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The Scattering of Polarized Protons from Si in the Giant Resonance Region of ^{29}P *

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Abstract: A simultaneous measurement has been made of analyzing powers and cross sections of protons scattered elastically from Si between 17 and 29 MeV. An optical model analysis shows an anomalous non-monotonic behavior of the spin orbit potential in this energy region.

* Work performed under the auspices of the USAEC and of AECB of Canada.

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Recent studies of inelastic proton scattering from a broad range of nuclei provide evidence for excitation of a giant quadrupole or monopole resonance just below the well known giant dipole resonance (1). The proton widths of these broad states seem to imply that a resonance effect should be present in proton elastic scattering through this region of excitation. It should be observable provided that the shape elastic scattering, as described by the optical model (OM), is not dominant. It has been also pointed out that the proton polarization analyzing power of silicon was inadequately known above 15 MeV, particularly for the purposes of its use in a proton polarimeter (2). Such is the case for most nuclei with the exception of helium and carbon, traditionally used as proton polarization analyzers. While the scattering of protons (unpolarized and polarized) from helium is amenable to a detailed phase shift analysis (3), the scattering from carbon and other nuclei has been analyzed by the optical model with varying degrees of sophistication (4-6). It is well known that OM parameters and wave functions are extensively used in the distorted wave Born approximation (DWBA) calculations of nuclear reactions (7). The OM parameters for the proton -nucleus interactions are obtained from elastic scattering cross sections at and above 10 MeV laboratory energy. Experimental data and OM parameters are available at rather widely spaced energy intervals and smooth interpolations of them are usually assumed appropriate in applications. This results in monotonically varying parameters. However the validity of the latter and of the corresponding wave

functions may be affected by resonances and, in particular, by the giant resonances present in nuclei. The region of the giant dipole resonance for ^{29}P is located near 20 MeV in the ^{28}Si + p channel, while the evidence for the quadrupole or monopole resonances in other nuclei would centre them about 2 MeV lower in energy (1). No information on cross sections or polarizations has been available between 17 and 29 MeV (8, 9) as is the case for most nuclei.

The polarized proton beam facility of the Berkeley 88-inch cyclotron was used to measure relative cross sections and asymmetries in the scattering from Si at 2 MeV intervals between 17 and 29 MeV inclusive. A description of the facility has been published by Bacher et al. (10) and most of the details of the experimental procedure may be found there. The natural Si target (92.2% of ^{28}Si) was prepared from crystalline high purity material. The thickness was determined to be 6.5±0.2 mg cm^{-2} using a method of alpha particle transmission from a source of ^{241}Am, this implies an energy loss of approximately 150 keV at 17 MeV proton energy, and 100 keV at 29 MeV. Four pairs of cooled silicon detectors were used at symmetrical angles with respect to the beam, and geometrical asymmetries were compensated by performing measurements with two opposite spin orientations of the proton beam. The polarization of the latter was continuously monitored and measured with a helium polarimeter, using recently published accurate analysing power values (10). The analyzing power $A(\theta)$ was calculated from the left and right detector

yields with both spin orientations of the beam as described by Plattner et al (11), and the relative cross sections were obtained from averaging yields. Figure 1 shows the cross sections and analysing powers obtained in the present experiment, the solid lines correspond to best fits calculated with the optical model code Magali (12). Table I shows the geometrical parameters used and the results of the search for the well depth parameters. A search varying the stated geometrical parameters does not improve the fits of table I. The poorer quality of fits obtained when V_{SO} is interpolated linearly between 17 and 29 MeV is illustrated in table II, the convergence of V_{SO} to the values of table I is also demonstrated.

It was conjectured by Satchler (13) sometime ago that the nature of the spin-orbit interaction could be determined unambiguously from high quality polarization data, particularly at forward angles. Figure 2 shows indeed that the parameters obtained from the forward angle data fit successfully the full angular distributions at 17 (8), 25 (14), and 29 (9) MeV Figure 3 is a plot of the OM parameters of table I as functions of energy. The salient features are, firstly, a transition from a volume absorption W to a surface absorption W_d (with a fairly monotonic sum $W+W_d$)* and, secondly, a clear non-monotonic variation of the spin-orbit potential with a maximum near 21 MeV, corresponding well to the expected location of the giant dipole resonance. No theoretical calculations are available for ^{29}P, but the neighboring nucleus ^{28}Si has been extensively studied (15), and it is well known that the giant dipole resonance energy varies slowly as a function of nuclear mass.

* The quality of the fits depends on the sum $W + W_d$, and weakly on the values of W and W_d.

The standard optical model calculation does not include contributions to the scattering from resonances other than those from single-particle potential scattering. Thus, it is possible that the anomalous behaviour of the potential parameters found in this analysis is due to a giant resonance contribution to the scattering which is not specifically included in the calculation.

An examination of the behaviour with energy of the partial wave scattering amplitudes was made with the following results: The $p_{1/2}$ and $p_{3/2}$ amplitudes show stronger absorption between 17 and 25 MeV with best fit parameters of table I than for those obtained with V_{SO} interpolated linearly, as would be expected for absorption through a giant dipole resonance. However, other amplitudes also show increased absorption, which is due to the fact that the OM potential has no specific l-dependence and thus, the effect of changes in the potential parameters cannot be limited to particular partial waves. A more detailed phase shift analysis is contemplated, which should make it possible to identify a resonance effect in a particular partial wave. The extension to other nuclei of the experimental investigation of elastic proton scattering in the giant resonance regions is also planned.

In summary, the optical model treatment of elastic scattering provides good fits to the data over the investigated energy region, but it is necessary to determine the parameters with considerable detail due

to the anomalous behaviour of the spin orbit interaction, probably related to the giant dipole resonance. The latter is located for most nuclei between 10 and 30 MeV in the proton channel. A similar situation may exist for other particle channels across this broad resonance.

Some of the authors (R. L., B. F., R.J. S and R. de S.) would like to gratefully acknowledge the generous hospitality of Lawrence Berkeley Laboratory. Many thanks are due to the Centre de Traitement de l'Information of Université Laval for the use of its computing facilities. The cooperation of the 88" cyclotron staff was essential to the success of this experiment and we express our warmest thanks.

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TABLE I. OPTICAL-MODEL PARAMETERS FOR BEST FITS

THE FOLLOWING PARAMETERS WERE HELD FIXED AT THE VALUES

r_o=1.17fm, r_i=1.33fm, r_{so}=.94fm, a_o=.65fm, a_i=a_{so}=.6fm

E_{LAB}	V	W	W_d	V_{so}	χ^2_σ	χ^2_p	χ^2_t/N
17.13	51.52	3.75	2.92	6.51	27	240	6.8
19.04	51.58	5.16	2.3	8.26	16	76	2.3
20.84	49.96	4.48	2.59	8.46	65	122	4.7
22.99	48.83	3.06	3.76	7.42	19	55	1.85
24.93	47.77	1.36	5.26	6.58	47	79	3.0
27.14	46.64	0.136	6.76	5.29	37	167	5.0
28.98	46.01	0.0	6.74	4.62	56	436	12.0

The last three columns contain the χ-squared of the cross sections, of the analyzing powers and the combined χ^2 per point respectively.

TABLE II. OPTICAL MODEL PARAMETERS FOR BEST FITS WITH THE SPIN-ORBIT REAL DEPTH HELD FIXED

THE FOLLOWING PARAMETERS WERE HELD FIXED AT THE VALUES

r_o=1.17fm, r_i=1.33fm, r_{so}=94fm, a_o=.65fm, a_i=a_{so}=.6fm

E_{LAB}	V	W	W_d	V_{so}	χ^2_σ	χ^2_p	χ^2_t/N
19.04	49.3	0.62	6.2	5.5	32	330	9.05
†19.04	51.6	5.16	2.3	6.2	29	647	16.9
19.04	49.08	0.0	6.98	6.2	40	163	5.07
19.04	49.3	0.02	6.7	6.5	31	117	3.7
20.84	47.8	0.0	6.25	5.5	61	736	19.9
†20.84	49.96	4.48	2.59	5.9	80	1107	29.67
20.84	47.83	0.0	6.22	5.9	84	529	15.33
20.84	47.8	0.0	6.25	6.5	58	316	9.3
22.99	47.8	0.0	6.27	5.0	29	511	13.5
†22.99	48.83	3.06	3.76	5.6	26	461	12.17
22.99	47.78	0.0	6.26	5.6	36	270	7.65
22.99	47.8	0.0	6.27	6.0	25	163	4.7
24.93	47.4	0.0	6.5	5.0	56	394	11.8
†24.93	47.76	1.36	5.26	5.3	51	329	9.5
24.93	47.37	0.0	6.51	5.3	54	273	8.17
24.93	47.4	0.0	6.5	6.0	50	108	4.1
27.14	46.6	0.136	6.8	4.5	34	325	9.0
†27.14	46.64	0.136	6.76	4.9	39	206	6.12
27.14	46.64	0.136	6.76	4.9	39	206	6.12
27.14	46.8	0.465	6.45	5.5	27	172	5.0

† V_{SO} interpolated linearly, other parameters as in table I. The following line is a best fit.

Figure captions.

Fig 1: Analyzing powers and cross sections obtained in the present experiment solid lines are optical model best fits.

Fig 2: Cross sections and analyzing powers at 17 MeV from ref. 8, at 25 MeV from ref. 14 and at 29 MeV from ref. 9. Solid lines are obtained from optical model fits with parameters identical to those of Fig 1.

Fig 3: Plot of optical model parameters for the best fits shown on figure 1. The sum $W + W_d$ is approximately constant. The spin orbit potential V_{SO} shows a maximum near 20 MeV. The scale on the right is for W, W_d, and V_{SO}.

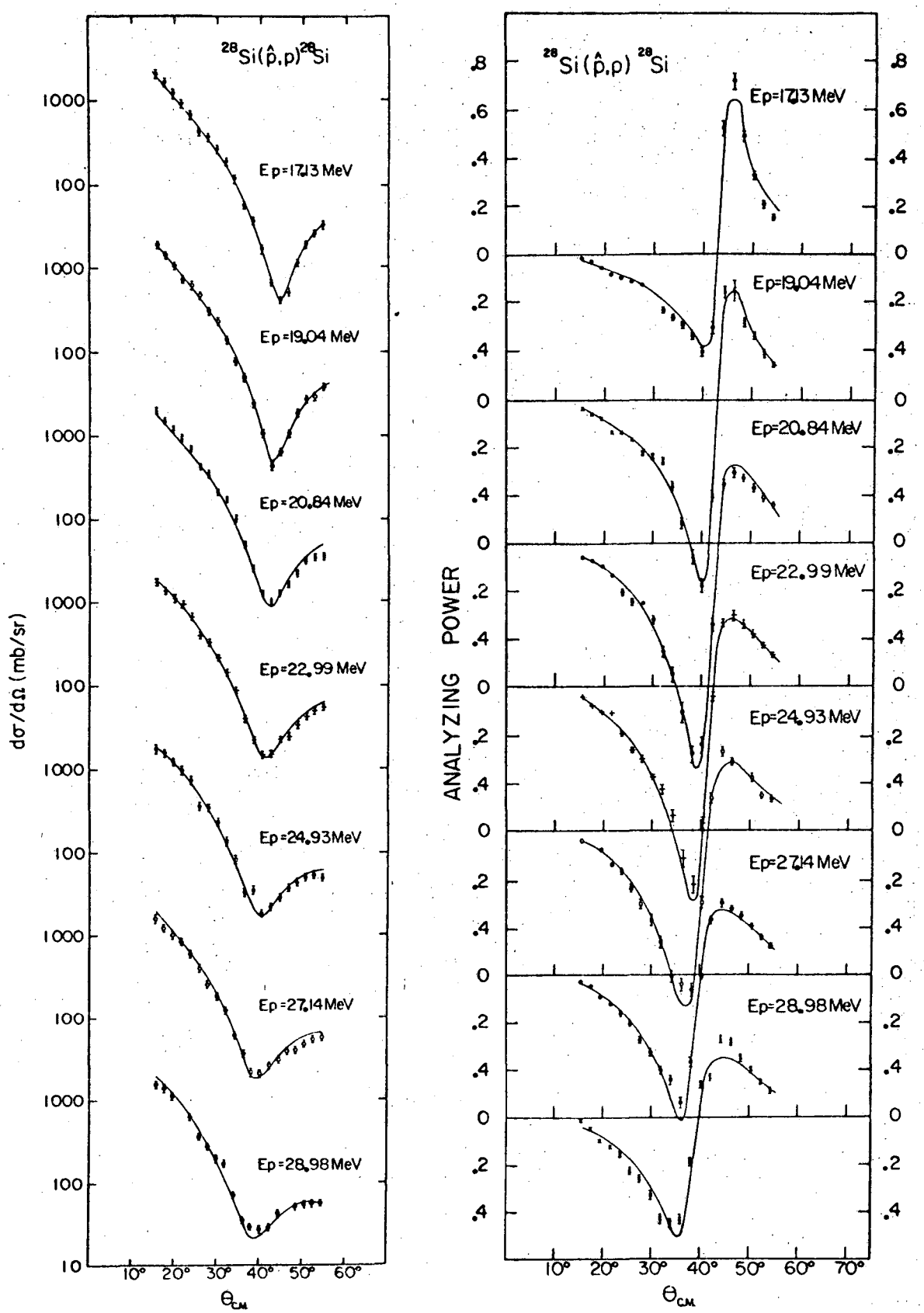
$^{28}Si(\hat{p},p)^{28}Si$
Ep=17.13 MeV
Ep=19.04 MeV
Ep=20.84 MeV
Ep=22.99 MeV
Ep=24.93 MeV
Ep=27.14 MeV
Ep=28.98 MeV
dσ/dΩ (mb/sr)
ANALYZING POWER
Θ_{CM}

Fig. 1

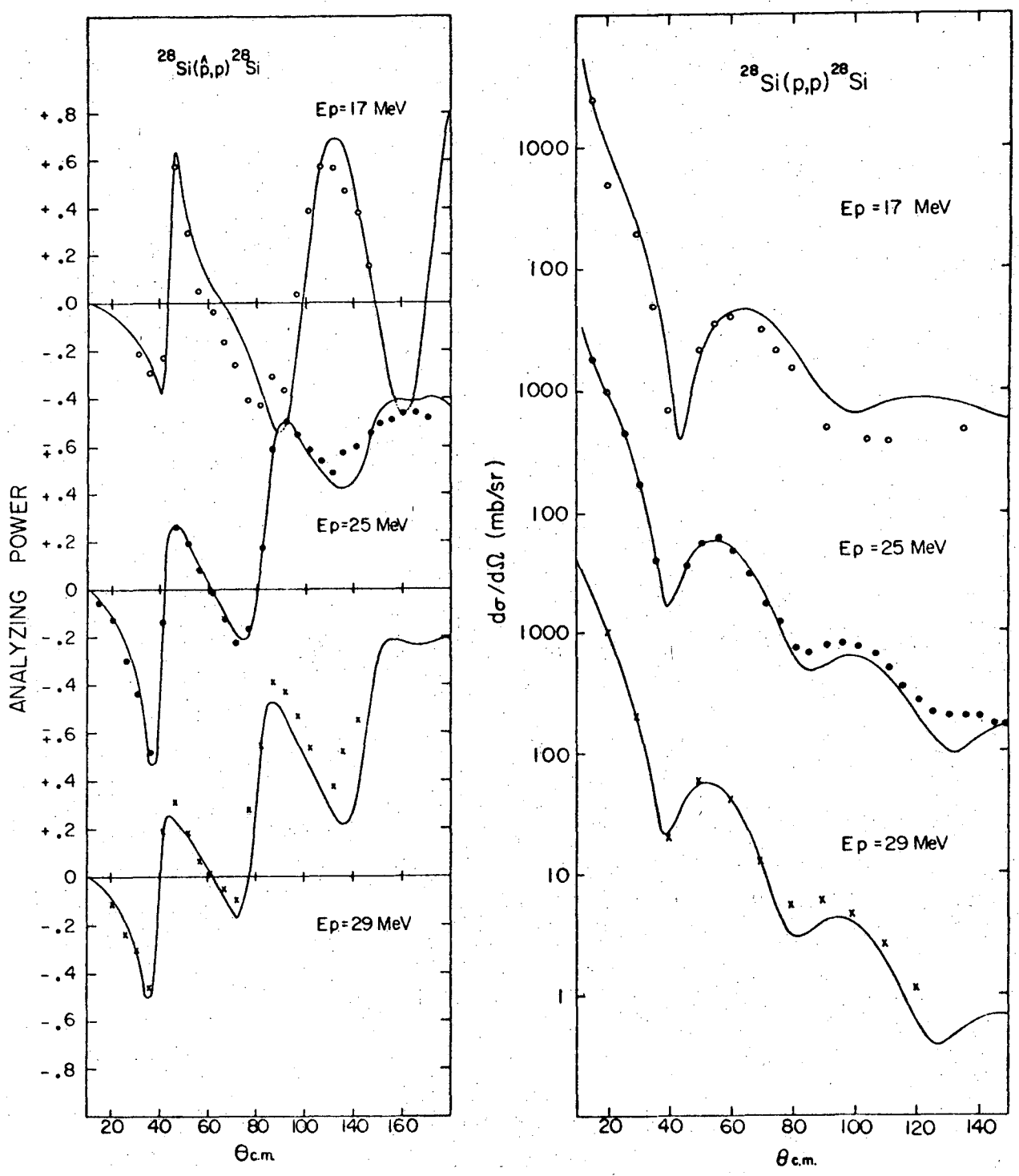
$^{28}Si(\hat{p},p)^{28}Si$
Ep=17 MeV
Ep=25 MeV
Ep=29 MeV
ANALYZING POWER
+.8
+.6
+.4
+.2
.0
-.2
-.4
-.6
-.8
20
40
60
80
100
140
160
θc.m.
$^{28}Si(p,p)^{28}Si$
Ep =17 MeV
Ep =25 MeV
Ep =29 MeV
dσ/dΩ (mb/sr)
1000
100
10
1
20
40
60
80
100
120
140
θc.m.

Fig. 2

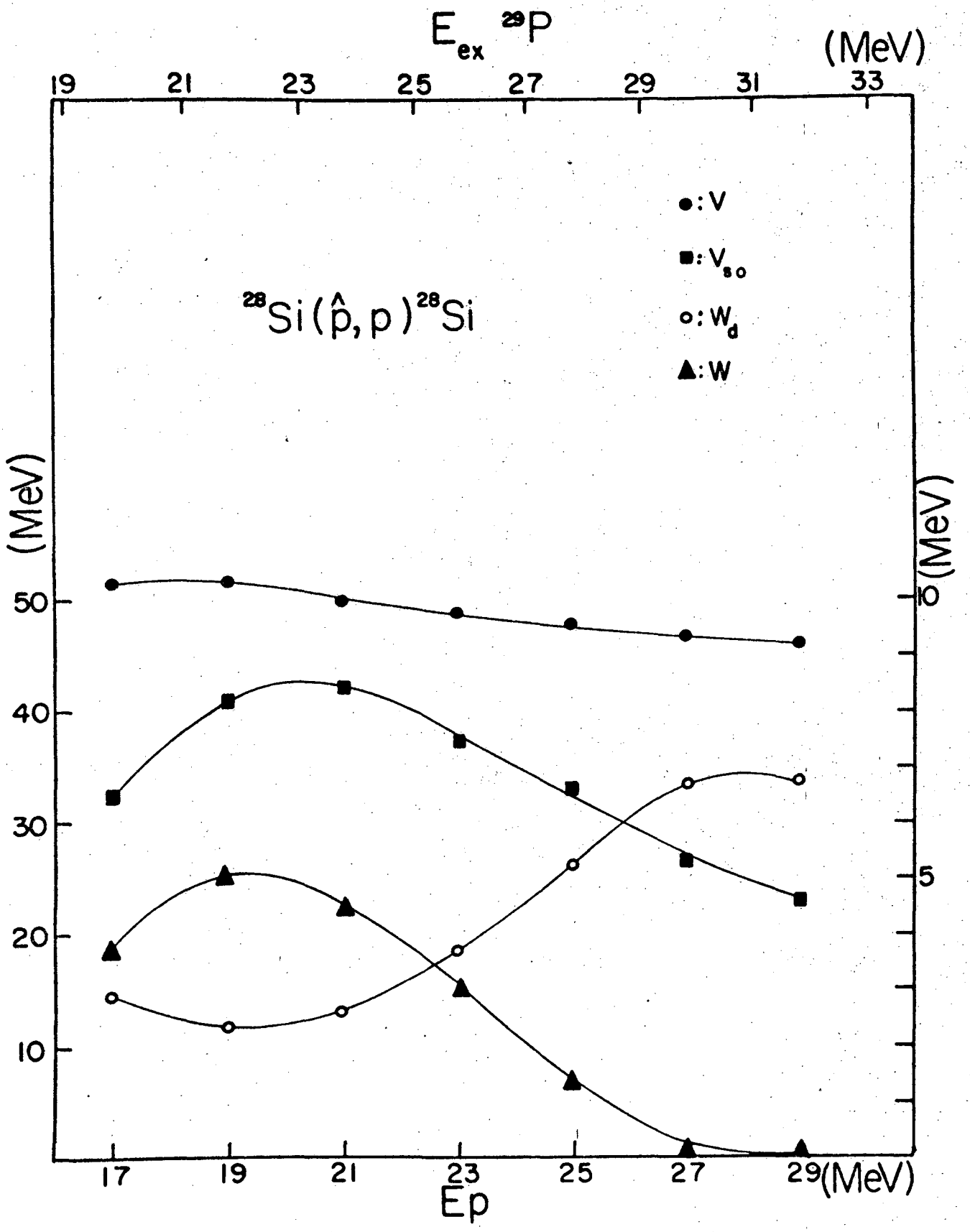
E_{ex} ^{29}P (MeV)
19
21
23
25
27
29
31
33
●: V
■: V_{so}
○: W_d
▲: W
$^{28}Si(\hat{p},p)^{28}Si$
(MeV)
50
40
30
20
10
(MeV)
10
5
17
19
21
23
25
27
29(MeV)
Ep

Fig. 3

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