}(\alpha, n\gamma)^{33}\text{S}$ Angular-Correlation Measurements, Phys. Rev. C 2, 942 (1970).
4. J. E. Cummings and D. J. Donahue, Mean Life Measurements in ^{29}P , Phys. Rev. C 2, 1570 (1970).
5. K. S. Burton and L. C. McIntyre, Jr., Mean Lives and Angular Correlations in ^{35}S with the $^{34}\text{S}(d, p\gamma)^{35}\text{S}$ Reaction, Nucl. Phys. A154, 551 (1970).
6. C. A. Pearson, D. Rickel and D. Zisserman, Effects of the D-State of the Deuteron in the WBP Model for (d,p) Reactions, Nucl. Phys. A148, 273 (1970).

Articles Accepted for Publication

1. K. S. Burton and L. C. McIntyre, Jr., Mean Lives and Angular Correlations in ^{57}Co with the $^{54}\text{Fe}(\alpha, p\gamma)^{57}\text{Co}$ Reaction, by Phys. Rev.
2. L. E. Porter, L. C. McIntyre, and W. Haeberli, Stopping Power of Havar for 2.5 to 7.0 MeV Deuterons, by Nucl. Instr. and Meth.

Abstracts

1. K. S. Burton and L. C. McIntyre, Jr., Mean Lives and Angular Correlations in ^{35}S with the $^{34}\text{S}(d, p)^{35}\text{S}$ Reaction, Bull. Am. Phys. Soc. 15, 600 (1970) (HH4).
2. A. S. Goodman and D. J. Donahue, Mean Lives of Some States in V^{51} , Bull. Am. Phys. Soc. 15, 601 (1970) (HH7).

3. K. S. Burton and L. C. McIntyre, Jr., Mean Lives and Angular Correlations in ^{57}Co with the $^{54}\text{Fe}(\alpha, p)^{57}\text{Co}$ Reaction, Bull. Am. Phys. Soc. 15, 601 (1970) (HH9).
4. R. L. Hershberger and D. J. Donahue, Lifetime Measurements of Low-Lying States in ^{55}Fe , Bull. Am. Phys. Soc. 15, 602 (1970) (HH12).
5. H. J. Kennedy and J. D. McCullen, Isospin Purity in the Beta Decay of ^{42}Sc , Bull. Am. Phys. Soc. 15, 1666 (1970) (CB12).