CHARGED PARTICLE cross sections
NEON TO CHROMIUM

LOS ALAMOS SCIENTIFIC LABORATORY
UNIVERSITY OF CALIFORNIA

LOS ALAMOS, NEW MEXICO
LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.
CHARGED PARTICLE cross sections
NEON TO CHROMIUM
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico JUNE 1960

Compiled and edited by
Darryl B. Smith

Associate Editors
Nelson Jarmie and John D. Seagrave

This report expresses the opinions of the author or authors and does not necessarily reflect the opinions or views of the Los Alamos Scientific Laboratory.

Contract W-7405-ENG. 36 with the U. S. Atomic Energy Commission

Report distributed:
January 31, 1961
INTRODUCTION

The present report is a continuation of a projected series titled Charged Particle Cross Sections. The first volume appeared in 1957 as Los Alamos Report LA-2614. The purposes and justifications of such a compilation are many. First and most obvious, it will be of immediate use to experimental theoretical physicists, since no compilation of this type has existed. It should encourage experimenters to make absolute measurements and to raise the quality of such measurements. By presenting existing data in a compact and integrated form, it should stimulate new experiments and theoretical investigations. It may also serve to standardize the notation.

Scope: This volume of the compilation attempts to include the "best" cross sections of all nuclear processes involving charged nuclear projectiles of all energies and targets of the medium-mass elements from neon through chromium. An effort has been made to include all absolute data published in a generally available source before January 1, 1960, although in some cases later or unpublished data may have been used. Only results that are absolute or that can be normalized easily to existing absolute data are included. Data with uncertainties over 100 percent, or with no experimental error limit stated, have been omitted at the discretion of the compiler.

Method of Presentation: It should be noted that the compilation is a graphical representation of experimental data. Tables of results that duplicate information on the curves are not given.

An effort has been made to avoid pitfalls for the reader, such as shifted, overlapping, or other non-monotonic scales, unusual units, and various complex representations. Almost without exception, the units of the ordinate are expressed in some form of barns. In several cases of elastic scattering, the ratio of the experimental cross section to the Rutherford cross section is plotted. Appendix II lists the numerical factors necessary in computing the Rutherford cross section for targets from hydrogen through copper.

It was usually deemed unnecessary to plot angular distributions for these targets in both the laboratory and the center-of-mass coordinate systems, since the difference in cross section due to coordinate transformation was usually only a few percent. If this difference is less than the absolute experimental errors or if the difference in the data plotted in both systems is not readily apparent, only one plot (usually in the C.M. system) is presented.

Excitation functions are presented in the laboratory system except where specifically marked, and the energy scale is always the laboratory energy. Whenever bombarding energies were given in the literature for the C.M. system, they have been transformed non-relativistically into the laboratory system. Q-values for two-body reactions are taken from the report by Ashby and Catron.1 Values not given in that reference, such as the Q's of most spallation reactions, were calculated from the masses.2 In each case, the ground state Q-value is given. Energy level designations are taken whenever possible from Endt and Braams3 or from Way et al.4

Unless otherwise marked, curves are smooth lines representing experimental data. The usual nomenclature is followed in the titles for the graphs: in the title X(a,b)Y, X is the target nucleus, a is the incident particle, b is the fragment to which the cross section refers (usually the light fragment), and Y is the residual nucleus or recoil particle. An effort has been made in each case to indicate which particle was actually observed by placing its symbol furthest to the right in the final parenthesis of the title. That is, where the title is written as X(p,py)Y, the cross section refers to the gamma ray. If the proton cross section were shown, the reaction would have been written as X(p,p')Y*. Spallation reactions and other reactions in which the β-activity of one of the product nuclides was observed are written as X(α,β)YβZ.

The sequence of the graphs is according to (1) increasing Z and mass of the target, (2) increasing Z and mass of the projectile, and (3) decreasing Z and mass of the recoil fragment. Further differentiation is given by the energy of the incident particle, excitation functions preceding angular distributions, and ground state preceding excited state reactions. Reactions on targets of normal isotopic

3P. M. Endt and C. M. Braams, Rev. Mod. Phys. 29, 683 (1957).
composition are placed with the graphs for the most abundant stable isotope. Since there are some ambiguous cases, the reader is advised to wander through the pages a bit before giving up the search.

A serious attempt has been made to include with each graph some indication of the absolute error limits for the cross sections. When the error was not stated in the reference and could not be obtained by private communication, the compiler often has made a conservative guess from the information in the reference. The error designation used in this compilation is the probable error. Error bars shown graphically on the experimental points represent counting statistics unless otherwise designated.

No collected bibliography has been made for the material plotted. References and information of interest have been placed on the page with the data to which they pertain. References containing only relative data or data that was not plotted (usually because of a lack of information on absolute error limits) are collected in Appendix 1. These references are listed by reaction and pertain only to those reactions for which no material is plotted.

Although due care has been taken, it should be emphasized that anyone desiring very accurate values should always use the original reference. Unavoidable errors in tracing, graph paper distortion, and final reproduction always occur. In extreme cases, where data had to be copied from tiny graphs in journals, errors of 5 percent or more may be expected. Our experience has shown the value of using tabular form for publishing experimental information when accuracy is important.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the help and services of all draftsmen, plotters, calculators, and others who have contributed to this work. Great appreciation is also extended to the numerous correspondents who have furnished unpublished data, error calculations, large graphs, tabular data, and other information.
$\text{Ne}^{20}(p, \gamma) \text{Na}^{21}(\beta^+) \text{Ne}^{21}; \text{Ne}^{20}(p, p') \text{Ne}^{20}\*$

M. Kondo and T. Yamanaki
Absolute P.E. = ±10%.

See also
Crowe, Heydenburg, and Phillips
Phys. Rev. 87, 304 (1952)
Galonsky et al.
Phys. Rev. 91, 439 (1953)

$\sigma = \frac{\Delta \text{energy}}{\Delta \text{angle}}$

$\sigma = (2.4 \pm 1.0) \times 10^{-2} \text{ mb}$

at $E_p = 0.390 \text{ Mev}$

N. Tanner
Phys. Rev. 114, 1068 (1959) and
private communication

$\sigma = 0.74 \pm 0.15 \text{ mb at } E_p = 1.050 \text{ Mev}$
M. Kondo and T. Fumazaki
Absolute P.E. = ±10%

See also
Oda et al.
For detailed data see
Hestler, May, and Powell

K. Matsuda and S. Kobayashi
to be submitted for publication
in J. Phys. Soc. Japan
Absolute P.E. = ±5-10%
Relative P.E. = ±5%

Note: A neon target of normal isotopic composition was used.
Ne (p,p) Ne

K. Matsuda and S. Kobayashi

to be submitted for publication in J. Phys. Soc. Japan

Absolute P.E. = ±5-10%
Relative P.E. = ±5%

Note: A neon target of normal isotopic composition was used.
Ne(p,p)Ne

Proton energy 9.51 ± 0.03 Mev
Gibson, Prowse, and Rothig
Absolute P.E. = 15%

Note: A neon target of normal isotopic composition was used.
K. Matsuda and S. Kobayashi
To be submitted for publication in J. Phys. Soc. Japan
Absolute P. E. = ±5.10%
Relative P. E. = ±5%.

Note: A neon target of normal isotopic composition was used.
Integrated total cross sections

<table>
<thead>
<tr>
<th>$E_p$ (Mev)</th>
<th>$\sigma$ (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>387</td>
</tr>
<tr>
<td>4.9</td>
<td>259</td>
</tr>
<tr>
<td>5.1</td>
<td>387</td>
</tr>
<tr>
<td>5.3</td>
<td>387</td>
</tr>
<tr>
<td>5.5</td>
<td>143</td>
</tr>
</tbody>
</table>

$E^* = 1.63$ Mev

M. Kondo and T. Yamazaki

Absolute P. E. = ±10%
$\sigma(\theta)$, Millibarns per Steradian

Lab Angle of Proton, $\theta$

C.M. Angle of Proton, $\theta'$

$E^* = 1.63$ Mev
Proton energy 0.51 Mev
Gibson, Prowse, and Rothblatt
Absolute P.E. = ±7%
Note: A neon target of normal isotopic composition was used.

Note: Relative data below 2.2 MeV were arbitrarily normalized to absolute data above 2.2 MeV.

Lab angle $\theta = 0.15^\circ$
Marion, Slattery, and Chapman
Phys. Rev. 103, 678 (1956)
Absolute P. E. = $\pm 10%$
Only about half the original experimental points are shown.

The authors assign the following thresholds

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$E_1$(Mev)</th>
<th>$Q$(Mev)</th>
<th>$E^\ast$(Mev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne disproportion $^{21}$</td>
<td>1.45</td>
<td>-1.24</td>
<td>1.46</td>
</tr>
<tr>
<td>Ne disproportion $^{22}$</td>
<td>2.292</td>
<td>-1.866</td>
<td>8.435</td>
</tr>
<tr>
<td>Ne disproportion $^{23}$</td>
<td>2.554</td>
<td>-2.201</td>
<td>2.426</td>
</tr>
<tr>
<td>Ne disproportion $^{24}$</td>
<td>2.887</td>
<td>-2.443</td>
<td>9.012</td>
</tr>
</tbody>
</table>

Ne $(d, n) Na$
Ne(α, α) Ne

Alpha energy 18.02 Mev
Seidtitz, Bieuler, and Tezdam
Phys. Rev. 119, 682 (1951)
Absolute P.E. = ±8-10%

Note: A neon target of normal isotopic composition was used.
$E^* = 1.53$ Mev
Alpha energy 18.01 Mev
Seifritz, Bleuler, and Teudam
Phys. Rev. 115, 682 (1959)
Absolute P.E. = $\pm 10\%$
See reference for inelastic scattering to higher states
in Ne$^{20}$
$^{23}\text{Na} (p, 2\alpha) ^{15}\text{O} (\beta^+) ^{15}\text{N} ; \quad ^{23}\text{Na} (p, x) ^{22}\text{Na} (\beta^+) ^{22}\text{Ne}$

$^{22}\text{Na}$ may be formed by the $(p, d)$ or the $(p, p\alpha)$ reactions.

- J. W. Meadows and R. B. Holt
  Phys. Rev. 85, 47 (1952) and J. W. Meadows, private communication
- Absolute P. E. $= \pm 5\%$ (does not include errors in the $^{14}\text{C}(p, n)^{14}\text{N}$ monitor)
- B. L. Cohen
  Phys. Rev. 109, 453 (1958)
  Absolute P. E. $= \pm 5\%$
  Relative P. E. $= \pm 1\%$
  (private communication)

The cross sections for the $^{13}\text{C}$ and $^{14}\text{N}$ activities produced by protons on $^{23}\text{Na}$ are less than 0.2 mb at 31 Mev.
$^{23}\text{Na}(p, x)^{18}\text{F}(\beta^+)^{18}\text{O}$

$^{23}\text{Na}(p, d)^{18}\text{F}$ and $^{23}\text{Na}(p, p^+)^{18}\text{F}$ are probably the reactions by which $^{18}\text{F}$ is formed initially. In the vicinity of 50 Mev other reactions such as $(p, \gamma)$ become energetically possible.

O. J. W. Meadows and R. B. Holt
Phys. Rev. 53, 47 (1958) and
J. W. Meadows, private communication

Absolute P. E. = ±8% [does not include errors in the $^{12}\text{C}(p, p)n^{11}\text{C}$ monitor]

B. L. Cohen
Phys. Rev. 102, 458 (1956)
Absolute P. E. = ±8%
Relative P. E. = ±15% (private communication)
For relative data see
P. Shapiro
Phys. Rev. 93, 290 (1954)
Bretschner et al.
Phys. Rev. 96, 103 (1954)
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 70, 893 (1946)
C. E. Dickerman
C. L. Bailey and J. H. Williams
Phys. Rev. 91, 539 (1943)
Lawrence, McMillan, and Thornton
Phys. Rev. 48, 493 (1935)
Takemoto, Dasso, and Chiba
Phys. Rev. 91, 1024 (1953)

$Q = 4.73$ Mev
Deuteron energy 14.8 Mev
W. F. Vogelsang and J. N. McGrher
Phys. Rev. 109, 1663 (1958)
Absolute P. E. = ±50%
Relative P. E. = ±10%
Note: Relative angular distributions were normalized to the absolute measurements given:
$E^* = 1.34$ Mev, $\sigma(14.8^\circ) = 18.1$ mb/st
See also
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 69, 231 (1944) (excitation function)
For relative data see
F. A. El Bedawi and M. A. El Wahab
Nuclear Physics 1, 305 (1957)
J. Hughes

Q = 9.46 MeV
Deuteron energy 9.02 ± 0.06 MeV
Calvert et al.
Absolute P.E. ±5%
Relative P.E. ±20%

Note: Relative angular distributions were normalized to measured points.

\begin{tabular}{|c|c|c|}
\hline
E^* (MeV) & \theta' (degrees) & \sigma(\theta') (mb/str) \\
\hline
0 & 0 & 0.04 \\
1.368 & 0 & 0.3 \\
4.122 & 30 & 0.40 \\
4.33 & 0 & 2.0 \\
5.1 & 0 & 0.32 \\
5.5 & 0 & 0.32 \\
6.3 & 0 & 3.0 \\
7.5 & 0 & 4.3 \\
8.4 & 0 & 4.4 \\
\hline
\end{tabular}
$\text{Na}^{23}(\alpha, \beta)\text{Mg}^{26}$

$Q = 1.84$ Mev
Alpha energy 30.4 Mev
C. E. Huntig and N. S. Wall
Phys. Rev. 115, 956 (1959)
Absolute P. E. = +100 ± 50%

For relative data see
G. M. Temnor and N. P. Heydenburg
Phys. Rev. 95, 426 (1954)
\[ \text{Mg}^{24} (p, p) \text{Mg}^{24} \]

Lab angle \( \theta = 164 \pm 5^\circ \)

Mooring et al.
Phys. Rev. 84, 702 (1951)

"It is thought that the cross section values are known to within 10 percent over most of the energy range covered."

See reference for better resolution data over narrow resonances.

See also:
G. W. Greenlees

For relative data see also
Latherland et al.
Phys. Rev. 102, 208 (1956)
See also
G. A. Wrenshall
Phys. Rev. 63, 56 (1943)
E. H. Rutherford

Note: A magnesium target of normal isotopic composition was used.

Greenlee et al.
Absolute P. E. = ±5%
Relative P. E. = ±3%
Note: A magnesium target of normal isotopic composition was used.
Similar data at E<sub>p</sub> = 8.62 MeV
Proton energy 9.83 Mev
G. W. Greenlee and A. E. Souch
Absolute P. E. ±10%
Relative P. E. ±5%

Proton energy 9.8 Mev
Baker, Dodd, and Simmons
Phys. Rev. 85, 1051 (1952)
Normalized to 9.55 Mev data
at θ° = 50°

Note: A magnesium target of normal
isotopic composition was used.

Proton energy 9.94 Mev
G. E. Fischer
Phys. Rev. 96, 704 (1954) or
UCRL. - 2546 (1954)
Absolute P. E. ±3%
Relative P. E. ±2.5%

Proton energy 9.55 Mev
Greenlee (6 Fl)
Absolute P. E. ±5%
Relative P. E. ±3%
Note: A magnesium target of normal isotopic composition was used.

Proton energy 540 Mev
Richardson et al.,
Phys. Rev. 85, 29 (1952) or
R. E. Richardson
Report UCRL-1408 (1951)

Statistical errors as shown
Absolute P.E. = ±5% (Author now admit the absolute
errors to be quite this low --
private communication, R. E.
Richardson)
Angular resolution = ±1/2°

See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
See also

S. Yamabe

E. H. Rhoderick

$E^* = 1.368$ MeV

Proton energy 5.64, 6.34, 6.94, and 7.30 MeV

F. D. Seward
Phys. Rev. 114, 614 (1959)

Absolute scale assumes elastic scattering at 23° to be Coulomb

Proton energy 4.8, 5.1, 5.4, 5.7 MeV

Yamabe et al.

Absolute P. E. = +20%
Proton energy 9.02 and 8.86 Mev
G. W. Greenlees and A. E. Bouwh
Absolute P.E. = ±10%
Relative P.E. = ±3%

Proton energy 9.15, 8.83, and 8.63 Mev
Greenlees et al.
Absolute P.E. = ±8%
Relative P.E. = ±3%
Also similar data at 9.13 and 7.86 Mev

For relative data see
H. E. Gove and B. F. Stoddart
Phys. Rev. 85, 572 (1952)

\[ \text{Mg}^{24} (p, p') \text{Mg}^{24} \]

E' = 1.368 Mev
Proton energy 9.94 Mev
G. E. Fischer
Phys. Rev. 95, 704 (1954) also
Report UCRL-2546 (1954)
Absolute P.E. = ±5%
Relative P.E. = ±2.5%
See also
P. C. Oegelot and P. R. Phillips
Phys. Rev. 101, 1614 (1956)
(Data at $E_p$ = 18 Mev)

$E^* = 1.368$ Mev
Proton energy $11.87 \pm 0.08$ Mev

H. E. Consett
Phys. Rev. 125, 1324 (1962) and
Private communication

Absolute P.E. less than $\pm 6.5%$
Relative P.E. as shown

Total cross section $\sigma = 233.3 \pm 7.4$ mb
\( \sigma(\theta) \), Millibarns per Steradian vs. Lab Angle of Proton, \( \theta \)

\( \sigma(\theta') \), Millibarns per Steradian vs. C.M. Angle of Proton, \( \theta' \)

Proton energy 9.93 MeV
G. W. Greenlee and A. E. Souch
Absolute P.E. = ±10%
Relative P.E. = ±5%

\( \text{Mg}^{24} (p, p') \text{Mg}^{24*} \)
Note: A magnesium target of normal isotopic composition was used.

Note suppressed zero.
Mg(p, α)Na
Q = -6.0 MeV (weighted average of the values for the stable isotopes)
Lab angle θ = 90°
C. B. Palmer and C. D. Goodman
to be submitted for publication
in Phys. Rev.
Absolute P.E. = ±5%

Note: A magnesium target of normal isotopic composition was used.

Mg²⁴(p, α)¹⁸O
Mg²⁴(p, x)¹⁸F (β⁺) O¹⁸

J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951)
and
J. W. Meadows, private communication
Absolute P.E. = ±6% (does not include possible error in the monitor reaction)
Author believes the initial reaction to be Mg²⁴(p, α)¹⁸O (Q = -36.4 MeV)
or Mg²⁴(p, He³)¹⁸O (Q = -24.9 MeV)
\begin{itemize}
\item \textbf{Mg}^{24}\text{(d,}\,p')\text{Mg}^{25}\text{X}
\item \(Q = 5.106\text{ MeV (ground state)}\)
\item \(E^* = 0.58\text{ MeV}\)
\item J. R. Holt and T. N. Marsham
\item Absolute P. E. \(= 10\%\)
\item Relative angular distributions were normalized to measured maximum cross section values.
\item \(E^* = 8.9\text{ MeV}\)
\item Hinde, Middleton, and Parry
\item Absolute P. E. \(= 25\%\)
\end{itemize}

Differential cross sections at angular distribution maxima (corrected according to J. R. Holt and T. N. Marsham, Ibid A68, 1022 (1953))

\begin{align*}
E^* \text{ (MeV)} &\quad \sigma(\theta) \text{ (mb/steradian)} \\
0.583 &\quad 4.25 \\
0.976 &\quad 2.32 \\
1.611 &\quad 0.90 \\
1.957 &\quad 2.22 \\
3.405 &\quad 25.0
\end{align*}
E* = 1.96 Mev

Deuteron energy 4.9 Mev

Hinds, Middleton, and Parry
Absolute P. E. = ±25%

See reference for similar data for other Mg* energy levels

Deuteron energy 4.2 Mev

J. R. Holt and T. N. Marsham
Absolute P. E. = ±12%

Relative angular distribution was normalized to a measured maximum cross section value.

E* = 3.40 Mev
Deuteron energy 15 Mev

J. P. Martin
Report SMIRL-TR-1 (1959)
Absolute P. E. = ±29%

For relative (d,p) data see
Endt, Haffner, and Van Patter
Phys. Rev. 96, 518 (1954)

H. E. Allen and C. A. Wilkinson

S. A. Cox and R. M. Williamson
Phys. Rev. 105, 1799 (1957)
Mg (d, d) Mg

Deuteron energy 21.6 ± 0.2 Mev

J. L. Yntema
Phys. Rev. 113, 261 (1959)

P. E. = ±2% (small angles)
±4% (large angles)

Deuteron energy 19.6 ± 0.2 Mev

G. W. Greenlees
University of Birmingham
To be published

Absolute P. E. = ±10%
Relative P. E. as shown
See also
G. W. Greenlees
E. A. Romanovskii and G. F. Timoshov

For relative data see
J. R. Holt and C. T. Young
Nature 164, 1009 (1949)

Deuteron energy 15 Mev
J. W. Haffner
Phys. Rev. 103, 1308 (1956)
Absolute errors "a factor of ±2"
Relative errors as shown

Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Absolute P.E. = ±25% Relative P.E. as shown

Deuteron energy 19.6 Mev
G. W. Greenlees
University of Birmingham
to be published
Absolute P.E. = ±10%
Relative P.E. as shown
Mg$^{24}(d,a)$Na$^{22}$(β$^+$)Ne$^{22}$

Note: Magnesium targets of normal isotopic composition were used.
See also
Bu et al.
(angular distribution at $E_a = 22.8$ Mev)

For relative data see
O. v. Shook
Phys. Rev. 114, 310 (1959)
Kaufmann et al.
Phys. Rev. 87, 873 (1953)
(relative excitation function)

$\sigma (\theta)$, Millibars per Steradian

0.0 10 20 30 40 50 60 70

Lab Angle of Alpha, $\theta$

0.0 $\times 1/100$

$\sigma (\theta)$, Millibars per Steradian

0.0 10 20 30 40 50 60 70

C.M. Angle of Alpha, $\theta'$

0.0 $\times 1/100$

$\alpha$ Alpha energy 31.5 $\pm$ 0.4 Mev
H. J. Watters
Phys. Rev. 103, 1763 (1956)

Absolute P. E. = $\pm$5% or less

$\alpha$ Alpha energy 42 Mev
P. C. Gugelot and M. Rickey
Phys. Rev. 101, 1613 (1956)

Absolute P. E. = $\pm$20% (small angles)
$\pm$10% (large angles)
See also
Ru et al.
For relative data see
G. H. Shook
Phys. Rev. 114, 310 (1959)

\[ \sigma(\theta), \text{ Millibarns per Steradian} \]

\[ \sigma(\theta'), \text{ Millibarns per Steradian} \]

\[ ^{24}\text{Mg} \rightarrow (\alpha, \alpha')^{24}\text{Mg}^* \]

\( E^* = 1.37 \text{ Mev} \)

- Alpha energy 42 Mev
  - P. C. Gugelot and M. Rickey
  - Phys. Rev. 101, 1613 (1956)
  - Absolute P. E. - <20\% (small angles)
    - <10\% (large angles)

- Alpha energy 31.5 ± 0.4 Mev
  - H. J. Watters
  - Phys. Rev. 103, 1763 (1956)
  - Absolute P. E. = ±2\% in addition to the relative errors.
  - Relative P. E. as shown

Angular distributions at 30.9 and 30.4 Mev fall within the experimental uncertainties of the 31.5 Mev data.
$^{24}\text{Mg} (a,a')^{24}\text{Mg}$

$E^* = 4.12$ MeV  
Alpha energy 31.5 MeV

H. J. Watters  
Phys. Rev. 113, 1763 (1959)

Absolute P. E. = ±2% in addition to the relative errors  
Relative P. E. as shown
$\text{Mg}^{24}(N^{14},N^{13})\text{Mg}^{25}$

$Q = -3.32 \text{ Mev}$

Halbert et al.
Phys. Rev. 106, 251 (1957)

Absolute P. E. = \pm 20\%

Relative P. E. = \pm 10\%
Mg$^{25}(p,2p)$ Na$^{24}(\beta^-)$ Mg$^{24}$

- J. W. Meadows and R. B. Holt
  Phys. Rev. 83, 47 (1951)
  Absolute P. E. = ±20%.

- Cohen, Reynolds, and Zucker
  Phys. Rev. 95, 1617 (1954)
  Absolute P. E. about ±16%.
Mg$^{25}(p, x) Na^{22}(\beta^+) Ne^{22}$

Na$^{22}$ is initially produced by the $(p, n)$ reaction ($Q = -3.15$ Mev). Above about 31 Mev the $(p, 2p2n)$ reaction ($Q = -31.4$ Mev) becomes energetically possible.

○ Cohen, Reynolds, and Zucker
  Phys. Rev. 95, 1517 (1954).
  Absolute P.E. about ±10%.

□ J. W. Meadows and R. B. Holt
  Absolute P.E. ±6% (private communication).

Cohen et al. believe the rise beginning at about 19 Mev to be due to the Mg$^{25}(p, \alpha n)$ reaction.

See also
R. E. Bartell and G. H. Coleman
Phys. Rev. 93, 280 (1954)
F. O. Bartell and S. Sofley
Phys. Rev. 54, 453 (1938)
$^{25}\text{Mg} (p, x) ^{18}\text{F} (\beta^+) ^{18}\text{O}$

$^{18}\text{F}$ is initially produced by the $^{25}\text{Mg} (p, 2p)^{18}\text{F}$ reaction ($Q = -11.6$ MeV). At about 35 MeV other reactions become energetically possible.

- J. W. Meadows and H. B. Holt
  Phys. Rev. 83, 47 (1951)
  Absolute P.E. $\approx 6\%$
  (private communication, J. W. Meadows)

- Cohen, Reynolds, and Zucker
  Phys. Rev. 96, 1817 (1954)
  Absolute P.E. about $15\%$

See also
- F. O. Bardsel and S. Botley
  Phys. Rev. 84, 463 (1951)
$^{25}\text{Mg}(d,p)^{26}\text{Mg}$, $E^* = 1.83$ MeV
Deuteron energy 8.2 MeV
J. R. Holt and T. N. Marsham
Relative angular distribution normalized to measured cross section maxima
Absolute P. E. = ±50\%
Relative P. E. = ±15\%
For relative data see
Endt, Haffner, and Van Patter
Phys. Rev. 86, 518 (1952)
H. R. Allan and C. A. Wilkinson

$^{25}\text{Mg}^{(d,p)}^{26}\text{Mg}$, $E^* = 0.57$ MeV
Halbert et al.
Phys. Rev. 106, 351 (1957)
Absolute P. E. = ±20\%
Relative P. E. = ±15\%

Maximum differential cross sections corrected according to J. R. Holt and
T. N. Marsham, Ibid., 95, 1032 (1955)

<table>
<thead>
<tr>
<th>$E^*$ (MeV)</th>
<th>$\sigma(\theta')$ (mb/sterad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.825</td>
<td>1.0</td>
</tr>
<tr>
<td>2.972</td>
<td>2.5</td>
</tr>
<tr>
<td>3.899</td>
<td>4.2</td>
</tr>
<tr>
<td>4.353</td>
<td>4.7</td>
</tr>
<tr>
<td>6.147</td>
<td>3.0</td>
</tr>
</tbody>
</table>

$^{25}\text{Mg}^{(d,p)}^{26}\text{Mg}$
$^{25}\text{Mg}^{(N^{14},N^{13})}^{26}\text{Mg}$

See also
M. L. Halbert and A. Zucker
Angular distribution at $E_{N} = 27.9$ MeV
$^{24}\text{Na}$ is probably initially formed by the $(p,pd)$ reaction ($Q = -21.0$ Mev) or the $(p,2pn)$ reaction ($Q = -23.2$ Mev)

J. W. Meadows and R. B. Holt
Phys. Rev. 83, 47 (1951)

Absolute P. E. $\pm 6\%$

(J. W. Meadows, private communication)

The authors believe $^{22}\text{Na}$ to be formed primarily by the $(p,2pn)$ reaction ($Q = -42.6$ Mev) although other reactions are energetically possible.

J. W. Meadows and R. B. Holt
Phys. Rev. 83, 1257 (1951)

Absolute P. E. $\pm 6\%$

(J. W. Meadows, private communication)
$^g\text{Mg}^{26}(p, x)^{18}(\beta^+)Q^{18}$

$^g\text{Mg}^{26}$ is probably initially formed by the $(p, 2n)$ reaction ($Q = -22.8$ Mev). At about 40 Mev other reactions become energetically possible.

J. W. Meadows and R. R. Holt  
Phys. Rev. 85, 47 (1951)  
Absolute P. E. = $\pm 9\%$  
(J. W. Meadows, private communications)
E* = 0.99 MeV
Deuteron energy 8.9 MeV
Hinds, Middleton, and Parry
Absolute P.E. = ±50%
See reference for angular distributions of additional energy levels in Mg26

Deuteron energy 8.05 MeV
J. R. Holt and T. N. Marsham
Relative angular distribution normalized to measured maximum cross section (corrected according to Holt and Marsham, Ibid., A66, 1032 (1953))
E* (MeV) σ(θ') (mb/sterad)
gs 27.5
0.99 2.175

Q = 4.21 MeV
Deuteron energy 8.9 MeV
Hinds, Middleton, and Parry
Absolute P.E. = ±50%
See also
M. C. Henderson
Phys. Rev. 46, 855 (1935)
M. D. Kamen
Phys. Rev. 90, 537 (1941)
For relative data see
Endt, Hassner, and Van Patter
Phys. Rev. 96, 518 (1952)
S. R. Allan and C. A. Wilkinson
$^{26}\text{Mg}(d,\alpha)^{24}\text{Na} \quad Q = 2.89 \text{ Mev}$

- K. L. Hall and W. W. Meinke
  J. Inorg. and Nuclear Chem. 9, 192 (1959) or
  K. L. Hall
  Report AECU-3126 (1955)
  Absolute P. E. = ±3%.

$^{26}\text{Mg}(d,\alpha)^{24}\text{Na} \rightarrow^{24}\text{Mg}$ ; $^{26}\text{Mg}(N^{14},N^{13})^{27}\text{Mg}$

- K. L. Hall and W. W. Meinke
  J. Inorg. and Nuclear Chem. 9, 192 (1959) or
  K. L. Hall
  Report AECU-3126 (1955)
  Absolute P. E. = ±3%.

---

$\sigma$, Millibarns

Deuteron Energy, Mev

---

$\sigma$, Millibarns

Nitrogen Energy, Mev

---

See also:
E. T. Clarke and J. W. Irvine, Jr.
Phys. Rev. 90, 680 (1946)
Proton energy 7.55 Mev
W. F. Waldorf and N. S. Wall
Phys. Rev. 107, 1802 (1957)
Absolute P. E. = ±3%
Relative P. E. = ±2%

O Proton energy 9.85 Mev
N. M. Blunt
Phys. Rev. 108, 1201 (1957) and private communication
Absolute P. E. = ±5%
Relative P. E. = ±5%

Proton energy 15.5 Mev
P. C. Gugelot
Phys. Rev. 87, 525 (1953)
Errors as shown

O Proton energy 17.6 Mev
J. E. Dayton and G. Schrank
Phys. Rev. 101, 1358 (1956)
Absolute P. E. = ±3%
Proton energy 18.3 Mev
P. C. Gugelot
Phys. Rev. 87, 525 (1952)
Errors as shown

Proton energy 18.4 Mev
I. E. Dayton
Phys. Rev. 92, 754 (1954) or
Report NYO-6414 (1954)
Absolute P. E. = ±2%

Proton energy 18.6 Mev
J. W. Burkit and B. T. Wright
Phys. Rev. 82, 461 (1951)
Arbitrarily normalized at 50°

Proton energy 22 Mev
B. L. Cohen and R. V. Nestligh
Phys. Rev. 93, 282 (1954)
Absolute P. E. = ±2%
(B. L. Cohen, private communication)

See also
B. E. Kinsey and T. Stone
Phys. Rev. 102, 975 (1956)
Proton energy 30.0 ± 0.4 MeV
R. T. Wright
Report UCRL-2422 (1953)
Absolute P.E. = ±0% (small angles)
=1% (large angles)

Proton energy 30.4 MeV
Levinthal, Martinelli, and Silverman
Phys. Rev. 79, 196 (1950)
Absolute P.E. not stated

Proton energy 31.5 MeV
R. Britten
Phys. Rev. 88, 283 (1952) or
Report NYO-971 (1951)
Absolute P.E. as shown

Proton energy 31.5 ± 0.25 MeV
J. Leaky
Report UCRL-3273 (1956)
Absolute P.E. not stated

Proton energy 92.9 MeV (5° – 20°)
95.7 MeV (20° – 70°)
Gerstein, Niederer, and Strauch
Phys. Rev. 109, 477 (1958) and
G. Gerstein, private communication
Absolute P.E. not stated but should range from a few percent at small angles to a few tens of percent at large angles.
Relative P.E. = ±5%

Proton energy 140 MeV
Richardson et al.
Phys. Rev. 89, 29 (1953) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P.E. = ±5% (the author no longer believes the absolute errors to be quite this small)

See also
Booth et al.
J. M. Cassela and J. D. Lawson
L. E. Bailey
Report HEBR-3354 (1966) and
Report UCRL-3394 (1956)
(protons from high energy proton bombardment of Al)
For excitation functions of elastic scattering see
Bender et al.,
Phys. Rev. 76, 273 (1949)
Shoemaker et al.,
Phys. Rev. 83, 1011 (1951)

\[ A^{27}_1 (p, p') A^{27}_1 \]

\( E^* = 2.21 \text{ Mev} \)
F. D. Seward
Absolute P. E. = \pm 10%
\( Q = -10.8 \)
Proton energy 18.9 Mev
J. D. Reynolds and K. G. Standing
Phys. Rev. 101, 158 (1956)
Relative angular distribution was normalized to the measured absolute
cross section value of 1.3 \( \pm \) 0.4
mb/sterad at \( \theta' = 32^\circ \)
See also
B. L. Cohen and A. G. Rubin
Phys. Rev. 114, 1143 (1959)
$\text{Al}^{27}(p, t)\text{Al}^{25}$

$Q = -15.9$ MeV

- Currie, Libby, and Wolfgang
  Phys. Rev. 101, 1597 (1956)
  Absolute P.E. = ±24%

- L. A. Currie
  Phys. Rev. 114, 878 (1959)
  Absolute P.E. = ±20%

- V. V. Kuznetsov and V. N. Melnikov
  Absolute P.E. = ±20%

See also
L. E. Bailey
Report UCRL-3334 (1956)
\[ \text{C. M. angle } \theta' = 45^\circ (\theta = 45^\circ) \]

Flasche et al.
Phys. Rev. 110, 286 (1958)

Maximum Absolute P.E. = ±15%.

Note: Cross sections are given in the C. M. system.

See also
Kumabe et al.

For relative data
J. M. Freeman and A. S. Baxter
Nature 182, 696 (1948)

Sheenaker et al.
Phys. Rev. 62, 1011 (1951)

\[ \text{Q = 1.60 Mev} \]

Lab angle \( \theta = 90^\circ \)

C. B. Fulmer and C. D. Goodman
to be submitted to Phys. Rev.

Absolute P.E. = ±5%.

Proton energy 8.5 MeV

G. W. Greenlee

\[ \begin{align*}
\text{E}^* \text{ (MeV)} & \quad \sigma \text{(90\(^\circ\)) (mb/sterad)} \\
9.9 & \quad 160 \pm 20\% \\
1.37 & \quad 610 \pm 20\% \\
4.12 + 4.23 & \quad 150 \pm 20\% 
\end{align*} \]

Note suppressed zero.
$^{27}\text{Al} (p, \alpha)^{24}\text{Mg}$

$Q = 1.60 \text{ MeV}$

- Maximum absolute P.E. = $\pm 15\%$


Total cross section at 23 MeV is $175 \pm 50\%$ mb.

$\sigma (\theta)$, Millibarns per Steradian

$E_p = 10.97 \text{ MeV}$

$E_p = 20.81 \text{ MeV}$

Lab Angle of Alpha, $\theta$

C.M. Angle of Alpha, $\theta'$
$^{27}\text{Al} (p, \alpha')^{24}\text{Mg}$

$E^* = 1.368$ MeV

- Proton energy 10.87 MeV
- Proton energy 10.97 MeV

Fischer et al., Phys. Rev. 119, 286 (1960)

Maximum absolute P.E. = ±15%
Al_{27} (p, 3pn) Na_{24} (\beta^-) Mg_{24}

Q = -31.4 MeV

Hicks, Stevenson, and Nervijk
Phys. Rev. 122, 1390 (1961) and
H. G. Hicks, private communication
Absolute P. E. = ±2.5% except for the
point at 35 Mev where the error is ±10%.

Crandall et al.
Absolute P. E. = ±5%

Lev D. Prokoshkin and A. A. Tiapkins
[trans. Soviet Phys. JETP 5, 148 (1957)]
Normalized to Crandall et al. at 350 MeV
See also
L. Marquez and I. Perlman
Phys. Rev. 81, 953 (1951)
Chackett et al.
N. M. Hints and N. F. Ramsey
Phys. Rev. 89, 19 (1953)
Sternnson, Hicks, and Folger
Report UCRL-4371 (1954)

\[ \text{Al}^{27}(p, 3\text{pn})\text{Na}^{24}(\beta^-)\text{Mg}^{24} \]

See previous page

\[ \Delta \text{ L. Marquez}
Phys. Rev. 96, 405 (1952)
Absolute P.E. = ±10% \]

\[ \bullet \text{ Cumming, Friedlander, and Swartz}
Phys. Rev. 111, 1386 (1958) and
R. L. Wolfgang and G. Friedlander
Phys. Rev. 98, 190 (1954) and Phys. Rev. 98, 1871 (1955)
Absolute P.E. = ±6% \]

\[ \Delta \text{ Friedlander, Hudis, and Wolfgang}
Absolute P.E. = ±30% \]

\[ \square \text{ A. Turkevich}
Phys. Rev. 94, 775 (1954)
Absolute P.E. = ±50% \]

Note: Cumming, Friedlander, and Swartz, op. cit., point out that although the line drawn through the experimental points shows a decrease of about 10% from 0.3 to 3 Gev, the results are also consistent with a constant cross section of 10.7 ± 0.6 mb in this energy region.
The graph shows the cross section for the reaction \( \text{Al}^{27} (p, x) \text{Na}^{22}(\beta^+)\text{Ne}^{22} \). The cross section is plotted against proton energy in MeV. Noteworthy observations include:

- X. M. Hints and N. F. Ramsey
  Phys. Rev. 88, 9 (1952)
  Normalized to 775 mb at 11.6 MeV because of remeasurement of monitor reaction
  Relative P. E. = ±5%

- R. E. Bateel and G. H. Coleman
  Absolute P. E. = ±25%
  Relative P. E. = ±5%

- L. Marquez
  Phys. Rev. 99, 405 (1952)
  Absolute P. E. = ±10%

- J. D. Prokoshkin and A. A. Tlapkin
  Normalized to L. Marquez, op. cit.
  Relative P. E. as shown

See also:
- L. Marquez and I. Perlman
  Phys. Rev. 86, 953 (1952)
- R. E. Bateel
  Report LWS-12019 (1951)
- Hudis et al.
  Phys. Rev. 86, 775 (1954)

Cross section for formation of \( \text{Na}^{22} \) obtained from the ratio \( \sigma(\text{Na}^{22})/\sigma(\text{Na}^{24}) \) and the cross section values for the formation of \( \text{Na}^{24} \) by protons on \( \text{Al} \);
  Relative P. E. as shown
Possible reaction mechanisms include:

\[ ^{27}\text{Al}(p,5\alpha)^{18}\text{F} \quad Q = -91 \text{ Mev} \]
\[ ^{27}\text{Al}(p,3\alpha)^{18}\text{F} \quad Q = -45 \text{ Mev} \]
\[ ^{27}\text{Al}(p,2\alpha)^{18}\text{F} \quad Q = -30 \text{ Mev} \]
\[ ^{27}\text{Al}(p,\alpha)^{20}\text{Ne} \quad Q = -24 \text{ Mev} \]

○ N. M. Hintz and N. F. Ramsey
   Phys. Rev. 89, 19 (1953)
   Absolute P. E. = ±20%
   Relative P. E. = ± 3%
   Not adjusted for remeasurement of
   C12(p,\alpha)C11 monitor reaction

△ Chudley et al.
   Cross section ratios \( \sigma(^{19}\text{F})/\sigma(^{24}\text{Na}) \)
   treated as those of Friedlander et al.,
   Absolute P. E. of ratios = ±15%

× L. Marquez
   Phys. Rev. 85, 405 (1952)
   Absolute P. E. = ±15%

○ Friedlander, Hudis, and Wolfgang
   Phys. Rev. 85, 303 (1955)
   Cross section for formation of \( ^{18}\text{F} \)
   obtained from the ratio \( \sigma(^{19}\text{F})/\sigma(^{24}\text{Na}) \)
   and the cross section values for the formation of \( ^{24}\text{Na} \) by protons on Al.
   Relative P. E. as shown

× Hudis et al.
   Phys. Rev. 84, 175 (1954)
   Absolute P. E. = ±50%

See also
   L. Marquez and I. Perelman
   Phys. Rev. 81, 953 (1951)
$^{27}$Al (p,x)$^{13}$N + (0+)C$^{13}$

L. Marquez
Phys. Rev. 85, 405 (1952)
Absolute P. E. = ±15%

Friedlander, Hudis, and Wolfgang:
Cross sections for the formation of $^{13}$N were obtained from the ratios
$\sigma(N^{13})/\sigma(N^{24})$ and the cross section values for the formation of $^{24}$Na by
protons on Al
Relative P. E. as shown

Chackett et al.
Preliminary ratio $\sigma(N^{13})/\sigma(N^{24})$ was
treated as those of the above reference

Hudis et al.
Phys. Rev. 94, 775 (1954)
Absolute P. E. = ±50%

See also
B. L. Cohen
Phys. Rev. 102, 453 (1956)
Al$^{27}(p,x)$O$^{15}$

Friedlander, H及a，and Wolfgang
Phys. Rev. 95, 263 (1955)

Cross sections for the formation of O$^{15}$ were obtained from the ratio $\sigma(p^{12}/p^{16}O^{15})$ and the cross sections values for the formation of N$^{14}$ by protons on Al.

Relative P.E. as shown

Note: The observed 2-minute activity was assumed to be O$^{15}$.

See also
B. L. Cohen
Phys. Rev. 102, 453 (1956)

\[Al^{27}(p,x)O^{15}(\beta^+)N^{15}; \quad Al^{27}(p,x)N^{13}(\beta^+)C^{13}\]
Friedlander, Hudis, and Wolfgang

Cross sections for the formation of
C^{11} were obtained from the ratio
\sigma(C^{11})/\sigma(Na^{24}) and the cross section
values for the formation of Na^{24} by
protons on Al.
Relative P.E. as shown

△ L. Marquez
Phys. Rev. 96, 405 (1953)
Absolute P.E. = ±15%

□ Hudis et al.
Phys. Rev. 94, 775 (1954)
Absolute P.E. = ±50%

JJ. Chackett et al.

Preliminary ratio \sigma(C^{11})/\sigma(Na^{24})
treated as were those of Friedlander,
Hudis, and Wolfgang, op. cit.
Relative P.E. as shown

See also
L. Marquez and I. Perlman
Phys. Rev. B1, 953 (1951)

\begin{align*}
\text{Al}^{27}(p, x) \text{C}^{11} (\beta^+) \text{B}^{11} & ; \text{Al}^{27}(p, x) \text{Be}^{7} (\alpha, \gamma) \text{Li}^{7} \\
\end{align*}

Baker, Friedlander, and Hudis
Phys. Rev. 112, 1319 (1958)

Cross sections are based on a
value of 10.7 ± 0.8 mb for the
\text{Al}^{27}(p, \text{3n}) \text{Na}^{24} monitor re-
solution between 0.4 and 3.0 Gev
Absolute P.E. = ±25%

△ L. Marquez and I. Perlman
Phys. Rev. 81, 953 (1951)

Data not corrected for \(\beta\)-ray
absorption losses
Relative error as shown

△ Hudis et al.
Phys. Rev. 94, 775 (1954)
Absolute P.E. = ±50%

See also
Friedlander, Hudis, and Wolfgang
Q = 9.37 Mev (ground state)
Deuteron energy 9.02 ± 0.06 Mev
Calvert et al.
Relative curves were normalized to measured values \( \sigma(0') = 0.18 \text{ mb/sterad (gs)} \)
and \( \sigma(0') = 0.49 \text{ mb/sterad (E}^* = 1.78 \text{ Mev)} \)
Absolute P.E. = ±35%
Relative P.E. = ±28%

See also
Best et al.
Phys. Rev. 100, 774 (1955)
For relative data see
C. E. Falk
Phys. Rev. 83, 499 (1951)
J. Hughes

E' = 9.3 Mev
Deuteron energy 6.00 ± 0.005 Mev
A. G. Rubin
Phys. Rev. 108, 63 (1957)
Relative curve was normalized to measured value \( \sigma(0') = 31 \pm 8 \text{ mb/sterad} \).
For relative data for other \( Si^{28} \) excited states at bombarding energies \( E_d = 6 \text{ Mev} \) and \( E_d = 2.16 \text{ Mev} \)

\( \sigma(0') \) = 15 mb/sterad
Absolute P.E. = ±30%
Relative P.E. = ±20%
See also
Enge, Angleman, and Jarrell
Report ARCU-337
Bent et al.
Phys. Rev. 100, 774 (1955)
H. E. Gove
Phys. Rev. 81, 364 (1951)
E. McMillan and C. O. Lawrence
Phys. Rev. 47, 345 (1935)

For relative data see
J. R. Holt and C. T. Young
Lawrence, McMillan, and Thornton
Phys. Rev. 48, 405 (1935)

Q = 5.5 Mev
Deuteron energy 8 Mev
J. R. Holt and T. N. Marsham
and Ibid. A69, 1032 (1953)

Estimates of the absolute cross sections were made by comparing the intensity of the \(d,p\) proton groups with the intensity of the deuteron scattered elastically from the target at an angle of 50° and assuming the latter cross section to be due entirely to Rutherford scattering.
\[ \text{Al}^{27}(d,d')\text{Al}^{27} \; ; \; \text{Al}^{27}(d,2p)\text{Mg}^{27}(\beta^-)\text{Al}^{27} \]

- Energy \( E_d = 4.07 \) MeV
- Energy \( E_d = 3.73 \) MeV
- Energy \( E_d = 3.32 \) MeV

See also:

Errors as shown. These do not include errors in the \( \text{Al}^{27}(d,x)\text{N}^{24} \) monitor reaction as measured by R. E. Bates and G. E. Coleman, Phys. Rev. 93, 280 (1954)
E. T. Clarke, Phys. Rev. 71, 187 (1947)

Possible reaction mechanisms include $\text{Al}^{27}(d, p)\text{Na}^{24}(Q = -5.4 \text{ MeV})$ and $\text{Al}^{27}(d, \alpha)\text{Na}^{24}(Q = -33.7 \text{ MeV})$

$\text{Baixel, Crane, and O'Kelley}$
Phys. Rev. 91, 939 (1953) or Report MTA-26 (1953)
P.E. = ±10% or less

$\text{Crandall et al.}$
Absolute P.E. = ±1% or less

$\text{N. W. Hubbard}$
Phys. Rev. 75, 1470(A) (1949)
Absolute P.E. as shown
Authors believe the reaction mechanism to be \( \text{Al}^{27}(d,x)\text{Na}^{22}(\beta^{+})\text{Ne}^{22} \) (Q = -22.5 Mev)

S. O. Ring and L. M. Lits

Authors obtained cross section values by comparing Na\(^{22}\) and Na\(^{24}\) activities and normalizing to the cross section values for the formation of Na\(^{24}\) by protons on Al measured by Batsel, Crane, and O'Kelley, Phys. Rev. \textbf{81}, 939 (1951)

Broken portion of the curve is the authors' "guess". They believe the cross section to be too low in this energy region.
See also
C. E. Hunting and N. S. Wall
Phys. Rev. 106, 904 (1957)

For relative data see
P. von Herrmann and G. F. Pieper
Phys. Rev. 109, 1556 (1957)
(Alpha energy 7.1 and 8.1 Mev)
Roy, Quequin, and Janssens
Report NP-5547 (1951)
(Alpha energy 4.0 and 4.44 Mev)
W. E. Duncan and H. Miller
Figure: Al\textsuperscript{27}(α, α)Al\textsuperscript{27}

- Alpha energy 18.7 Mev
- Alpha energy 19.5 Mev
- Alpha energy 18.95 Mev

Gailar, Bleuler, and Tendam
Phys. Rev. 112, 1949 (1950) and
E. Bleuler, private communication
Absolute P.E. = ± 20% or less
See reference for inelastic scattering

E. Bleuler and D. J. Tendam
quoted in the above reference
Absolute P.E. not stated
\[ \text{Al}^{27} (\alpha, \alpha) \text{Al}^{27} \]

Alpha energy 40 MeV
Eisberg, Igo, and Wegner
Phys. Rev. 99, 1066 (1955)
Energy resolution = 4% 
Angular resolution = ±1.0°
Absolute P.E. = ±10% 
See also
Igo, Wegner, and Eisberg
Phys. Rev. 101, 1598 (1956)
$\text{Al}^{27}(\alpha, x) \text{Na}^{24}(\beta^-) \text{Mg}^{24}$

$\text{Na}^{24}$ is probably formed initially by the $\text{Al}^{27}(\alpha,\alpha')\text{Na}^{24}$ ($Q = -2.37$ Mev) reaction. Other reaction mechanisms are also energetically possible: $\text{Al}^{27}(\alpha,\alpha'p)\text{Na}^{24}$ ($Q = -2.53$ Mev), $\text{Al}^{27}(\alpha,\alpha'n)\text{Na}^{24}$ ($Q = -3.15$ Mev), and $\text{Al}^{27}(\alpha,p3n)\text{Na}^{24}$ ($Q = -5.98$ Mev).

Crandall et al.
Phys. Rev. 101, 320 (1956)
Absolute P. E. = +5.5% -4%

O. M. Linder and R. N. Osborne
Phys. Rev. 91, 342 (1953)
No error stated...may be considered normalised to the above reference.

See also
H. Chang Fung
Report UCRL-1465
$Q = -2.8 \text{ Mev}$

Webb, Reynolds, and Zucker
Phys. Rev. 102, 749 (1956)
Absolute P.E. = ±30%

Volkov, Pasuk, and Flerov
[trans. Soviet Phys. JETP 6, 459 (1956)]

See also
K. F. Chackett and J. H. Fremlin
Phil. Mag. 45, 725 (1954)

Note suppressed zero
Greenlee et al.
Absolute P.E. = ±5%
See reference for similar distributions
at 9.38 and 9.45 MeV

See also
D. R. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)
Rubin, Bailey, and Passell
Phys. Rev. 113, 1110 (1959)

Proton energy 340 Mev
Richardson et al.
Phys. Rev. 89, 29 (1953) or
R. E. Richardson
Report UCRL-1408 (1951)
Absolute P.E. = ±5%
(The author no longer believes
the errors to be quite this
small - private communication,
R. E. Richardson)
Angular resolution = ±1/2°
$\Sigma^{28}(p, p') \Sigma^{28}$

$E^* = 1.78$ Mev
Lab angle $\theta = 90^\circ$
Yamabe et al.
Absolute P.E. = ±20%.

See also
Okada et al.
Willard et al.
Ball. Am. Phys. Soc. 1, 204 (1956)

Note suppressed zero

Proton Energy, Mev

$\sigma(90^\circ)$, Millibarns per Steradian

$\sigma(\theta)$, Millibarns per Steradian

C.M. Angle of Proton, $\theta'$

Total cross sections
$E_p$ (MeV) $\sigma$ (mb)
5.3 211
5.4 466
5.5 443

$E_p = 5.4$ Mev
Absolute P.E. = ±20%.

$E_p = 5.5$ Mev

$E_p = 5.3$ Mev
$\text{Si}^{28} (p, p') \text{ Si}^{28}$

$E^* = 1.78 \text{ MeV}$

Greenlees et al.

Absolute P.E. = ±3%
Angular resolution = ±30'

See reference for similar data at
$E_p = 5.55$ and $8.28$ Mev

See also
P. D. Seward
Phys. Rev. 114, 514 (1959)
\[ \sigma(\theta), \text{ Millibarns per Steradian} \]

\[ \sigma(\theta')', \text{ Millibarns per Steradian} \]

Lab Angle of Proton, \( \theta \)

C.M. Angle of Proton, \( \theta' \)

\( E^* = 1.78 \text{ MeV} \)
Proton energy 11.84 ± 0.15 MeV
H. E. Consett
Phys. Rev. 109, 1224 (1957)
Absolute P. R. = ±3.4 - 6.8%
Total cross section \( \sigma = 154.8 ± 4.4 \text{ mb} \)
For relative data see
J. Hughes

\[ Q = 0.50 \text{ MeV} \]
Deuteron energy 9 MeV

Calvert, Jaffe, and Maslin

Absolute P.E. = ±0.5% 
Relative P.E. = ±1%

Relative angular distributions were normalized to measured cross section values:

\begin{align*}
E^* \text{ (MeV)} & \quad \sigma(\theta) \text{ (mb/steradian)} \\
0 & \quad 28 (0^\circ) \\
1.3 & \quad 7.5 (0^\circ) \\
1.9 & \quad 7.0 (0^\circ) \\
2.5 & \quad <3.0 (15^\circ) \\
3.0 & \quad <4.0 (15^\circ) \\
3.5 & \quad <9.5 (15^\circ)
\end{align*}
For relative data see
I. B. Teplov and B. A. Luz'nev
[trans: Soviet Phys. JETP 7, 233 (1958)]

Ju. A. Nemilov and V. F. Litvin
[trans: Soviet Phys. JETP 5, 696 (1957)]

Takezumi, Dazai, and Suganuma

\[ Q = 6.25 \text{ Mev} \]
Deuteron energy 8.2 Mev

J. R. Holt and T. N. Marsham

Relative angular distributions were normalized to measured maximum cross section values.

\begin{align*}
E^* & \quad \sigma (\text{mb/steradian}) \\
0.16 & \quad 62 \\
0.20 & \quad 4.6 \\
0.43 & \quad 0.24 \\
0.70 & \quad 1.2 \\
1.00 & \quad 4.0 \\
4.93 & \quad 5.5 \\
\end{align*}

Absolute P. E. = ± 50% 
Relative P. E. = ± 10%
See reference for similar angular distributions at other bombarding energies between 2.9 and 3.3 Mev

Deuteron energy (Mev)

- 2.882 ± 0.005
- 3.100 ± 0.004
- 3.197 ± 0.004

Absolute P.E. = ±30%
Relative P.E. = ±5%

See reference for similar angular distributions at other bombarding energies between 2.9 and 3.3 Mev

Deuteron energy (Mev)

- 2.799 ± 0.005
- 2.882 ± 0.005
- 3.008 ± 0.004
- 3.077 ± 0.004
$^{28}\text{Si} (d, d')^{28}\text{Si}$

$E^* = 1.78$ Mev
Deuteron energy 8.9 Mev
Hinds, Middleton, and Parry
Absolute P. E. = ±25%
$^{28}\text{Si} (p, 2p) A^{28} \text{Al} (\beta^-) ^{28}\text{Si}$

$Q = -12.3$ Mev

B. L. Cohen
Phys. Rev. 102, 453 (1956)

Absolute P. E. = ±25%
Relative P. E. = ±10%
(private communication)
Cross section for $^29_{\text{Si}}(d, p)^{30_{\text{Si}}}$

$E^* = 2.24$ MeV is $\sigma = 1.55$ mb/sterad

at $\theta = 38^\circ$

First excited state of $^{30}_{\text{Si}}$ ($E^* = 3.24$ MeV) and $^{29}_{\text{Si}}$ ground state from $^{28}_{\text{Si}}(d, p)^{29_{\text{Si}}}$

$Q = 8.4$ MeV
Deuteron energy 4.3 MeV

V. G. Sukharevskii
[trans: Soviet Phys. JETP 9, 37 (1959)]

Absolute P.E. = +40%
$\text{Si}^{29}(\alpha,n)\text{S}^{32}, \text{S}^{32^*}$

$Q = -1.52$ Mev

J. H. Gibbons and R. L. Macklin
Phys. Rev. 114, 571 (1959)

Absolute P. E. = ±7%
(private communication, J. H. Gibbons)

Note: The author states, "For alpha energies less than 4.3 Mev, all neutrons lead to the ground state of S^{32}..."
\( \text{p}^{31}(d, p)^{32} \)
\( Q = 5.71 \text{ MeV} \)
Deuteron energy 4 MeV

Calvert et al.

Absolute P. E. = ±50%
Relative P. E. = ±20%

See also
Bent et al.
Phys. Rev. 106, 774 (1957)

For relative data see
F. A. El Bedewi and M. A. El Wahab

\( \text{p}^{31}(d, p)^{32} \)
\( Q = 5.71 \text{ MeV} \)
Deuteron energy 4 MeV

I. B. Teplov
[trans: Soviet Phys. JETP 4, 31 (1957)]

Absolute P. E. "several tens of percent" and
I. B. Teplov and B. A. Iar'ev
[trans: Soviet Phys. JETP 7, 233 (1958)]

Absolute P. E. = ±20-40%

See also
Bent et al.
Phys. Rev. 106, 774 (1957)

M. D. Kames
Phys. Rev. 67, 537 (1941)

For relative data see
Dalton, Hind, and Parry

W. C. Parkinson
Phys. Rev. 110, 485 (1958)

Parkinson, Beach, and King
Phys. Rev. 87, 387 (1952)
\[ p^{34}(a, p) S^{34} \]

\( Q = 0.63 \text{ Mev} \)

Alpha energy 30.4 Mev

C. E. Hasting and N. S. Wall

Phys. Rev. 115, 956 (1959)

Absolute P. E. = +200% 
-70%

See also

C. E. Hasting and N. S. Wall


For relative data see

P. von Herrmann and G. F. Pieper

Phys. Rev. 109, 1986 (1958)

(Alpha energies 7.0 and 8.1 Mev)
$S^{32}(p,p)S^{32}$

C. M. angle $\theta' = 63.9^\circ$

Obens, Haefeli, and Lewis
Phys. Rev. 112, 1702 (1958)
Absolute P. E. $\pm 5\%$
$S^{32}_{(p,p)}S^{32}$

Oines, Hasen, and Lewis
Phys. Rev. 119, 1792 (1958)
Absolute P. E. = ±5% except at
$\theta'' = 187.8^\circ$ where the error
is ±3%.

C. M. angle $\theta'' = 125.5^\circ$

$\theta'' = 141.0^\circ$

$\theta'' = 167.8^\circ$

Proton Energy, Mev
See also
B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)

$E_p = 340$ Mev

Richardson et al.
Phys. Rev. 85, 29 (1952) or
R. E. Richardson
Report UCRL-1468 (1951)

Absolute P. E. = ±5%
(The author no longer believes
the error to be quite this low--
private communication, R. E.
Richardson)
Angular resolution = ±1/2°
$^{32}\text{(d,p)}^{33}\text{S}$

- $Q = 5.41$ MeV
- Deuteron energy 4 MeV
- I. B. Teplov and B. A. Iur'ev
- Absolute P.E. 30-40%

**Total cross sections**

<table>
<thead>
<tr>
<th>$E_g$ (MeV)</th>
<th>$E^*$ (MeV)</th>
<th>$\sigma$ (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>0, 0.077</td>
<td>22.6</td>
</tr>
<tr>
<td>4.0</td>
<td>0</td>
<td>13.4</td>
</tr>
<tr>
<td>2.2</td>
<td>0</td>
<td>5.25</td>
</tr>
<tr>
<td>1.3</td>
<td>0</td>
<td>0.23</td>
</tr>
<tr>
<td>4.0</td>
<td>0.04</td>
<td>11.0</td>
</tr>
</tbody>
</table>

See also:
- P. W. Davison
  Phys. Rev. 75, 757 (1949)

For relative data see:
- J. R. Hoit and T. N. Marsham
- Teplov, Iur'ev, and Markelova
  (trans. Soviet Phys. JETP 5, 134 (1957))
$^{32}$S($^{14}$N, p)$^{34}$S, 2$p$+$^{34}$Mg)

This cross section is given as the sum of the cross sections for the formation of $^{32}$S($^{14}$N, p)$^{34}$S ($Q = 1.55$ MeV) and of $^{32}$S($^{14}$N, 2$p$)$^{34}$Mg ($Q = 1.8$ MeV).

---

$^{32}$S($^{14}$N, p)$^{34}$S, 2$p$+$^{34}$Mg)

$Q = 0.868$ MeV

$^{32}$S($^{14}$N, p)$^{34}$S, 2$p$+$^{34}$Mg)

$Q = 1.90$ MeV

Fisher, Zucker, and Gropp
Phys. Rev. 113, 542 (1959) or
D. E. Fisher
Report ORNL-2525 (1958)

Absolute P.E. not stated. The cross sections were obtained by differentiating the smooth curves drawn to fit the experimental yield points. The errors in the absolute yields were on the order of 20%.
$^{34}(p, p) ^{34}(\beta^+) ^{34}; ^{34}(d, a) P^{32}$

$Q = -6.17$ Mev

N. M. Hintz and N. F. Ramsey
Phys. Rev. 85, 19 (1952)

Relative P. E. = ±5%.

Note: These data have not been adjusted for a remeasurement of the $^{12}(p, p)c^{11}$ monitor reaction -- see Crandall et al., Phys. Rev. 101, 328 (1956)

M. D. Kamen
Phys. Rev. 69, 537 (1941)

Error as shown

$^{34}(d, a) P^{32}$

K. L. Hall
Report AECL-3136 (1955) or
K. L. Hall and W. W. Meinke
J. Inorg. and Nuclear Chem. 9, 193 (1959)

$\sigma = 0.3 \pm 0.2$ barn at $E_p = 7.7 \pm 0.1$ Mev
Deuteron energy 4 Mev

J. E. Teplov
[trans: Soviet Phys. JETP 4, 31 (1957)]
Absolute P.E. "several tens of percent"

For relative data see
J. S. King and W. C. Price
Phys. Rev. 81, 141 (1951)

$E^* = 1.6$ Mev

$C_1^{36}(d,p')C_1^{36}$; $C_1(p,x)F^{18}(\beta^0)O^{18}$

$Q = 6.35$ Mev
Deuteron energy 4 Mev
L. B. Teplov and B. A. Grinev
[trans: Soviet Phys. JETP 7, 233 (1958)]
Absolute P.E. = 30-40%
Total cross section $\sigma = 2.9$ mb

$C_1(p,x)F^{18}(\beta^0)O^{18}$
L. Marquez
Phys. Rev. 85, 401 (1952)
$\sigma = 2.2$ mb at $E_p = 420$ Mev

95
A^{36}(\alpha,p)K^{39} ; A(p,p)A

- Proton energy 9.51 Mev
  Gibson, Prowse, and Rothblatt
  Absolute P.E. = +5%

- Proton energy 9.72 Mev
  N. M. Hints
  Absolute P.E. = +5-7%

- Proton energy 0.98 Mev
  Bashkin, Carlson, and Douglas
  Phys. Rev. 114, 1543 (1959)
  $\sigma(90^\circ) = 479 \pm 15$ mb/sterad

See also:
- Freier et al.
  Phys. Rev. 110, 446 (1958)
- B. B. Kinsey and T. Stone
  Phys. Rev. 103, 975 (1956)
- Freemantle et al.
  Phys. Rev. 95, 1270 (1954)

A^{36}(\alpha,p)K^{39} \quad Q = -1.29$ Mev
Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)
$\sigma(90^\circ) = 8.5 \pm 35%$ mb at $E_{\alpha} = 7.4$ Mev
\[ \sigma(\theta), \text{ Millibarns per Steradian} \]

- For \( E_p = 9.0 \text{ MeV} \), \( \sigma(\theta) \) is observed across different \( \theta \) values.
- For \( E_p = 8.5 \text{ MeV} \), \( \sigma(\theta) \) is also observed across different \( \theta \) values.
- For \( E_p = 9.51 \text{ MeV} \), \( \sigma(\theta) \) is observed across different \( \theta' \) values.

**Notes:**
- See also Freiman et al., Phys. Rev. 96, 1270 (1954)
- Absolute F. E. = ±5%
- R. M. Eisberg and N. M. Hintz, Phys. Rev. 103, 645 (1956)
- "The flags represent an estimate of the over-all accuracy of the data"
$Q = 3.87$ Mev
Deuteron energy 7.81 Mev

W. M. Gibson and E. E. Thomas

Absolute P. K. = ±18%,
(W. M. Gibson, private communication)

For relative data see
A. H. Snell
Phys. Rev. 49, 555 (1936)
$A(d, d)A; A^{40}(a, n)Ca^{43}; A^{40}(a, p)K^{43}$

$A^{40}(a, n)Ca^{43}$ $Q = -2.3$ Mev
Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)

$\sigma(\theta') = 33.0 \pm a factor of 2 \text{ mb}$

at $E_a = 7.4$ Mev

$A^{40}(a, p)K^{43}$ $Q = -3.3$ Mev
Schwartz, Corbett, and Watson
Phys. Rev. 101, 1370 (1956)

$\sigma = 0.25 \pm 0.5 \text{ mb}$ at $E_a = 7.4$ Mev

See also
Tanaka of AI
Report NR-4032 (1958)
See also
G. Brubaker
Phys. Rev. 54, 1011 (1938)

$E_\alpha = 18$ Mev

Alpha energy 18 Mev
Seidlitz, Bleuler, and Tondani
Phys. Rev. 110, 682 (1958)
Absolute P.E. = ±22%

Alpha energy 40 Mev
A. I. Yavin and G. W. Farwell
Nuclear Physics 12, 1 (1959)
Absolute P.E. = ±20%
\[ \sigma(\theta), \text{Millibarns per Steradian} \]

\[ \sigma(\theta'), \text{Millibarns per Steradian} \]

**E^* = 1.46 Mev**

- Alpha energy 18 Mev
  - Städtitz, Bleuler, and Tendam
  - Phys. Rev. 115, 682 (1959)
  - Absolute P.E. = ±2-2%  
- Alpha energy 40 Mev
  - A. I. Yavin and G. W. Farwell
  - Nuclear Physics 10, 1 (1959)
  - Absolute P.E. = ±30%
For relative data see
Enge, Irwin, and Wessler
Phys. Rev. 115, 940 (1959)

Q = 5.57 Mev
Deuteron energy 4 Mev
I. B. Teplov and B. A. Tu'rev
[trans. Soviet Phys. JETP 6, 1011 (1958)]
Absolute P.E. = ±30 - 40%
See reference for similar angular distribution
of another proton group corresponding to
several levels in K30.

$E^* = 0.80$ and 0.89 Mev
Total cross section $\sigma = 13$ mb

$E^* = 6s$ and 0.031 Mev
Total cross section $\sigma = 12$ mb
Note: The observed residual nuclides are all positron emitters.

Absolute P. E. = ±30%
Proton energy 182 MeV
H. Tyree and Th. A. J. Math
Nuclear Phys. 4, 637 (1957)
Absolute P.E. = ±20% (solid curve)
±50% (dashed curve)

E' = 1.0 MeV

E' = 3.7 ± 0.3 MeV
(total cross section σ = 6.4 mb)

Lab Angle of Proton, θ
Note: The C.M. cross section is given.

Q = 6.13 Mev
L. L. Lee, Jr. and J. P. Schiffer
Phys. Rev. 107, 1340 (1957)
Absolute P.E. = ±30%

Note: These curves were taken from very small journal figures. Anyone desiring detailed cross section information is urged to consult the reference.
Relative angular distributions were normalized to measured maximum cross section values.

\[ E^* \text{ (MeV)} \quad \sigma \text{ (mb/sterad)} \]

- 0.9 ± 0.05 3.8 ± 20%
- 1.9 ± 0.05 23.0 ± 20%
- 2.42 ± 0.05 10.0 ± 20%
- 3.96 ± 0.05 6.0 ± 20%
- 4.76 ± 0.08 7.2 ± 20%
- 5.72 ± 0.08 7.8 ± 20%

See also:
C. K. Bockelman and W. W. Buechner
Phys. Rev. 107, 1366 (1957)

Angular distribution of proton group corresponding to \( E^* = 5.72 \text{ MeV} \) is very similar to that corresponding to \( E^* = 4.76 \text{ MeV} \).
$^{45}$Sc$^{(p, pn)}$ $^{44,44m}$

$Q = -11.3$ Mev

Meadows, Diamond, and Sharp
Phys. Rev. 102, 190 (1956)

Absolute P. E. = ± 15%.
Relative P. E. = ± 4%

Note: The activities of the residual nuclei were observed.

See also
S. M. Bailey
Report UCRL-8710 (1959)
\[ \text{Ti}^{46,47}(d,p)\text{Ti}^{47,48}; \text{Ti}^{47}(p,n)\text{V}^{47}(\beta^+)\text{Ti}^{47}; \text{Ti}^{48}(p,n)\text{V}^{48}(\beta^+)\text{Ti}^{48} \]

Deuteron energy 14 MeV
J. A. Harvey
Phys. Rev. 81, 353 (1951)

Target 
\[ \text{Q} = 0.06 \pm 0.02 \%
\]
\[ \text{Ti}^{47} = 2.5 \pm 1.0 \text{ mb/sterad} \]

For relative data see
W. W. Fratt
Phys. Rev. 97, 131 (1955)
L. L. Lee, Jr. and W. Rall
Phys. Rev. 99, 1384 (1955)
Bretcher et al.
Phys. Rev. 98, 103 (1954)

S. Tanaka and M. Furukawa

Representative absolute error shown (this does not include possible uncertainty in the "nuclear data" used)

See also
R. D. Albert
Phys. Rev. 115, 925 (1959)
Kondo et al.
Absolute P.E. = ±12%

—W. F. Waldorf and N. S. Wall
Phys. Rev. 107, 1602 (1957)
Absolute P.E. = ±5% if Au(p,p)Au
is entirely Rutherford

See also
Rubin, Bailey, and Passell
Phys. Rev. 115, 1110 (1959)
B. W. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)

Hu et al.
Report NSJ-20 (1959) also
Hu et al.
J. Phys. Soc. Japan 14, 661 (1959) and
Kikutani, Kobayashi, and Matsuda
Absolute P.E. = ±10%
Note: The data was originally given as a function of C.M. energy. The transformation back to laboratory proton energy was made non-relativistically. The C.M. energy scale is indicated by the tick marks.

Horizontal bars indicate target thickness.

E* = 0.90 Mev
F. D. Seward
Phys. Rev. 111, 514 (1958)
Absolute errors not stated: the inelastic proton scattering from Ti_{48} at 90° was monitored by elastic scattering from Au at 25°. The elastic scattering was assumed to be entirely Coulomb. The errors should, therefore, be 10% or less.
Proton energy 5.43 MeV
F. D. Seward
Phys. Rev. 114, 514 (1959)
Absolute P.E. not stated (see note on previous page)
See reference for relative angular distribution at $E_p = 7.02$ MeV

$E^* = 0.99$ MeV

- Proton energy 12.2 MeV
- Proton energy 14.3 MeV

Hu et al.
Report INRJ-20 (1959) also
Hu et al.
J. Phys. Soc. Japan 14, 861 (1959) and
Kikuchi, Kobayashi, and Matsuda
Absolute P.E. = ±10%
See also
B. L. Cohen and A. G. Rubin
Phys. Rev. 113, 579 (1959)

**Note:** This data includes a 10% contribution from the first excited state of Ti$^{48}$
Ti(\(p,\alpha\))Sc; Ti\(^{48}\) (d,p) Ti\(^{49}\)

\[ Q = -2.34 \text{ MeV (see note)} \]
Lab angle \(\theta = 90^\circ\)
C. B. Palmer and C. D. Goodman
to be submitted to Phys. Rev.
Absolute P.E. less than 5\%

For relative data see
W. W. Pratt
Phys. Rev. 97, 131 (1955)
L. L. Lee, Jr. and W. Pratt
Phys. Rev. 99, 1384 (1955)
Breitweiser et al
Phys. Rev. 96, 103 (1954)

Note: A target of normal isotopic composition was used. The Q-value is a weighted average of the values for the stable isotopes of Ti.
$^{48}\text{Ti}^{(d,2n)}\rightarrow ^{48}\text{V}^{(\beta^+)}\rightarrow ^{48}\text{Ti}$

$Q = -7.04$ Mev

Burgess et al.,
Phys. Rev. 95, 750 (1954) or
Report UCRL-4923 (1954)

Absolute P.E. = ±10% (this does not include the possible errors in the values taken for the ratio $\beta^+$/K-capture)

Note: The dashed portion of the curve is thought to be due to $^{48}\text{Ti}^{(d,n)}$ reaction.
\[ Ti(d,d)Ti; \quad Ti^{48}(d,\alpha)Sc^{46}; \quad Ti(\alpha,\alpha)Ti \]

**Ti(d,d)Ti**

J. Sloan and W. P. Alford
Phys. Rev. 114, 1054 (1959) and
J. Sloan, private communication
Absolute P.E. = \pm 3\% if scattering from Au is entirely Rutherford

\[ E_d = 3.32 \text{ Mev} \]

\[ E_d = 4.07 \text{ Mev} \]

\[ \frac{\sigma}{\sigma_R} \]

C.M. Angle of Deuteron, $\theta'$

**Ti^{48}(d,\alpha)Sc^{46}**

Q = 3.98 Mev

K. L. Hall
Report ANL-3365 (1955) or
K. L. Hall and W. W. Melnik
J. Inorg. and Nuclear Chem. 9, 193 (1959)
\[ \sigma = 0.44 \pm 0.33 \text{ mb at } E_d = 7.0 \text{ Mev} \]

\[ \frac{\sigma}{\sigma_R} \]

C.M. Angle of Alpha, $\theta'$
$V^{51}(p,n)Cr^{51}, Q = -1.53 \text{ MeV}$

- R. A. Alberi, private communication
  Absolute P.E. = ±15%

- S. Tanaka and M. Purakawa
  Representative Abs. P.E. shown
  (Cr$^{51}$ decay γ was observed)

For relative data see:
- Baker et al.
  Phys. Rev. 81, 48 (1951)
- Richards, Smith, and Browne
  Phys. Rev. 89, 524 (1950)
- Gibbons, Markin, and Schmitt
  Phys. Rev. 105, 167 (1956)

$V(p,p')V$

- C. A. Presskill, Jr. and W. P. Alford
  Report NYO-2172 (1958) or
  Phys. Rev. 115, 389 (1959)
  Absolute P.E. = ±2% (est.)

See also:
- Mark, McClelland, and Goodman
  Phys. Rev. 98, 1245 (1955)
- B. B. Kinsey and T. Stone
  Phys. Rev. 103, 975 (1956)
- B. L. Cohen and A. G. Rubini
  Phys. Rev. 113, 579 (1959)
\[ \sigma / \sigma_0 \]

\( E_p = 6.23 \text{ MeV} \)

\( E_p = 6.03 \text{ MeV} \)

\( E_p = 5.78 \text{ MeV} \)

\( E_p = 5.31 \text{ MeV} \)

C.M. Angle of Proton, \( \theta' \)

\[ \sigma / \sigma_0 \]

\( E_p = 14 \text{ MeV} \)

\( E_p = 6.52 \text{ MeV} \)

C.M. Angle of Proton, \( \theta' \)

---

V. (p, p)V

- C. A. Preskill and W. P. Alford
  Absolute P.E. = \( \pm 2 \% \) (est.)

- C. D. Schrader
  Report UCRL-4507 (1955)
  Absolute P.E. = \( \pm 50 \% \)
\[ V^{31}(p,a)T^{48}, V(p,x) \]

Proton energy 170 Mev (most probable energy)

G. Rudstam
Report NP-4391 (1956) also
Phil. Mag. 44, 1131 (1955)
(first reference contains values corrected
for new monitor cross section values)

The absolute error given for each measurement
includes 15% error in the absolute monitor.

Proton energies 60, 100, 175, and 240 Mev
C. G. Heisinger and E. O. Wilg
Phys. Rev. 101, 1074 (1956)

\[ V(p,x) \] (b activity of product nuclides was observed)

\[ V^{31}(p,a)T^{48}, V(p,x) \]

CROSS SECTION FOR NUCLEI PRODUCTION IN MILLIBARNS

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>60 Mev</th>
<th>100 Mev</th>
<th>170 Mev</th>
<th>175 Mev</th>
<th>240 Mev</th>
</tr>
</thead>
<tbody>
<tr>
<td>C^49</td>
<td>81 ±19</td>
<td>17 ±3</td>
<td>1.7 ±0.4</td>
<td>7±1</td>
<td>2.8 ±0.5</td>
</tr>
<tr>
<td>C^48</td>
<td>5.3 ±0.9</td>
<td>2.1 ±0.8</td>
<td>0.22 ±0.07</td>
<td>0.36</td>
<td>0.28±0.05</td>
</tr>
<tr>
<td>V^46</td>
<td>83 ±4</td>
<td>37 ±4</td>
<td>23 ±4</td>
<td>17 ±4</td>
<td>15 ±4</td>
</tr>
<tr>
<td>V^45</td>
<td>...</td>
<td>4.3 ±0.9</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>T^45</td>
<td>2.4 ±0.5</td>
<td>5.8 ±1.4</td>
<td>6.8 ±1.3</td>
<td>6.2 ±1.7</td>
<td>10 ±4</td>
</tr>
<tr>
<td>Be^48</td>
<td>3.2 ±1.9</td>
<td>11 ±2</td>
<td>7.6 ±1.6</td>
<td>6.3 ±1.1</td>
<td>7.8 ±1.4</td>
</tr>
<tr>
<td>Be^47</td>
<td>11 ±6</td>
<td>10 ±2</td>
<td>12 ±4</td>
<td>8.4 ±3.0</td>
<td>8.4 ±2.3</td>
</tr>
<tr>
<td>Be^46</td>
<td>10 ±6</td>
<td>5.8 ±1.7</td>
<td>4.4 ±1.7</td>
<td>8.0 ±2.5</td>
<td></td>
</tr>
<tr>
<td>Sc^44</td>
<td>0.05</td>
<td>20 ±6</td>
<td>9.4 ±2.5</td>
<td>7.3 ±4.0</td>
<td>13 ±4</td>
</tr>
<tr>
<td>Ca^47</td>
<td>0.011</td>
<td>0.09±0.02</td>
<td>0.087±0.019</td>
<td>0.07±0.04</td>
<td>0.14±0.06</td>
</tr>
<tr>
<td>Ca^46</td>
<td>0.33</td>
<td>1.0±0.2</td>
<td>2.5 ±0.6</td>
<td>1.0 ±0.4</td>
<td>1.7 ±0.7</td>
</tr>
<tr>
<td>K^42</td>
<td>0.8 ±0.2</td>
<td>0.7</td>
<td>2.0 ±0.6</td>
<td>1.0 ±0.6</td>
<td>4.1 ±0.9</td>
</tr>
<tr>
<td>Na^28</td>
<td>0.13±0.13</td>
<td>0.6</td>
<td>3.8 ±0.8</td>
<td>3.8 ±1.2</td>
<td>7.0 ±1.2</td>
</tr>
<tr>
<td>Mg^27</td>
<td>0.009</td>
<td>0.26±0.002</td>
<td>0.25 ±0.005</td>
<td>0.20±0.008</td>
<td>1.6 ±0.9</td>
</tr>
<tr>
<td>Ca^26</td>
<td>0.024 ±0.01</td>
<td>0.18±0.02</td>
<td>0.60 ±0.13</td>
<td>1.0 ±0.6</td>
<td>2.4 ±1.1</td>
</tr>
<tr>
<td>C^24</td>
<td>...</td>
<td>0.025±0.003</td>
<td>...</td>
<td>0.7 ±0.3</td>
<td></td>
</tr>
<tr>
<td>O^18</td>
<td>0.99</td>
<td>4.6 ±0.13</td>
<td>0.22±0.08</td>
<td>0.4 ±0.2</td>
<td></td>
</tr>
<tr>
<td>P^31</td>
<td>0.89</td>
<td>0.89±0.08</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S^32</td>
<td>...</td>
<td>0.39 ±0.09</td>
<td>0.23±0.06</td>
<td>0.9 ±0.3</td>
<td></td>
</tr>
<tr>
<td>Cl^35</td>
<td>...</td>
<td>0.16 ±0.04</td>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kr^35</td>
<td>...</td>
<td>0.002</td>
<td>0.008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xe^36</td>
<td>0.019±0.003</td>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cs^37</td>
<td>0.004</td>
<td>...</td>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba^141</td>
<td>...</td>
<td>0.004</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Note suppressed zero.
$V^{51}(d,p)V^{52}, V^{51}(d,d) V^{51}$

For relative data see
F. A. El Bedewi and S. Tadros
Nuclear Phys. B, 71 (1958)
J. S. King and W. C. Parkinson
Phys. Rev. 99, 1080 (1955)

$V^{51}(d,d')V^{51}$
I. Stias and W. P. Allford
Phys. Rev. 114, 1094 (1959) and
I. Stias, private communication
Absolute P. E. = ±3%
B. Linder and R. A. James
Phys. Rev. 114, 322 (1959)
Absolute P.E. ~ ±30-40% 

See also
Boehm, Marmier, and Preiswerk

S. Tanaka and M. Furukawa
Representative absolute error shown

\[ \text{Cr}^{52}(p, n) \text{Mn}^{52} \beta^2 \gamma \text{Cr}^{52} \]

Note: This curve is the sum of the cross sections for the formation of Mn\(^{52}\) and Mn\(^{54}\).
Cr(p,p)Cr

C. A. Preskill, Jr. and W. P. Alford
Phys. Rev. 115, 989 (1959) or
Report NYO-2172 (1958)
Absolute P. E. = ±2%
Note: These ratios were obtained by dividing the reported cross sections by the Rutherford cross sections.

- *E_p = 14.1 Mev*
- *E_p = 10.0 Mev*
- *E_p = 7.0 Mev*

Cr(p,p)Cr

- *Ref.:* Hu et al.
- Absolute P.E. of cross section measurements = ±10%
- Relative P.E. = ±5%

- *Ref.:* Kikuchi, Kobayashi, and Matsuda
- Absolute P.E. of cross section measurements = ±5%
Note: The data was given originally as a function of C.M. energy. The transformation back to laboratory proton energy was made non-relativistically. The C.M. energy scale is indicated by the tick marks.
\[ {\text{Cr}}^{52}(p, \gamma){\text{Cr}}^{52*} \]
\[ E^* = 1.44 \text{ MeV} \]

- Hu et al.
  and Report INSJ-20 (1959)
  Absolute P. E. = ±15% or less

- Kikuchi, Kobayashi, and Matsuda
  Absolute P. E. = 0-27%

- F. D. Seward
  Phys. Rev. 114, 514 (1959)
  Absolute P. E. = ±10%
$Cr^{52}(d,p')Cr^{53}$

Q = 5.71 Mev

I. Blaa
Nuclear Physics 19, 157 (1959)
Absolute P. E. = ±10%
\[ Q = -7.74 \text{ Mev} \]

- Absolute P.E. = ±10\% (does not include possible errors in the values taken for \( \beta^+ / K^- \) capture)
- No experimental error stated
Cr(d,d)Cr

I. Slaus and W. P. Allford
Phys. Rev. 114, 1054 (1959) and
I. Slaus, private communication
Absolute P.E. = ±3%

For relative data see
F. A. El Bedewi and S. Tadros
Nuclear Physics 6, 424 (1958)
(inelastic scattering at $E_d = 0.97$ Mev)
Appendix I

BIBLIOGRAPHY OF UNPLOTTED MATERIAL

Most of the references in this bibliography contain only relative data, although references are also listed for data for which no estimate of error limits was given or could be obtained by private communication.

\begin{align*}
\text{Na}^{23}(d,p')\text{Na}^{24} & \quad \text{R. Middleton and C. T. Tai} \\
\text{Burrows et al.} & \quad \text{Proc. Phys. Soc. (London) A59, 310 (1956)} \\
\text{Na}^{23}(d,\gamma)\text{Na}^{24} & \quad \text{R. Middleton and C. T. Tai} \\
\text{I. J. Van Heerden} & \quad \text{Nuclear Physics} 7, 55 (1958) \\
\text{Thornton, Meads, and Coille} & \quad \text{Phys. Rev. 119, 480 (1960)} \\
\text{Singh, Davis, and Krohe} & \quad \text{Phys. Rev. 115, 170 (1959)} \\
\text{Broström, Høse, and Koch} & \quad \text{Nature 182, 486 (1947)} \\
\text{Na}^{23}(d,p')\text{Na}^{24} & \quad \text{Burrows et al.} \\
& \quad \text{Proc. Phys. Soc. (London) A59, 310 (1956)} \\
\text{Na}^{23}(d,\gamma)\text{Mg}^{24} & \quad \text{Gemmill, Morton, and Smith} \\
& \quad \text{Nuclear Physics 15, 45 (1959)} \\
\text{Flack, Rutherford, and Grant} & \quad \text{Proc. Phys. Soc. (London) A57, 973 (1954)} \\
\text{R. Tangen} & \quad \text{Kgl. Norske Videnskab Selskab Skrifter (1946)} \\
\text{W. Gestner} & \quad \text{Z. Physik 127, 384 (1937)} \\
\text{P. H. Nelson and W. M. Preston} & \quad \text{Phys. Rev. 95, 974 (1954)} \\
\text{H. Cassen} & \quad \text{Phys. Rev. 95, 809 (1953)} \\
\text{S. C. Curran and J. E. Sherwood} & \quad \text{Proc. Roy. Soc. (London) A122, 72 (1939)} \\
\text{Teener, Seagondollar, and Krohe} & \quad \text{Phys. Rev. 93, 1035 (1954)} \\
\text{Grant et al.} & \quad \text{Proc. Phys. Soc. (London) A68, 369 (1955)} \\
\text{Prosser et al.} & \quad \text{Phys. Rev. 105, 369 (1956)} \\
\text{Na}^{23}(d,p')\text{Na}^{24} & \quad \text{Blaser et al.} \\
& \quad \text{Helv. Phys. Acta 24, 465 (1951)} \\
\text{Willard, Kington, and Bair} & \quad \text{Phys. Rev. 85, 269 (1952)} \\
\text{Baumann et al.} & \quad \text{Phys. Rev. 134, 376 (1965)} \\
\text{G. Dearmanly} & \quad \text{Phil. Mag. 1, 821 (1956)} \\
\text{P. H. Nelson and W. M. Preston} & \quad \text{Phys. Rev. 95, 974 (1954)} \\
\text{W. G. Redd and W. W. Krohe} & \quad \text{Phys. Rev. 105, 1018 (1956)} \\
\text{Prosser et al.} & \quad \text{Phys. Rev. 105, 369 (1956)} \\
\text{Baumann et al.} & \quad \text{Phys. Rev. 134, 376 (1965)} \\
\text{Flack, Rutherford, and Grant} & \quad \text{Proc. Phys. Soc. (London) A57, 973 (1954)} \\
\text{J. M. Freeman and A. S. Baxter} & \quad \text{Nature 162, 696 (1948)} \\
\text{Prosser et al.} & \quad \text{Phys. Rev. 114, 369 (1959)} \\
\text{Teener, Seagondollar, and Krohe} & \quad \text{Phys. Rev. 93, 1035 (1954)} \\
\text{P. H. Nelson and W. M. Preston} & \quad \text{Phys. Rev. 95, 974 (1954)} \\
\text{P. H. Nelson} & \quad \text{Phys. Rev. 95, 1584 (1954)} \\
\text{W. F. Vogelsgang and J. N. McGruder} & \quad \text{Phys. Rev. 105, 1663 (1958)} \\
& \quad \text{[Izvest. Soviet Phys. JETP, 3, 932 (1958)]} \\
\text{W. F. Vogelsgang and J. N. McGruder} & \quad \text{Phys. Rev. 105, 1663 (1958)} \\
\text{W. F. Vogelsgang and J. N. McGruder} & \quad \text{Phys. Rev. 109, 1663 (1958)}
\end{align*}
\[ \mathrm{Na}^{22}(\alpha,\gamma)\mathrm{Na}^{26} \]

G. M. Turner and N. P. Heydenburg
Phys. Rev. 96, 426 (1954)

Gove et al.
Phys. Rev. 111, 608 (1958)

J. Varma and W. Jack

Litherland et al.
Phys. Rev. 128, 208 (1966)

Green, Singh, and Wilmott
Phil. Mag. 46, 882 (1955)

Klyver, Van der Leun, and Endt
Physica 29, 1287 (1954)

Hunt et al.

H. Cassau
Phys. Rev. 92, 609 (1953)

S. E. Hunt and W. M. Jones
Phys. Rev. 99, 1283 (1955)

R. Tangen
Kgl. Norrake Videnskafe Selakske Skrifter (1956)

E. Goldberg
Phys. Rev. 98, 760 (1955) or Report AECU-2281

J. Hughes

C. E. Falk
Phys. Rev. 83, 499 (1951)

F. O. Bartell and S. Softky
Phys. Rev. 84, 463 (1951)

F. O. Bartell and S. Softky
Phys. Rev. 84, 463 (1951)

F. O. Bartell and S. Softky
Phys. Rev. 84, 463 (1951)

W. E. Duncanson and H. Miller

Kaufmann et al.
Phys. Rev. 82, 673 (1952)

Taylor, Russell, and Cooper
Report AECU-2743 (1953) or

Barjon, Lambert, and Schmoukler
J. phys. radium 19, 47 (1958)

Green, Singh, and Wilmott

S. E. Hunt and D. A. Hancock
Phys. Rev. 97, 567 (1955)

Kavanagh, Mills, and Sherr
Phys. Rev. 97, 248 (1955)

Hunt et al.

Klyver, Van der Leun, and Endt
Physica 29, 1287 (1954)

S. C. Curran and J. E. Strothers

Murray et al.

Gove et al.
Nuclear Phys. 2, 132 (1959)

Blaser et al.

Schneider et al.

Endt, Hafner, and Van Patter
Phys. Rev. 95, 518 (1952)

F. O. Bartell and S. Softky
Phys. Rev. 84, 463 (1951)

Russell, Taylor, and Cooper
Phys. Rev. 95, 99 (1954)

Murray et al.

Barjon, Lambert, and Schmoukler
J. phys. radium 19, 47 (1958)

R. Cassau
Phys. Rev. 93, 809 (1953)

S. C. Curran and J. E. Strothers
Proc. Roy. Soc. A177, 72 (1939)

S. E. Hunt and W. M. Jones
Phys. Rev. 99, 1292 (1955)

R. Tangen
Kgl. Norrake Videnskafe Selakske Skrifter (1956)

Gemmell, Morton, and Smith
Nuclear Physics 10, 45 (1959)

Anderson et al.
Nuclear Physics 5, 384 (1959)

R. O. Bondelid and C. A. Kennedy
Report NRI-6983 (1958)

Anderson et al.
Nuclear Physics 5, 38 (1957)
H. H. Staub
Nuovo cimento 5, Suppl. 1, 396 (1957)
Bomilier, Staub, and Weaver
Rutherford et al.
H. Casse
Phys. Rev. 92, 809 (1953)
S. E. Hunt and W. M. Jones
Phys. Rev. 95, 1283 (1954)
Shoemaker et al.
Phys. Rev. 93, 1011 (1954)
Brooks, Haus, and Tangen
Phys. Rev. 72, 661 (1947)
R. Tangen
Kgl. Norske Videnskab Selskabs Skrifter (1946)
Plaia et al.
Phys. Rev. 66, 187 (1949)
S. G. Curran and J. E. Brothers
W. Gontier
Z. Physik 127, 354 (1933)
Herb, Krest, and McKibben
Phys. Rev. 49, 691 (1937)
Blaser et al.
Hindle et al.
Phil. Mag. 44, 625 (1953)
H. E. Adelson
UCRL-8568 (1958)
B. L. Cohen
Phys. Rev. 99, 49 (1955)
Miller, Sewell, Wright
Phys. Rev. 91, 374 (1953)
E. Gross
UCRL-3330 (1956)
(neutrons from high energy proton bombardment of Al^2)
L. E. Bailey
Report UCRL-3334 (1956)
(deuterons from high energy proton bombardment of Al^2)
Bent et al.
Phys. Rev. 105, 774 (1956)
Scheiberg, Sampson, and Cochran
Phys. Rev. 99, 574 (1950)
F. O. Hartell and S. Softky
Phys. Rev. 83, 465 (1951)
L. E. Bailey
Report UCRL-3334 (1956) and
Report UCRL-3334 (1956)
(High energy alpha bombardment)
R. Tangen
Kgl. Norske Videnskab Selskabs Skrifter (1946)
C. P. Browne
Phys. Rev. 113, 807 (1959)
Hu et al.
S. van der Leun and P. M. Endt
Phys. Rev. 115, 96 (1959)
Bromley et al.
S. Sekerdji and A. K. Larruffea
[trans: Soviet Phys. Doklady 2, 487 (1957)]
V. G. Salikharevich
J. Exp. and Theoret. Phys. 34, 152 (1959)
W. Ritzler
Naturewiss. 34, 157 (1957)
Lawrence, McMillan, and Thornton
Phys. Rev. 85, 493 (1952)
Gemmell, Morton, and Smith
Nuclear Physics 12, 45 (1955)
R. D. Kerr and L. W. Cochran
Phys. Rev. 103, 741 (1956)
Paul et al.
R. Tangen
Kgl. Norske Videnskab Selskabs Skrifter (1946)
S. G. Curran and J. E. Brothers
B. B. Kinsey and T. Stone
Phys. Rev. 101, 975 (1956)
Van Putter et al.
Phys. Rev. 105, 171 (1957)
Clarke, Almqvist, and Paul
Phys. Rev. 89, 541 (1953)
J. M. Freeman and J. Seed

Best et al.
Phys. Rev. 102, 774 (1956)

R. T. Dagen
Kgl. Norske Videnskab Selskab Skrifter (1948)

Brocken et al.

Middleton, El-Badawi, and C. T. Tai

J. Hughes

Broström, Madsen, and Madsen
Phys. Rev. 38, 1265 (1931)

S. C. Curran and J. E. Brothers

R. Tagen
Kgl. Norske Videnskab Selskab Skrifter (1946)

B. B. Kinsey and T. Stone
Phys. Rev. 103, 975 (1956)

Rubin, Bailey, and Passell
Phys. Rev. 114, 1110 (1959)

Broström, Madsen, and Madsen
Phys. Rev. 39, 1265 (1931)

S. C. Curran and J. E. Brothers

Blaser et al.

H. T. Richards and R. V. Smith
Phys. Rev. 74, 1227 (1948)

Schoenfeld et al.
Phys. Rev. 55, 873 (1955)

Broström, Madsen, and Madsen
Phys. Rev. 55, 1265 (1935)

Richards, Smith, and Browne
Phys. Rev. 55, 524 (1955) and Report AECU-918 (1956)

Broström, Madsen, and Madsen
Phys. Rev. 83, 1265 (1951)

M. D. Kamen
Phys. Rev. 96, 537 (1941)

H. T. Richards and R. V. Smith
Phys. Rev. 74, 1280 (1948)

A°(p, n)K°

A°(p, pK)K°

K°(p, γ)Ca°

K°(p, p)K

K°(p, n)Ca°

K°(p, n)Be°

Ca°(p, He°)

Ca°(α, α')Ca°

Ca°(d, p)Ca°

Ca°(d, p)He°

Ca°(d, p)Ca°

Ca°(d, p)Be°

Sc°(d, n)Y°

Sc°(d, p)Sc°

Sc°(α, α)Sc°

Ti°(d, n)Y°

V + heavy nuclei

Tanaka et al.
Report NPS-6532 (1958)

Towle, Berman, and Matthews

Rubin, Bailey, and Passell
Phys. Rev. 114, 1110 (1959)

H. T. Richards and R. V. Smith
Phys. Rev. 74, 1227 (1956)

Richards, Smith, and Browne
Phys. Rev. 55, 524 (1955) or Report AECU-918 (1956)

S. M. Bailey
Report UCRL-8719 (1955)

McCormick et al.

G. B. Shook
Phys. Rev. 114, 310 (1959)

Bockelman et al.
Phys. Rev. 107, 176 (1957)

Bockman, Marmier, and Preiswerk

McCormick et al.

W. R. Cobb and B. B. Guth
Phys. Rev. 107, 181 (1957)

Elwyn et al.
Phys. Rev. 112, 1250 (1958)

Brugger, Bosmer, and Marion
Phys. Rev. 100, 84 (1955)

Hanson, Tchenke, and Williams
Rev. Mod. Phys. 21, 635 (1949)

Baker et al.
Phys. Rev. 81, 46 (1951)

Rubin, Bailey, and Passell
Phys. Rev. 114, 1110 (1959)

Windham et al.
Phys. Rev. 103, 1321 (1956)

S. M. Bailey
Report UCRL-8719 (1959)

C. E. Falk
Phys. Rev. 83, 499 (1951)

Karapetyan, Girilin, and Myasoedov

[traces: Soviet Phys. JETP 2, 431 (1959)]
\[ \text{C}^{29}(d, n)\text{M}^{38} + \text{C}^{38}(\text{EC})\gamma \text{V}^{44} \text{ and} \]
\[ \text{C}^{29}(d, p)\text{C}^{38}(\text{EC})\gamma \text{V}^{44} \]
\[ \text{C}^{34}(d, \alpha)\text{V}^{44} + \text{C}^{34}(\text{EC})\gamma \text{V}^{44} \]
\[ \text{C}^{32}(p, \alpha)\text{V}^{44} \]
\[ \text{C}^{32}(p, n)\text{M}^{38} \]
\[ \text{C}^{34}(d, n)\text{M}^{38}(\text{EC})\gamma \text{C}^{44} \]
\[ \text{C}^{34}(p, n)\text{M}^{38} \]


Lovington, McCue, and Preston Phys. Rev. 85, 585 (1952)


Lovington, McCue, and Preston Phys. Rev. 85, 585 (1952)
Appendix II

NUMERICAL FACTORS NECESSARY FOR THE COMPUTATION OF RUTHERFORD CROSS SECTIONS

The Rutherford scattering cross section in the center-of-mass coordinate system is given by $c_n(\theta^1) = \frac{C}{E^2} \csc^4(\theta^1/2)$ in which $C$ for a given target and projectile is constant and is given by $C = \frac{Z_1 Z_2 e^4}{2} \left( M_1 + M_2 \right)^2$, $E$ is the laboratory bombarding energy in Mev, and $\theta^1$ is the center-of-mass scattering angle. The constant $C$ is given in Table I for the most abundant stable isotopes of the elements from hydrogen through copper. Those entries having no isotopic designation were computed using a weighted average of the masses of the stable isotopes of the target. Values of $\csc^4(\theta^1/2)$ are given in Table II for one degree intervals of $\theta^1$. 
<table>
<thead>
<tr>
<th>Target</th>
<th>(p, p)</th>
<th>(a, a)</th>
<th>0°</th>
<th>A</th>
<th>0°</th>
<th>A</th>
<th>0°</th>
<th>A</th>
<th>0°</th>
<th>A</th>
<th>0°</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>H²</td>
<td>5.1835 × 10⁹</td>
<td>1.6851 × 10¹</td>
<td>1.2810 × 10⁹</td>
<td>45</td>
<td>4.6638 × 10⁹</td>
<td>90</td>
<td>4.0060</td>
<td>135</td>
<td>1.3726</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>He²</td>
<td>8.1224</td>
<td>1.1713</td>
<td>8.2936 × 10⁹</td>
<td>46</td>
<td>4.2963</td>
<td>91</td>
<td>3.6836</td>
<td>136</td>
<td>1.3529</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li²</td>
<td>5.0295 × 10⁹</td>
<td>1.9412</td>
<td>1.1596 × 10⁹</td>
<td>47</td>
<td>3.3552</td>
<td>92</td>
<td>3.7352</td>
<td>137</td>
<td>1.3445</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li²⁺</td>
<td>1.3229 × 10⁹</td>
<td>1.2290</td>
<td>1.1506</td>
<td>48</td>
<td>3.6539</td>
<td>93</td>
<td>3.6310</td>
<td>138</td>
<td>1.3162</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be³⁺</td>
<td>5.2931</td>
<td>2.1097</td>
<td>1.7296</td>
<td>49</td>
<td>3.9302</td>
<td>94</td>
<td>3.4951</td>
<td>139</td>
<td>1.2991</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>3.8716</td>
<td>4.5588</td>
<td>2.4327</td>
<td>50</td>
<td>2.6736</td>
<td>95</td>
<td>3.3839</td>
<td>140</td>
<td>1.2836</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B²⁺</td>
<td>3.6600</td>
<td>4.5335</td>
<td>2.4694</td>
<td>51</td>
<td>2.1596</td>
<td>96</td>
<td>3.2784</td>
<td>141</td>
<td>1.2663</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C³⁺</td>
<td>5.4816</td>
<td>6.3828</td>
<td>3.5185</td>
<td>52</td>
<td>2.0790</td>
<td>97</td>
<td>3.0822</td>
<td>142</td>
<td>1.2511</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N⁴⁺</td>
<td>7.9967</td>
<td>6.3977</td>
<td>4.1994</td>
<td>53</td>
<td>2.5230</td>
<td>98</td>
<td>2.9991</td>
<td>143</td>
<td>1.2465</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O⁵⁺</td>
<td>9.3716</td>
<td>1.0514 × 10³</td>
<td>5.1855</td>
<td>54</td>
<td>2.3541</td>
<td>144</td>
<td>1.2325</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na⁺</td>
<td>1.1640 × 10³</td>
<td>1.2840</td>
<td>6.1541</td>
<td>55</td>
<td>2.1999</td>
<td>145</td>
<td>1.2195</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na²⁺</td>
<td>1.4266</td>
<td>1.2670</td>
<td>7.4447</td>
<td>56</td>
<td>2.0547</td>
<td>146</td>
<td>1.1975</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na³⁺</td>
<td>1.7085</td>
<td>1.8548</td>
<td>8.6461</td>
<td>57</td>
<td>1.9289</td>
<td>147</td>
<td>1.1763</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>2.0339</td>
<td>2.1978</td>
<td>1.0121 × 10³</td>
<td>58</td>
<td>1.8103</td>
<td>148</td>
<td>1.1572</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg³⁺</td>
<td>2.2523</td>
<td>2.1038</td>
<td>1.0163</td>
<td>59</td>
<td>1.7009</td>
<td>149</td>
<td>1.1395</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al⁶⁺</td>
<td>2.3867</td>
<td>2.2922</td>
<td>1.1552</td>
<td>60</td>
<td>1.6000</td>
<td>150</td>
<td>1.1229</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al⁷⁺</td>
<td>2.7254</td>
<td>2.9173</td>
<td>1.3261</td>
<td>61</td>
<td>1.5171</td>
<td>151</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al⁸⁺</td>
<td>2.7383</td>
<td>2.9188</td>
<td>1.3270</td>
<td>62</td>
<td>1.4321</td>
<td>152</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si⁹⁺</td>
<td>3.1085</td>
<td>3.3072</td>
<td>1.4873</td>
<td>63</td>
<td>1.3418</td>
<td>153</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>3.5593</td>
<td>3.7473</td>
<td>1.6790</td>
<td>64</td>
<td>1.2662</td>
<td>154</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oⁱ⁺</td>
<td>3.2929</td>
<td>3.7486</td>
<td>1.6800</td>
<td>65</td>
<td>1.2000</td>
<td>155</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3.8619</td>
<td>4.1826</td>
<td>1.6553</td>
<td>66</td>
<td>1.1365</td>
<td>156</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>3.8640</td>
<td>4.1839</td>
<td>1.6906</td>
<td>67</td>
<td>1.0778</td>
<td>157</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N⁺</td>
<td>4.4131</td>
<td>4.6325</td>
<td>2.0237</td>
<td>68</td>
<td>1.0227</td>
<td>158</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>4.9232</td>
<td>5.1742</td>
<td>2.5754</td>
<td>69</td>
<td>0.9756</td>
<td>159</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>5.4683</td>
<td>5.7919</td>
<td>3.0695</td>
<td>70</td>
<td>0.9382</td>
<td>160</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>5.8739</td>
<td>6.3838</td>
<td>3.7111</td>
<td>71</td>
<td>0.8919</td>
<td>161</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>6.3991</td>
<td>6.8100</td>
<td>4.3048</td>
<td>72</td>
<td>0.8452</td>
<td>162</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ar</td>
<td>6.6061</td>
<td>6.8100</td>
<td>4.3048</td>
<td>73</td>
<td>0.8000</td>
<td>163</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl⁺</td>
<td>7.1501</td>
<td>7.4079</td>
<td>5.1969</td>
<td>74</td>
<td>0.7563</td>
<td>164</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>7.3564</td>
<td>8.0526</td>
<td>5.4620</td>
<td>75</td>
<td>0.7142</td>
<td>165</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr⁺</td>
<td>7.7567</td>
<td>8.0543</td>
<td>6.3636</td>
<td>76</td>
<td>0.6742</td>
<td>166</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn⁺</td>
<td>8.3991</td>
<td>8.7039</td>
<td>7.2829</td>
<td>77</td>
<td>0.6363</td>
<td>167</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>9.0791</td>
<td>9.4033</td>
<td>8.0243</td>
<td>78</td>
<td>0.6006</td>
<td>168</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe⁺</td>
<td>9.0786</td>
<td>9.4023</td>
<td>8.0230</td>
<td>79</td>
<td>0.5663</td>
<td>169</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co⁺</td>
<td>9.7728</td>
<td>1.0103 × 10³</td>
<td>9.3095</td>
<td>80</td>
<td>0.5347</td>
<td>170</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni⁺</td>
<td>1.0511 × 10³</td>
<td>1.0869</td>
<td>9.4630</td>
<td>81</td>
<td>0.5066</td>
<td>171</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu⁺</td>
<td>1.0516</td>
<td>1.0878</td>
<td>9.4648</td>
<td>82</td>
<td>0.4804</td>
<td>172</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu²⁺</td>
<td>1.0504</td>
<td>1.0854</td>
<td>9.4624</td>
<td>83</td>
<td>0.4553</td>
<td>173</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn⁺</td>
<td>1.1247</td>
<td>1.1690</td>
<td>9.4258</td>
<td>84</td>
<td>0.4312</td>
<td>174</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn²⁺</td>
<td>1.1250</td>
<td>1.1697</td>
<td>9.4215</td>
<td>85</td>
<td>0.4081</td>
<td>175</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn³⁺</td>
<td>1.1239</td>
<td>1.1585</td>
<td>9.3573</td>
<td>86</td>
<td>0.3863</td>
<td>176</td>
<td>1.1072</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table II

C (gives c_e in millibars/steradian)
Appendix III

PARTICLE MECHANICS

REFERENCES ON PARTICLE MECHANICS

   Source of the information included in this compilation; notation has been changed for sake
   of consistency. Includes graphs and tables of elastic scattering of particles of mass 1, 2, 3,
   4 by targets of masses 1 to 16, and of the reactions Tnp, nHe3, T(0)p, He4, D(0)p, T
   and D0, nHe6 at E = 0, 8, 10, and 12 Mev. Also Rutherford scattering.

2. Hanson, Tatschek, and Williams, Rev. Mod. Phys. 21, 825 (1949)
   Presents formulae in a form convenient for endothermic reactions. Includes nomographs
   for the reactions D(d,n)He3, C(d,n)He3, T(d,n)He4, Li(d,n)He4, and Tnp, nHe3, and
   plots of neutron energy and solid-angle ratio for T(d,n)He3, 0.5 ≤ E ≤ 3 Mev.

   (a) K. T. Raudabridge, Part V in Vol. I, p. 689
   Gives equations for Q including relativistic effects. These and other equations may be
   obtained from the non-relativistic formulae included in this compilation by substi-
   tuting for each mass M the expression M + (E/c^2) providing |E/Mc^2| < 1. For
   excited nuclei use M = (E/c^2 + hv/c^2).
   (b) P. Morrison, Part VI in Vol. II, p. 3
   Gives fully relativistic equations for scattering and for collision with creation of new
   particles.

   Gives a geometrical interpretation of the relativistic cases.

5. F. Mariani, Nuovo cimiero 5, 297 (1951)
   Gives a nomograph for relativistic elastic scattering.

6. P. J. M. Farley, Nuclonica 12, No. 10, 94 (1954), and erratum, Nuclonica 13, No. 7, 67,
   (1955)
   Source of the nomogram for reaction calculations included in this compilation. Useful for
   rough preliminary calculations.

   A mechanical device.

CONVENTIONS AND SYMBOLS

0  Laboratory angle of observed particle.
0'  Center-of-mass angle of observed particle.
0(0)  The differential cross section in the laboratory system.
0(0)  The differential cross section in the center-of-mass system.
σ  The total cross section of the reaction.
E  Energy, always in the laboratory system. Subscripts p, d, t, etc., refer to protons,
    deuterons, tritons, etc.
C M  Center-of-mass system.
Lab  Laboratory system.
P E  Probable error.
γ  Observed width of a resonance
FR  Bombarding energy at which a resonance occurs.
### REACTIONS

Prized quantities in C. M. system.

![Diagram of reactions](image)

**Definitions:**

- \( A_{14} \cdot \frac{M_2}{M_1} \cdot \frac{A_{24}}{A_{14}} \cdot \frac{E_4}{E_T} \)
- \( A_{23} \cdot \frac{M_1}{M_2} \cdot \frac{M_2}{M_1} \cdot \frac{A_{24}}{A_{14}} \cdot \frac{E_4}{E_T} \)
- \( A_{13} \cdot \frac{M_1}{M_2} \cdot \frac{M_2}{M_1} \cdot \frac{A_{24}}{A_{14}} \cdot \frac{E_4}{E_T} \)

**Note:** \( A_{14} = A_{24} = A_{23} = 1 \)

| Lab energy of light product: | \( E_T = A_{13} \cdot A_{24} + 2 \cdot A_{14} \cdot A_{23} \cdot \cos \theta \) | Use only plus sign unless \( A_{13} > A_{24} \), in which case \( \cos \theta = \frac{1}{\sqrt{2}} \) | Lab energy of the scattered particle: | \( E_V = E_T + \frac{3M_2}{M_1 + M_2} \cdot (1 - \cos \theta) \) | Use only plus sign unless \( M_1 > M_2 \), in which case \( \cos \theta = \frac{1}{\sqrt{2}} \) |
| Lab energy of heavy product: | \( E_T = A_{14} + A_{23} + 4 \cdot A_{14} \cdot A_{23} \cdot \cos \theta \) | Use only plus sign unless \( A_{14} > A_{23} \), in which case \( \cos \theta = \frac{1}{\sqrt{2}} \) | Lab energy of the recoil nucleus: | \( E_V = E_T - \frac{M_2}{M_1 + M_2} \cdot 3 \cdot M_2 \cdot \cos \theta + \frac{3}{2} \) | \( \theta \leq \pi/2 \) |
| Lab angle of heavy product: | \( \sin \theta = \frac{A_{14} \cdot \frac{M_2}{M_1} \cdot \sin \theta}{2A_{24}} \) | C. M. angle of light product: | \( \sin \theta = \frac{E_T \cdot 2A_{24}}{M_1} \) | Lab angle of recoil nucleus: | \( \sin \theta = \frac{M_1 \cdot E_V}{M_1 \cdot E_T} \) | \( \theta = \frac{1}{2} (\pi - \phi) \), \( \tan \phi = \frac{M_1}{M_2} \cdot \cos \phi \) |
| Intensity or solid-angle ratio for light product: | \( (\frac{1}{\sin \theta}) \cdot \sin \theta \cdot \frac{\sin \theta}{\sin \phi} \cdot \frac{\sin \theta}{\sin \phi} \cdot \cos \phi \cdot \cos \phi \) | Intensity or solid-angle ratio for heavy product: | \( (\frac{1}{\sin \theta}) \cdot \sin \theta \cdot \frac{\sin \theta}{\sin \phi} \cdot \frac{\sin \theta}{\sin \phi} \cdot \cos \phi \cdot \cos \phi \) | Intensity or solid-angle ratio for scattered particle: | \( (\frac{1}{\sin \theta}) \cdot \sin \theta \cdot \frac{\sin \theta}{\sin \phi} \cdot \frac{\sin \theta}{\sin \phi} \cdot \cos \phi \cdot \cos \phi \) | Intensity or solid-angle ratio for recoil nuclei: | \( (\frac{1}{\sin \theta}) \cdot \sin \theta \cdot \frac{\sin \theta}{\sin \phi} \cdot \frac{\sin \theta}{\sin \phi} \cdot \cos \phi \cdot \cos \phi \) | Intensity or solid-angle ratio for associated particles in the lab system: | \( (\frac{1}{\sin \theta}) \cdot \sin \theta \cdot \frac{\sin \theta}{\sin \phi} \cdot \frac{\sin \theta}{\sin \phi} \cdot \cos \phi \cdot \cos \phi \) |
NUCLEAR REACTION NOMOGRAM

Nuclear Reaction Nomogram
This nomogram is based upon the version given in the reference, but with the scales correctly spaced and the rotation changed to that adopted in this compilation.

\[ k = \frac{V \cos \theta'}{V' \cos \phi} = \frac{M_2 M_3 E_3}{M_2 E_3 + M_3 E_3} \frac{1}{2} \]

where \[ E_3' = \frac{M^2}{M - E_3} \frac{M_3}{M} \]

1. Connect \( k \) on scale C with \( \phi \) on scale A to read \( \alpha \) on scale B. \( \alpha = \sin^{-1}(k \sin \phi) \)
   (use equation if \( k \) is off scale).
2. Locate \( \phi' = \phi - \alpha \) on scale B.
3. Connect \( \phi' \) and \( \phi'' \) to find \( k' = V' \sqrt{\phi''} \).
4. Connect \( k' \) with \( 90^\circ \) on scale A, and read \( E_y/E_3' = k'^2 \) on scale D.
5. Locate \( \beta = 90^\circ - \alpha \) on scale A.
6. Connect \( \beta \) and \( k' \) to read on scale D

\[ \sigma(\phi)/\sigma(\phi') = (\sin \phi'/\sin \phi) (1/\sin \phi) \]

Note: When \( k > 1 \) there are two solutions for \( \phi < \phi_{\text{max}} \), where \( \phi_{\text{max}} \) is found by connecting \( k \) to \( \alpha = 90^\circ \) on scale B.

NOTE: If either the energy or intensity ratio falls off of scale D, it is permissible to divide or multiply the value of \( k' \) by 10; this changes the answer by a factor of 100. Alternatively, in the case of the energy ratio, one can use the points X or Y on scale A instead of the point 90°; the answer will then be multiplied correspondingly by 10 or by 50.