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FUSION MEASUREMENTS IN LIGHT AND MEDIUM MASS HEAVY-ION REACTIONS

MASTER

Progress Report
for Period June 1, 1979 - May 31, 1980

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ABSTRACT

Data have been obtained on the γ-ray yield from the fusion reactions of $^{16,18}O + ^{24,26}Mg$ in the 25 to 70 MeV energy range. Analysis of these data in terms of the relative yields of specific residues as a function of bombarding energy is almost complete for $^{16}O + ^{26}Mg$. Of particular interest will be a comparison of these results with those for $^{18}O + ^{24}Mg$. The investigation of the fusion cross sections of $^{16}O + ^{24,26}Mg$ has been extended from 70 MeV to 140 MeV. An unexpected decrease in the fusion cross sections begins at about 100 MeV and persists to the highest energy obtained. This investigation will be continued to 170 MeV and expanded to include $^{18}O + ^{24}Mg$. Data have been obtained on the interaction of $^{16}O + ^{40}Ca$ at 128 MeV to determine the reaction mechanisms, other than fusion, present at higher energy. Plans for continuation of these experiments and for new experiments are discussed. A major effort has been the development of new programming to take advantage of a new color graphics interactive terminal for our data analysis.

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I. Update of computer systems

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I. Update of computer systems.

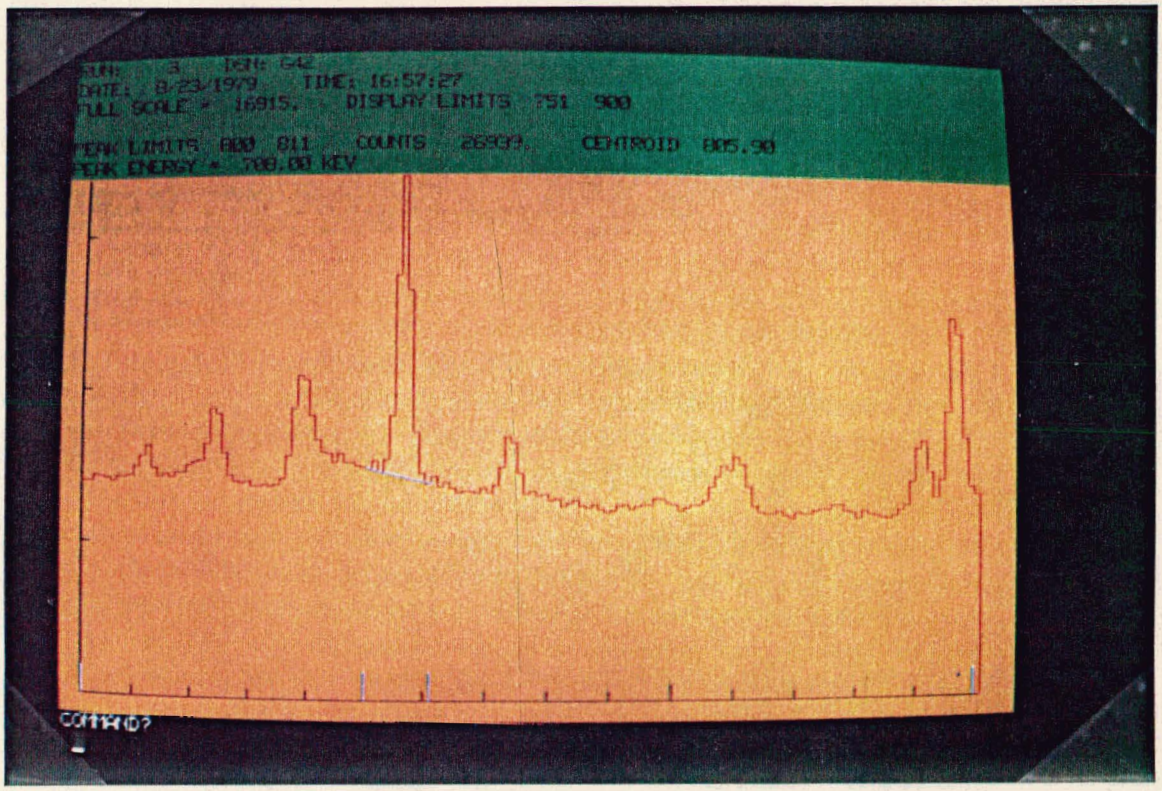
Two years ago, our inhouse Van de Graaff accelerator facility was deactivated and the accelerator sold. From the proceeds of that sale, several additions to the Mod Comp II computer system were made. A Tektronix 4027 color graphics terminal was purchased, as was an additional 16 K of memory. The latter change allowed an expansion to a three level multitasking system, so that we could also use this more modern system.

The interactive color graphics terminal has been of major assistance in our data analysis on this system. While the analysis of one-parameter spectra does not need the color capability, the use of different colors for the displayed data and for the steps of data analysis makes the process of analysis clearer and faster.

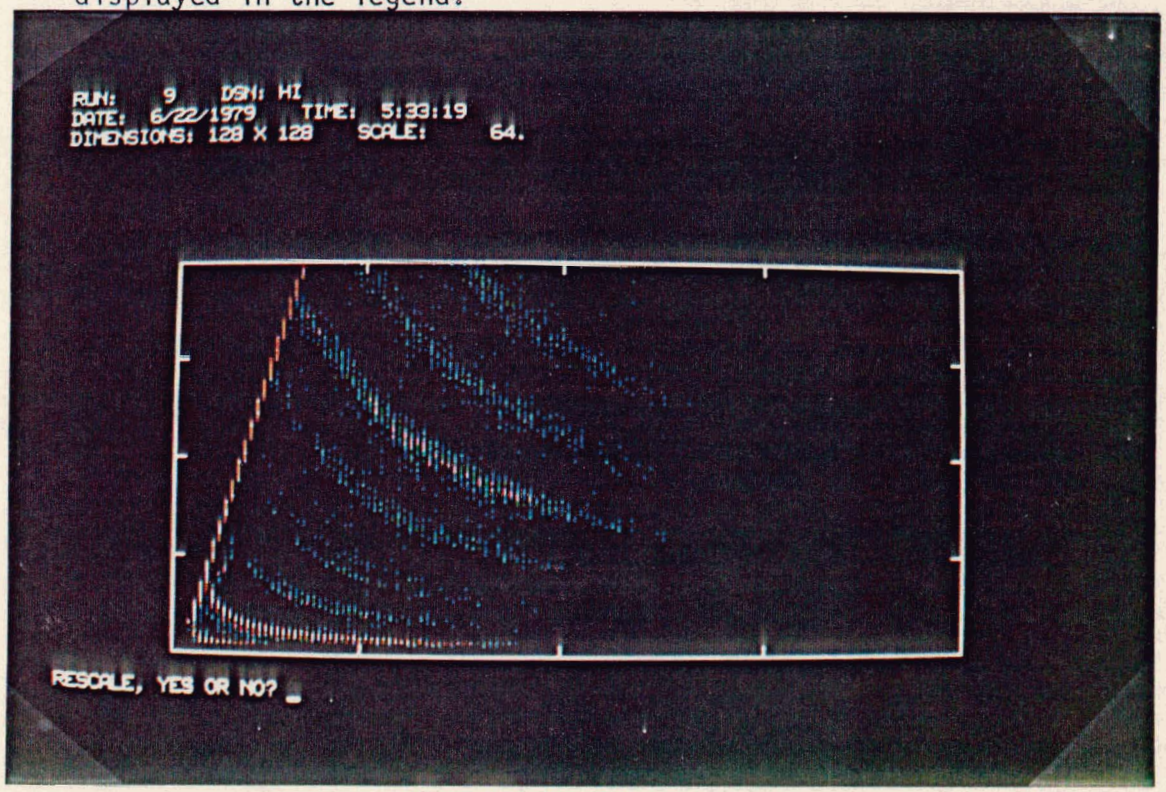
With two parameter data, the color capbility of the graphics terminal becomes more important. The third dimension, that of number of counts per cell, shows up much better on a color scale than on a gray level intensity scale. While only display routines have been written yet because of our emphasis this fall on the analysis of the γ-ray data discussed in Section IV, these have shown their promise from the display of the data discussed in Section III. Examples of the color display of one- and two- parameter data are shown in Fig. 1.

A major effort during the summer and early fall was that of rewriting the programs originally developed for the IBM 1800 for the Mod Comp II system to take advantage of the color graphics terminal. This was completed several months ago and has proved very useful in the analysis of the O + Mg γ-ray data.

Sale of additional equipment has allowed purchase of a digital X-Y plotter for the Mod Comp-Tektronix system. When implemented, this will



(a) Portion of a Ge(Li) spectrum from 40 - MeV ^{16}O on ^{26}Mg. A typical use of the background subtraction procedure, done with cross-hair cursors, is shown. The net peak counts, centroid and energy are displayed in the legend.



(b) Contour plot of counter telescope data obtained with 128 - MeV ^{16}O on ^{40}Ca at $\theta_{lab} = 25^{\circ}$. Brighter colors indicate regions of higher counting rate. The moderately intense group at left center is ^{16}O; that toward the lower left corner is ^{4}He.

Figure 1

enhance our ability to obtain hard copy graphical output, at a level that will produce publication quality plots.

II. Fusion of $^{15}N + ^{27}Al$.

Analysis of data obtained earlier was completed last summer and a paper reporting these results was submitted to Physical Review C in October. This paper has been accepted for publication. A copy of the preprint is attached.

This paper was concerned with a study of entrance channel effects in the A = 42 compound nucleus, previously investigated in the fusion of $^{16}O + ^{26}Mg$ and $^{18}O + ^{24}Mg$.[1] Rather unexpectedly an entrance channel effect was found in low energy region. If the low energy fusion cross section is represented as

$$\sigma_{fus} = \pi R_B^2 (1 - V_B/E_{c.m.}),$$

significant differences in R_B and V_B were found when the projectile was ^{16}O, rather than ^{15}N or ^{18}O. The latter were in excellent agreement when a small Coulomb correction to V_B was made. This same effect was also noted for fusion reactions initiated by ^{16}O and ^{18}O by Rascher et al.[2]

This effect is being investigated in experiments to be discussed in Sections IV and VI.

III. Reaction strengths of $^{16}O + ^{40}Ca$ at about 128 MeV.

We participated in June in an initial attempt to determine the reaction mechanisms in this system responsible for the reaction strength other than fusion, in the energy regions where the fusion strength begins to drop well below the total reaction strength. Our immediate involvement in thie experiment was to gain experience with the higher energy region provided by the Argonne superconducting linac, as well as the interest in the physics.

The analysis of the data from this experiment has been done at Argonne. The resuts do not lead to clearcut conclusions and the possible interference from carbon contamination of the target may mask the desired information.[3] Further work on this interaction is planned, but awaits the solution to the contamination problem.

IV. Fusion residues from $^{16,18}O + {}^{24,26}Mg$.

Data were obtained at Argonne in August, 1979, in collaboration with D. G. Kovar, C. N. Davids and K. Daneshvaar, on the γ rays emitted in interactions of $^{18}O + {}^{24}Mg$, $^{16}O + {}^{26}Mg$, and $^{16}O + {}^{24}Mg$. This experiment was undertaken with three goals in mind. First, as discussed in Section II and the attached preprint, an entrance channel effect has been observed between the use of ^{16}O and neighboring nuclei as projectiles in the barrier-dominated region of the fusion process. We are pursuing the question of whether this effect is observable in the relative production of specific residues. This is most easily determined by the intensities of γ rays characteristic of these residues. Second, while total fusion cross sections are best established by the measurement of the heavy residues with a particle detector, details of these cross secitons can be determined with better statistics with γ-ray data. We hope to establishe the presence or absence of cross section "resonances" in non-α-particle systems in the total or partial fusion cross sections with more precision than available at present. Third, if extended to include the $^{15}N + {}^{27}Al$ system, entrance channel effects may be found in the pattern of residues between the even-even and odd-odd target + projectile systems leading to the same fused nucleus. These data were obtained from about 25 to 70 MeV for $^{18}O + {}^{24}Mg$ and $^{16}O + {}^{26}Mg$ and from 40 to 50 MeV for $^{16}O + {}^{24}Mg$.

The analysis is still in its preliminary stages and it is apparent that additional data will be necessary. Spectra obtained for $^{16}O + ^{26}Mg$ have been examined to determine the lines present from the fusion residues from the reaction and from the interaction of the ^{16}O beam with the ^{16}O contamination of the target. The next step has been the determination of predominant decays in the residues that are representative of the strength with which specific residues are produced, e.g., the $2^+ \rightarrow 0^+$ transition in even-even nuclei. While a comparison of the $^{16}O + ^{26}Mg$ and $^{18}O + ^{24}Mg$ systems is not yet available, preliminary results for the former system are shown in Fig. 2. The results seem to be reasonable; residues produced by two and three nucleon, αN, and $\alpha 2N$ boiloff peak at low energy and become weaker at higher energies; 2α boiloff peaks at a higher energy; and at the highest energies 4N and possibly 3α boiloff appears.

We plan to request additional time for this experiment in April.

V. Fusion of $^{16}O + ^{24,26}Mg$ at 140 MeV.

As stated in the original proposal, one of the objectives was to extend the measurements of the fusion cross-section in previously studied systems to higher energies. During the fall, fusion of $^{16}O + ^{24}Mg$ and $^{16}O + ^{26}Mg$ was investigated. As expected, the fusion cross-section remained constant at approximately 1200 mb from the energy of the previous measurements to about 100 MeV. Then the cross-section began decreasing steadily and had decreased by about 200 mb at 140 MeV. This occurs at a much lower grazing angular momentum than predicted by the rotating liquid drop model.[4] Thus this phenomenon can not be explained as was a superficially similar fall off at higher energies in the $^{12}C + ^{14}N$ fusion reported by Gomez del Campo et al.[5]

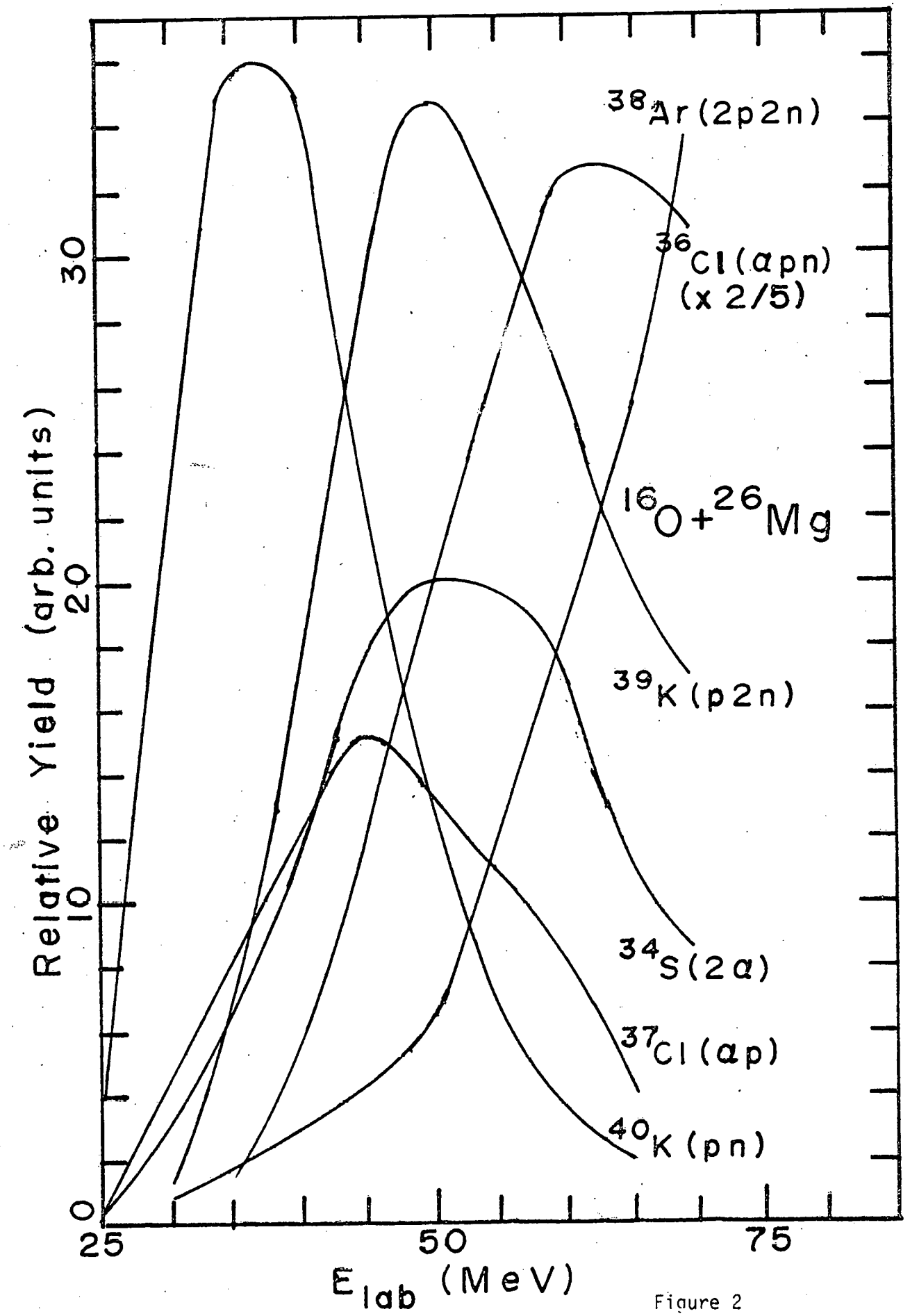

^{38}Ar(2p2n)
^{36}Cl(αpn)
(x 2/5)
^{16}O+^{26}Mg
^{39}K(p2n)
^{34}S(2α)
^{37}Cl(αp)
^{40}K(pn)
Relative Yield (arb. units)
0
10
20
30
25
50
75
E_{lab} (MeV)

Figure 2

A run to investigate these systems and $^{18}O + ^{24}Mg$ further and to extend the energy range to about 170 MeV is planned for the next linac run at Argonne to starg in mid-February.

VI. Summary of plans for further experiments.

The investigation of reaction mechanisms other than fusion in the high energy interactions of ^{16}O and ^{40}Ca has been postponed until the problem of carbon contamination can be solved. We hope to be able to return to this experiment this summer.

Further runs of obtain γ-ray yields from $^{16,18}O + ^{24,26}Mg$ will be necessary. Tentative plans are to request beam time for this in April. If definite entrance channel effects are found in the pattern of residues, it may prove desirable to extend the measurement to the $^{15}N + ^{27}Al$ system.

Continued investigation of the fusion cross-sections of these same systems at the higher energies available with the Argonne linac is planned for February.

A fourth experiment is being discussed for this summer. Kohlmeyer et al. have reported that their results for the fusion of $^{19}F + ^{12}C$ at 97 MeV are best explained by the assumption that, in aobut 30 per cent of the interactions, pre-equilibrium emission of an α-particle from the ^{19}F projectile occurs and the remaining ^{15}N nucleus interacts with the ^{12}C target. A test of this hypothesis for this system, or others where a similar mechanism might appear, can be made by investigation coincidences between α particles and heavy particles emitted in the interactions.

References:

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[5]J. Gomez del Campo, R. G. Stokstad, J. A. Biggerstaff, R. A. Dayras, A. H. Snell, and P. H. Stelson, Phys. Rev. C 19, 2170 (1979).

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Preprints removed.