ORO-3820-21

On-Line Alpha and Proton Decay Spectrometry

Ronald D. Macfarlane, Principal Investigator

Annual Progress Report, 1972

Sponsor:

United States Atomic Energy Commission

Division of Research

Contract No. AT-(40-1)-3820

Texas A&M University

Department of Chemistry and Cyclotron Institute

College Station, Texas 77843

January 15, 1973

I. General Report

A. Introduction

This is the fifth annual progress report of this project covering a period from January 1, 1972 to December 31, 1972. Funds received from the AEC for this project were used to support a continuing program at the Texas A&M Cyclotron.

Most of the objectives stated in the last proposal were realized. With the development of our "on-line" mass spectrometer which was completed during 1972, the emphasis of the project will in the future be shifting away from problems involving α- and p-decay to those which make use of the mass spectrometer. This report, therefore, is the last that will be presented under the present title.

B. Summary of Activities

Work on the question of β-decay mirror symmetry in the mass-20 multiplet was completed. The asymmetry was considerably smaller than what had been expected from the Wilkinson systematics based on the presence of an induced tensor component in the nuclear weak interaction. The result brings to light the role of binding energy effects in contributing to β-decay mirror asymmetries. The full Fermi strength to the isobaric analog state in ^{20}Ne was observed. The (β-ν) and (β-α) correlations measurements in ^{20}Na decay were completed.

The He-jet recoil transported method was used for the first time in transporting thermalized fission fragments from a ^{252}Cf source. An interesting photochemical effect was observed in the formation of the transport clusters.

Beta-recoil emission from a mono-layer source was observed for the first time using the helium-jet method to produce the source. High resolution mass spectra of β-recoils from the decay of short-lived nuclides in the A = 20-40 range produced by (p,n) reactions were obtained.

C. Personnel

1. Principal Investigator

R. D. Macfarlane, Professor of Chemistry, Texas A&M University

2. Research Scientist

D. F. Torgerson, Ph.D. McMaster

3. Visiting Professor (to October 1, 1972)

K. Wien, Professor of Physics, Technischen Hochschule, Darmstadt, Germany

4. Research Associate

John Fares, Ph.D. Florida, 1970

5. Graduate Students

a. Alton Hasseli, B.S. Baylor University, 1969

b. Raymund Skowronski, B.S. Michigan, 1970

c. Patricia Papa, B.S. Marquette University, 1970

6. Undergraduate Research Assistants

a. Salahuddin Yosufzai

b. Rosemary Christmas

D. Facilities Used

The cyclotron has been used for this project at an average rate of 50 hours per month. The Cyclotron IBM 7094 was used extensively in data analysis and the PDP-15 was used for "on-line" acquisition of data in the (β-α) and (β-ν) experiments. The new EGG time digitizer has proven to be a most versatile instrument for precise time-interval measurements.

The machine shop has provided an invaluable support for the development of our mass spectrometer. The success and performance of the spectrometer is due in a large measure to their considerable skill and close cooperation.

E. Publications and Presentations (1972)

1. Work published or appeared in refereed journals during calendar year 1972:

a. Use of an Electrostatic Particle Guide for Time-of-Flight Spectroscopy of Low Energy Ions, J. C. Abbe, S. Amiel, and R. D. Macfarlane, Nucl. Instr. Meth. 102, 73-76 (1972).

b. Precision Gamma-Ray Spectroscopy of Short-Lived Nuclides by the Helium-Jet Recoil-Transport Method, W. W. Bowman, T. T. Sugihara, and R. D. Macfarlane, Nucl. Instr. Meth. 103, 61-67 (1972).

c. Concerning the Anomalous Fermi Strength in the β^+-Decay of

^{20}Na and Mirror Symmetry in the Mass-20 Multiplet, D. F. Torgerson, K. Wien, and R. D. Macfarlane, Phys. Lett. 40B, 203-4 (1972).

d. A New Approach to On-Line Mass Analysis, H. Jungclas, R. D. Macfarlane, and Y. Fares, Radiochimica Acta 16, 141-7 (1971).

e. Beta-Delayed Alpha Emission from the Isomers of ^{24}Al, D. F. Torgerson, N. S. Oakey, and R. D. Macfarlane, Nucl. Phys. A178, 69-75 (1971).

f. Application of the Helium-Jet Recoil Transport Technique for Fission Fragment Transport from Spontaneous Fission Sources, K. Wien, Y. Fares, and R. D. Macfarlane, Nucl. Instr. Meth. 103, 181 (1972).

2. Work published in Conference Proceedings in 1972:

a. Yrast Trapping in Heavy Ion Compound Nucleus Reactions, R. A. Gough and R. D. Macfarlane, Statistical Properties of Nuclei (Plenum Press, N.Y. 1972, J. B. Garg, ed.) p. 497-504.

3. Contributed papers to meetings (1972):

a. The MAGGIE Recoil Time-of-Flight Spectrometer, D. F. Torgerson, R. D. Macfarlane, and A. Papa, Bull. Amer. Phys. Soc. 119 (1972).

b. Energy Loss and Straggling of ^{12}C, ^{14}N, and ^{12}O in Ni Foil, R. A. Gough and R. D. Macfarlane, Bull. Amer. Phys. Soc. 120 (1972).

c. Nuclear Alignment Effects in Beta Decay, R. J. Nickles, Jr., R. D. Macfarlane, and D. F. Torgerson, Bull. Amer. Phys. Soc. 137 (1972).

d. Beta-Recoil Spectroscopy of Low Z Nuclides, R. D. Macfarlane, D. F. Torgerson, K. Wien, and J. Fares, presented at First European

Nuclear Physics Conference (Aix-en-Provence, France, July 1972).

4. Invited colloquia and seminars:

a. "Recent Applications of the He-Jet Method," University of Louvain, Belgium, July 1972.

b. "The Nuclear Weak Interaction," University of Marburg, Germany, July 1972.

c. "The MAGGIE Recoil-Time-of-Flight Mass Spectrometer," Justus-Liebig University, Giessen, Germany, July 1972.

5. Papers accepted for publication (1972):

a. "Techniques for the Study of Short-Lived Nuclei," with W. McHarris. Chapter for book Nuclear Spectroscopy, edited by J. Cerny.

II. Work Completed and Published Since the 1971 Progress Report

The following studies have been completed. Abstracts of papers related to these studies appear below.

A. Use of an Electrostatic Particle Guide for Time-of-Flight Spectroscopy of Low Energy Ions, J. C. Abbe, S. Amiel, and R. D. Macfarlane, Nucl. Instr. Meth. 102, 73 (1972).

It is shown that the electrostatic particle guide technique can be utilized in time-of-flight measurements of low-energy ions to establish long flight paths without severe loss of intensity. The system was tested using ions from an electron impact ion source which simulated the properties of recoils from decay processes such as β-delayed neutron emission. Transmission efficiencies of up to 30% have been observed for recoil energies ranging from 500-3000 eV, corresponding to enhancements of up to 5000 for a 1 m flight path.

B. Precision Gamma-Ray Spectroscopy of Short-Lived Nuclides by the Helium-Jet Recoil-Transport Method, W. W. Bowman, T. T. Sugihara, and R. D. Macfarlane, Nucl. Instr. Meth. 103, 61 (1972).

The helium-jet recoil-transport method, which has been used principally in α spectroscopy, has been modified for use in preparing short-lived sources in a form suitable for γ-ray spectroscopy. Reaction products recoiling out of a cyclotron-irradiated target are thermalized in helium and collected on the surface of magnetic tape. The collection site is in a low-background area 10 m from the target. The system includes circuits

which control the source collection time, the transport and reproducible positioning of the source at a detector site, and the synchronized collection of γ-ray spectra as a function of time. Application of the method is illustrated by a coincidence study of the decays of 1.1s $^{177}Hf^{m}$ and 4.3 s $^{178}Hf^{m}$ as produced by the $^{176}Yb(^{4}He,xn)$ reactions. Characteristics and limitations of the method are discussed.

C. Concerning the Anomalous Fermi Strength in the β^{+}-Decay of ^{20}Na and Mirror Symmetry in the Mass=20 Multiplet, D. F. Torgerson, K. Wien, and R. D. Macfarlane, Physics Lett. 40B, 203 (1972).

The β^{+}-strength in the decay of ^{20}Na to the isobaric analog state in ^{20}Ne has been measured precisely. Contrary to previous measurements, it has been found that essentially the full Fermi strength is associated with this transition. A test of mirror symmetry has also been made for the decay to the first excited state of ^{20}Ne. There is evidence of an asymmetry somewhat smaller than that expected from the Wilkinson systematics.

D. A New Approach to On-Line Mass Analysis, H. Jungclas, R. D. Macfarlane, and Y. Fares, Radiochimica Acta 16, 141 (1971).

A system has been developed which can be used to simultaneously identify the mass and measure the nuclear radiation of a short-lived radioactive isotope. The system combines the helium jet recoil transport method with the elcctrostatic particle guide technique to measure coincident decay recoil spectra by the time-of-flight technique. Results have been obtained for the β-delayed α-emitters, ^{8}Li and ^{20}Na.

E. Beta-Delayed α-Emission from ^{24}Al and ^{24m}Al, D. F. Torgerson, N. S. Oakey, and R. D. Macfarlane, Nucl. Phys. A178, 69 (1971).

Alpha particles emitted from levels in ^{24}Mg following the β-decay of ^{24}Al have been measured. In addition to the α-groups previously reported in the β-decay of the 4^+ ground state of ^{24}Al, new groups were observed as a result of using special techniques to reduce the β-background and to increase particle energy resolution. Alpha-particle groups associated with the β-decay of the 1^+ isomeric state of ^{24}Al were observed for the first time. The α-particle transitions observed in this work have been correlated with known energy levels. Log ft values have been calculated or estimated from the relative intensities of the delayed α-particle groups.

F. Application of the Helium-Jet Recoil Transport Technique for Fission Fragment Transport from Spontaneous Fission Sources, K. Wien, Y. Fares, and R. D. Macfarlane, Nucl. Instr. Meth. 103, 181 (1972).

The helium-jet method has been adapted for the transport of fission products from a ^{252}Cf source. It has been found that the helium carrier gas must be seeded with H_2O vapor and irradiated with an ultra-violet light source to obtain high efficiencies. There is indication of the role of free radicals in producing high-molecular-weight species that are necessary for the transport of the fission products. Transport efficiencies of about 55% and mean transport times of 30 s have been achieved.

III. Work Completed - 1972

A. Beta Decay of ^{20}Na, D. F. Torgerson, K. Wien, Y. Fares, N. S. Oakey, and R. D. Macfarlane (to be submitted for publication in the Physical Review).

The decay scheme of ^{20}Na has been studied in detail to obtain information on the β-decay mirror symmetry properties of the mass-20 multiplet and to determine the Fermi decay strength to the T = 1 isobaric analog state in ^{20}Ne. The ratio $\frac{ft^+}{ft^-}$ was determined to be 1.026±0.024 for the β^+ transitions to the first excited state of ^{20}Ne. This value is in conflict with the Wilkinson systematics of asymmetries based on the existence of an energy-dependent induced tensor current. The ft-value for the transition to the T = 1, 10.278 MeV level was measured to be 2992±233 sec indicating that most of the Fermi strength is concentrated in this transition. A weak γ-transition from the 2^+ isobaric analog state to the 2^+, first excited state of ^{20}Ne was observed and new β^+-delayed α-groups are reported at 3.27, 5.272, and 5.701 MeV. Theoretical ft-values derived from the shell model wave functions are compared with experiment.

B. Beta-Neutrino Correlations in the Decay of ^{20}Na, R. D. Macfarlane, D. F. Torgerson, K. Wien, and R. J. Nickles (to be submitted for publication in the Physical Review).

The experimental data for this problem have been obtained. The α-spectrum in coincidence with the β-spectrum was recorded "on-line" using the PDP-15 computer and sorted as a function of β-energy. The α-spectrum in coincidence with the region around the β-end point was

used to obtain kinematically-free response functions for the data analysis. The response function gave an unsatisfactory fit to the data, possibly because of statistical fluctuations in the data. An analytic response function gives the best results thus far. The β-ν correlation coefficients, natural line-widths and chi-square values are given in table I.

Table I

Measured β-ν correlation coefficients in ^{20}Na decay

Energy Level in ^{20}Ne(MeV)	Alpha particle Energy (MeV)	α	$\Gamma^{1/2}$(keV$^{1/2}$)	χ^2/F
7.415±5	2.148±5	-0.216	2.43	1.28
7.826±7	2.477±7	-0.280	1.62	1.56
9.481±7	3.801±7	+0.0903	3.38	1.62
10.278±5	4.438±5	1.14	0.403	0.868
10.584±7	4.683±7	+0.059	4.91	0.336
10.848±7	4.894±7	-0.399	3.06	1.15

The α-values are not final numbers and the final analysis of the data is inprogress. The $\Gamma^{1/2}$ values derived from the analysis are consistent with other results obtained from nuclear reaction spectroscopy. A qualitative observation from the α-values is that there is some iso-spin mixing into the states at 9.481 and 10.584 MeV, and some of the Fermi strength is spread into these states. This is, perhaps, the most interesting result of this study, thus far.

C. Beta-Alpha Correlations in the Decay of ^{20}Na, K. Wien, D. F. Torgerson, and R. D. Macfarlane (to be submitted to Phys Rev.).

The β-α directional correlation has the potentiality of revealing induced tensor currents in the nuclear weak interaction. There are three transitions in ^{20}Na which have sufficient intensity that the (β-α) directional correlation can be made. Recent theoretical calculations of Holstein connect the correlation coefficients with the magnitude of induced tensor terms. We observed the β-α correlation to be isotropic for two of the transitions: the strongest α-decaying G-T transition to the level at 7.415 MeV in ^{20}Ne and the decay to the isobaric analog state at 10.278 MeV. The latter result disproves our previous observation of a strong anisotropy to the 7.415 MeV state. The experimental configuration for these experiments is vastly improved from the original system used. A significant anisotropy (6%) was observed for the transition to the 7.826 MeV level in ^{20}Ne. The effect is larger than expected for an induced tensor effect. It may be a nuclear structure effect relative to the rather special shell-model configuration of that particular state. It is known to be more deformed than the ground state. One possible explanation is that the deformed potential may give rise to anisotropic emission from an aligned nucleus. The nucleus is aligned by virtue of the G-T transition that precedes the α-decay. The experimental data accumulation and analysis have been completed. The theoretical interpretation of the results remains to be done.

IV. Work in Progress - 1972

A. MAGGIE Recoil-Time-of-Flight Mass Spectrometer

1. Developmental Work

a. Production of mono-layer sources in high vacuum

Mono-layer sources of short-lived nuclides were produced in steady state in vacuum using nozzle-skimmer separations to remove the bulk of the helium. Volatile carrier clusters were produced in Helium from an H_2O-trace CH_4 mixture by high intensity radiation from the cyclotron beam. It was found that the carrier clusters could be completely volatilized, using a heated collector foil, leaving the radioactive atom adsorbed on the surface.

b. Heavy-ion detection

A new technique was developed for low energy heavy-ion detection which has proven to be efficient for energies as low as 4 keV and masses at least up to A = 100. The heavy-ion first strikes a planar channel electron multiplier array (CEMA) and the electrons ejected are accelerated to 6 keV energy and injected into an NE102 plastic scintillator attached to a fast photomultiplier assembly. A timing resolution of 2 nsec has been achieved thus far with the system.

c. Electrostatic particle guide (EPG)

Considerable improvements were made in the electrostatic particle guide (8 meters long) which serves as the flight tube. Fringe-field end effects were minimized by inserting high transmission grids and connecting them to the center wire. The center wire is now 0.6 mil W and is operated between 10-100 volts. This establishes a well-defined and controlled

acceptance cone necessary to achieve high resolution in time.

2. Performance

a. Beta-Recoil Spectroscopy

Several high quality time-of-flight mass spectra have been obtained. The nuclides studied thus far are short-lived β^+-emitters. The positron is detected to generate the fast logic start pulse and the positively charged β-recoils are accelerated to 6-15 keV energy. Many of the recoils have slightly higher kinetic energies because of the initial β-recoil energy. These are observed particularly when the acceptance cone of the EPG is set at a large opening angle. A large fraction of the recoils, however, are thermalized before the acceleration and these give a sharp peak in the mass spectrum. To our knowledge, this is the first time that experiments of this type have been performed. Some very interesting results have been obtained for different target systems. These are discussed briefly below.

b. Mass Spectroscopy of Various Nuclear Reactions

(1) $^{27}Al + p$

Figure 1 shows a mass spectra of the products observed in the reaction of 25 MeV protons with ^{27}Al. Three dominant mass peaks were observed at masses-23, 26, 27. Half-life measurements of the mass spectrum were consistent with the assignment of mass-23 to ^{23}Mg (produced by a (p,nα) reaction), ^{26}Al produced by a (p,d) reaction and ^{27}Si produced by a (p,n) reaction. The process of β-recoil emission of thermalized positively

charged species appears to be dependent on the chemistry of the β-recoil. Alkali metal recoils, for example, seem to be most easily produced.

(2) Mg + p

The Mg + p spectrum at 25 MeV showed peaks at Mg^{23} (p, reaction), ^{24}Al (p,n reaction) $^{25}Al[Mg^{25}(p,n)]$, $^{26}Al[Mg^{26}(p,n)]$. The mass-23 dominated the spectrum again showing the greater sensitivity toward alkali metal recoils.

(3) ^{40}Ca + p

Figure 2 shows a mass spectrum of products from the reaction ^{40}Ca + 25 MeV protons. The Ca was mounted on an Al backing so that there are mass peaks from reactions in the Al. A dominant peak was observed at mass-39, presumably, ^{39}Ca, from a p,d reaction in ^{40}Ca. No mass-40 peaks were observed, probably because of a combination of low cross section and decreased sensitivity for Ca recoil positive ion emission.

(4) ^{20}Ne + p

This is the reaction studied extensively by us in our ^{20}Na work. Copious quantities of ^{20}Na were produced but no mass-20 peak was observed, again consistent with the notion that the ionization potential of the β-recoil is involved in the probability for observing positively charged thermalized recoils. However, another curious phenomenon was observed. The α-particles emitted in ^{20}Na decay, and which are in

coincidence with the β^+-particles detected in the start counter ionized molecules adsorbed on the surface of the collector. The molecules were then accelerated and were recorded in the time-of-flight spectrum as extremely sharp peaks (since no kinematic broadening was present). Peaks at mass-1 (H^+), mass-2 (H_2^+), and mass-18 (H_2O^+) were observed in relatively high yield. A mass spectrum is shown in Fig. 3.

c. Problems to be Solved

The main problem to be solved is the low efficiency for many elements of interest. The best efficiency thus far is ~1% observed for nuclei forming alkali metal recoils in β^+-decay. Another problem is the background. It must be reduced a factor of 100 before the system can be used to investigate very weak groups from low cross section products.

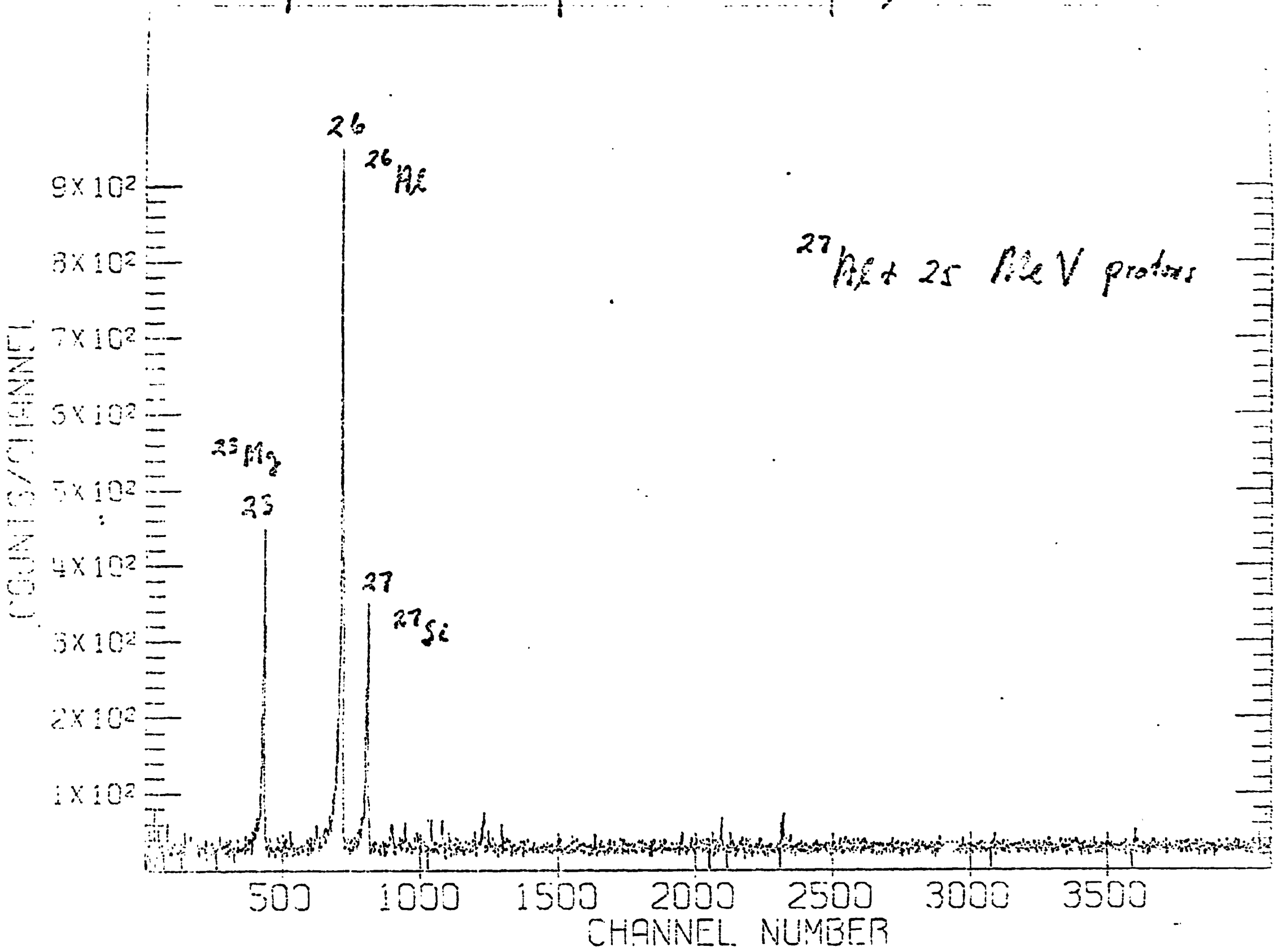

26
26Al
27Al + 25 MeV protons
23Mg
23
27
27Si
9X10²
8X10²
7X10²
6X10²
5X10²
4X10²
3X10²
2X10²
1X10²
COUNTS/CHANNEL
500
1000
1500
2000
2500
3000
3500
CHANNEL NUMBER

Figure 1.

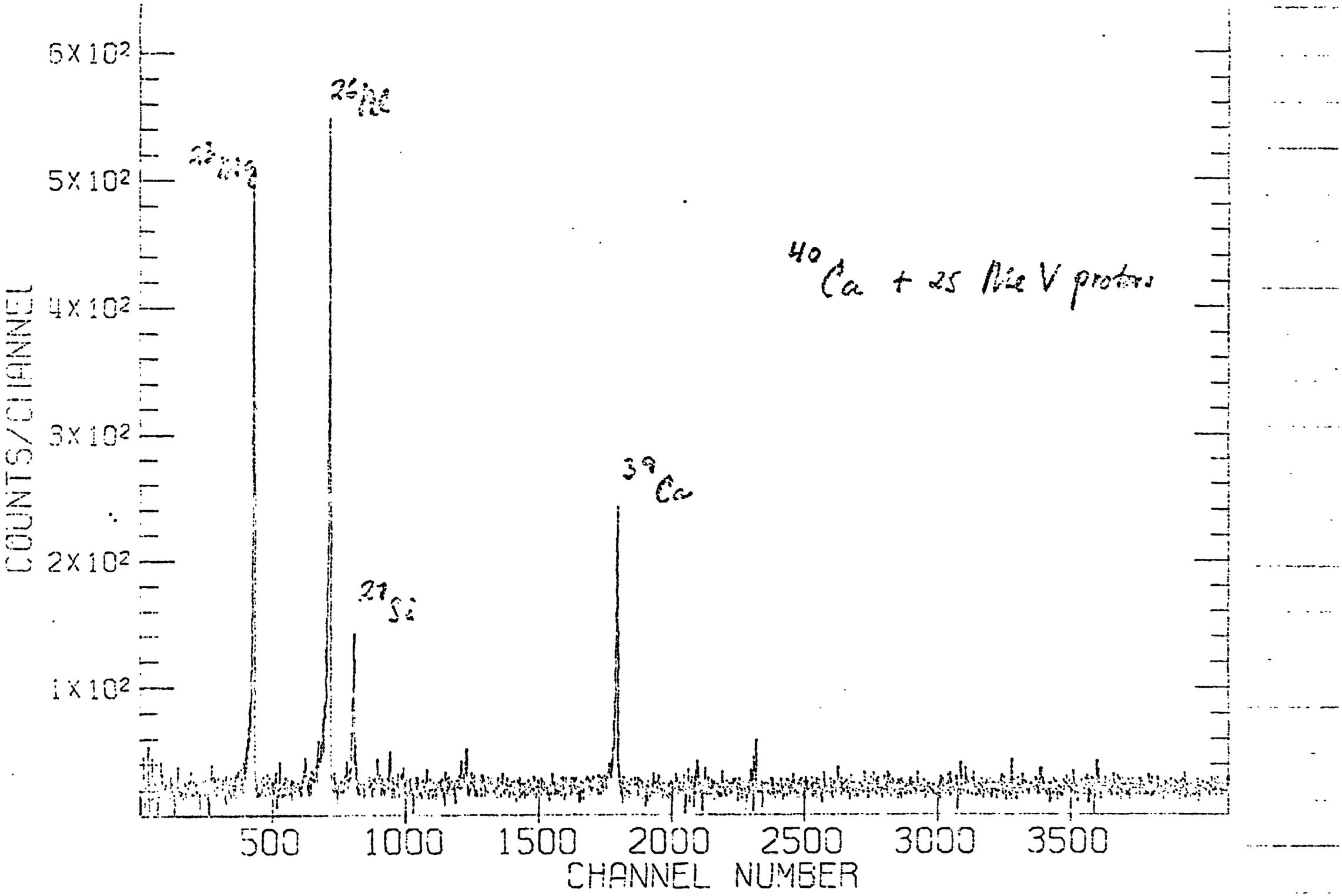
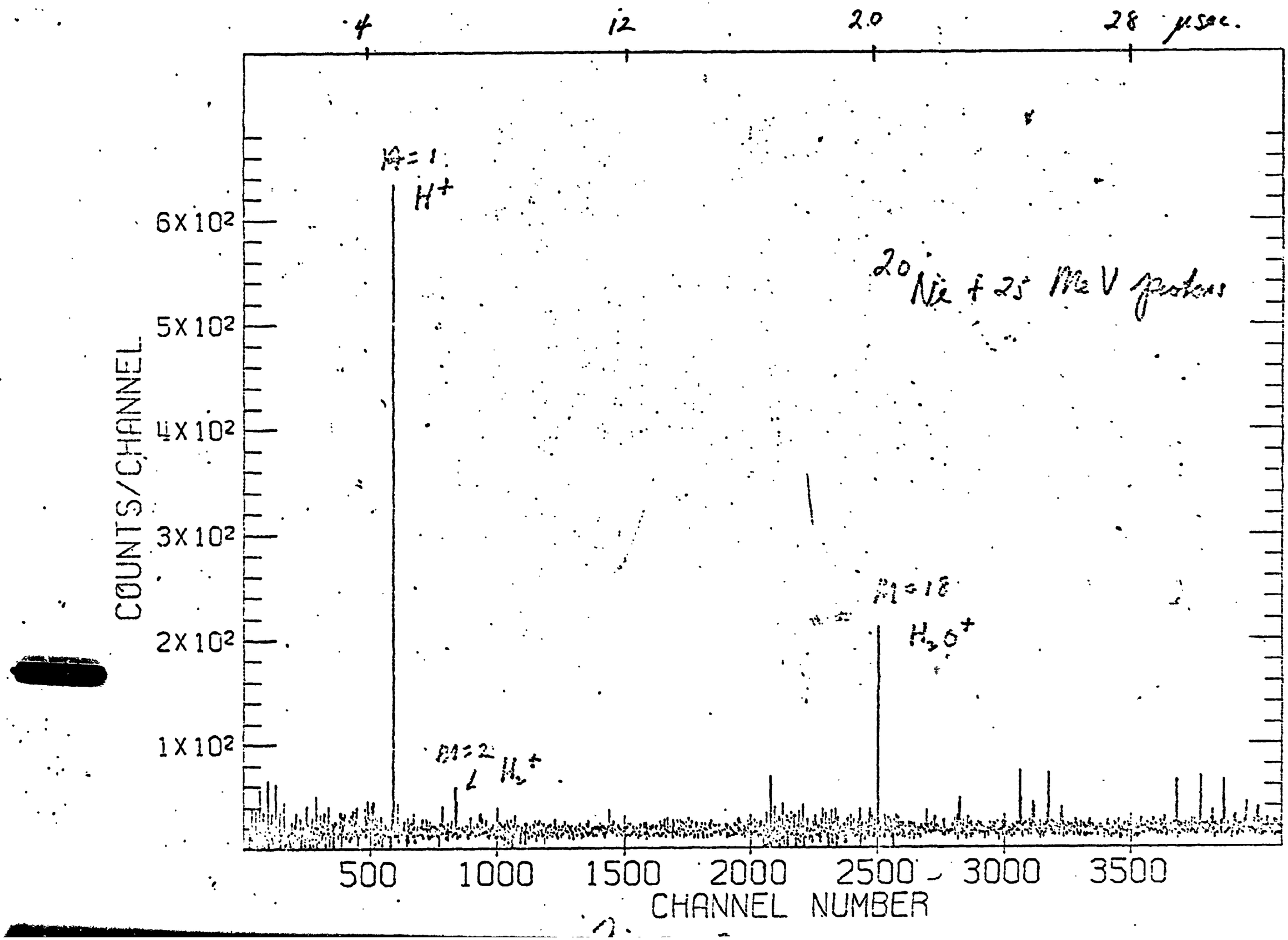

6X10²
5X10²
4X10²
3X10²
2X10²
1X10²
COUNTS/CHANNEL
500
1000
1500
2000
2500
3000
3500
CHANNEL NUMBER
40Ca + 25 MeV protons
26Mg
22Ne
27Si
39Ca

Figure 2

RUN 03 01/09/73 25P+ ON NE 15.16KV 0-32 MICROSEC AL203 ON CU



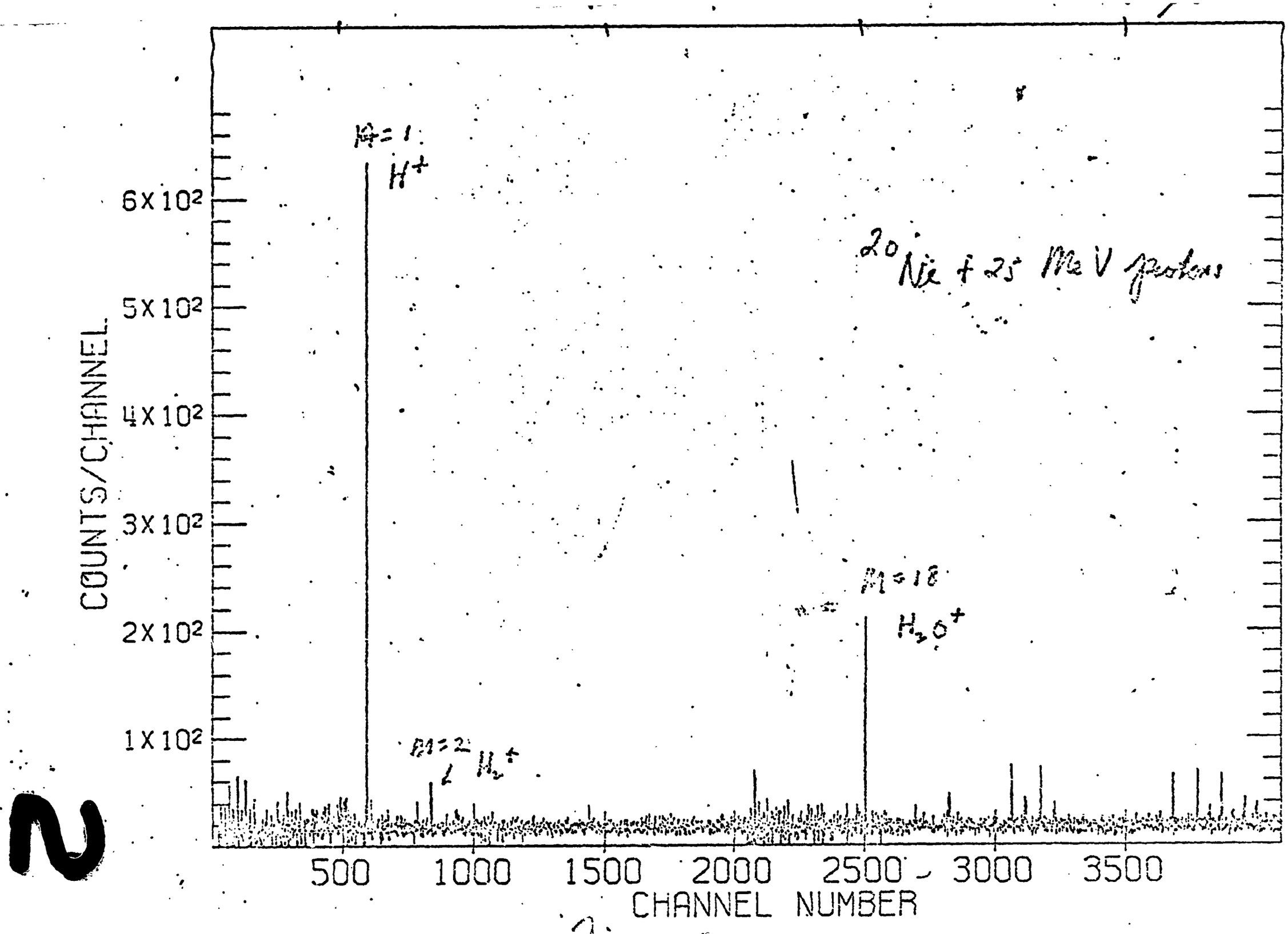

M=1
H+
20Ne + 25 MeV protons
M=2
H2+
M=18
H2O+
COUNTS/CHANNEL
6X10²
5X10²
4X10²
3X10²
2X10²
1X10²
500
1000
1500
2000
2500
3000
3500
CHANNEL NUMBER

Figure 5