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STATISTICAL ANALYSIS OF THE ENERGY LEVEL WIDTHS
IN CHARGED PARTICLE INDUCED REACTIONS*

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ABSTRACT

Characteristic nuclear level widths determined from various nuclear reactions for nuclei with $24 \leq A \leq 108$ are compared with a microscopic theory which includes the nuclear pairing interaction. Single particle levels of Nilsson et al. and Seeger et al. are used in the calculations. The gross features of the experimental data due to nuclear shells are reproduced with the microscopic theory. The agreement between experiment and calculated level widths obtained from this statistical analysis is good considering the uncertainties in the experimental data, the theoretical single-particle levels and the pairing energy.

Key Word :

NUCLEAR STRUCTURE statistical analysis of energy level widths; Comparison of the theoretical level widths with the experimental data for $24 \leq A \leq 108$.

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I. INTRODUCTION

Compilations of nuclear level widths, from charged particle reactions which lead to compound nucleus formation and subsequent particle emission have been prepared by several groups.¹⁻⁴ These compilations, summarized in Table 1, allow for the investigation of trends in energy level widths for various nuclei. Previously, comparisons between these data and theoretical level widths obtained using simple Bathe or Fermi gas type formulas^{5,6} have been reported. The purpose of this article is to improve upon the previous work by using a realistic microscopic theory. This theory utilizes realistic single-particle levels and the pairing interaction. The use of such a microscopic theory has been discussed by several authors.⁷⁻¹¹ There have been only a limited number of comparisons¹²⁻¹⁵ of experimental level densities to theoretical results using microscopic theory and its extension to energy level widths has, up to this point, not been made.

In the present paper, level widths have been calculated using a microscopic theory and are compared with experimental energy level widths for various nuclei with $24 \leq A \leq 108$. The theory will be outlined in Section II. The calculational procedure will be given in Section III and the results will be discussed in Section IV.

II. THEORY

A. Cross Section of Formation and the Spin Distribution of the Compound Nucleus

The cross section for the formation of the compound nucleus with spin J at an excitation energy U_c , from the reaction $A + a \rightarrow c^*$, is given by^{16,17}

$$\sigma(U_c, J) = \frac{\pi \lambda_a^2 (2J+1)}{(2i_a+1)(2I_A+1)} \sum_{S_a=|I_A-i_a|}^{I_A+i_a} \sum_{\ell_a=|J-S_a|}^{J+S_a} T_a^{\ell_a}(\epsilon_a), \quad (1)$$

where λ_a = deBroglie wave length of the entrance channel,

I_A = target spin,

i_a = projectile spin,

S_a = entrance channel spin;

$$\vec{S}_a = \vec{I}_A + \vec{i}_a$$

$T_a^{\ell_a}(\epsilon_a)$ = optical model transmission coefficient of particle a with orbit angular momentum ℓ_a and channel energy ϵ_a ,

ϵ_a = center of mass energy of entrance channel;

$$\epsilon_a = E_a \frac{M_A}{(M_a + M_A)},$$

M_x = mass of particle x ,

E_a = energy of projectile in the laboratory system.

The channel wave length λ_a is related to the channel energy by

$$\frac{1}{\lambda_a} = (2M_0 \epsilon_a)^{1/2} / \hbar, \quad (2)$$

where M_0 is the reduced mass of the system. Equation (2) yields

$$\frac{1}{\chi^2} = 4 \cdot 784 E_a \text{ (MeV)} \frac{M_a M_A^2}{(M_a + M_A)^2} \quad (3)$$

(χ_a^2 in Eq. (3) is in barns).

The total cross section for formation of compound nucleus c^* is given by

$$\sigma(U_c) = \sum_J \sigma(U_c, J) \quad (4)$$

and the probability P_J for the formation of the compound nucleus with spin J is given by

$$P_J = \frac{\sigma(U_c, J)}{\sigma(U_c)} \quad (5)$$

B. Energy Level Widths

A schematic diagram for the formation of a compound nucleus and its subsequent decay is shown in Fig. 1. Decomposition of the compound nucleus with spin and parity J^+ at an excitation energy U_c can occur by emission of one of several kinds of particles, for example, the probability of α -particle emission is proportional to¹⁷

$$G(J, +)_{\alpha^+} = \sum_{\ell_\alpha \text{ (even)}}^{\infty} \sum_{S_b = |J - \ell_\alpha|}^{J + \ell_\alpha} \sum_{I_B = |S_\alpha - i_\alpha|}^{S_\alpha + i_\alpha} \int_0^{U_B^{\max}} dU_B T_\alpha^{\ell_\alpha}(\epsilon_\alpha) \rho(U_\alpha, I_B^+) \quad (6)$$

It is assumed that the residual nucleus has positive parity. Similarly, the decay of the compound nucleus to the residual nucleus with negative parity is given by

$$G(J,+)_\alpha^- = \sum_{\ell_\alpha(\text{odd})}^{\infty} \sum_{S_\alpha=|J-\ell_\alpha|}^{J+\ell_\alpha} \sum_{I_B=|S_\alpha-i_\alpha|}^{S_\alpha+i_\alpha} \int_0^{U_B^{\max}} dU_B T_\alpha^{\ell_\alpha}(\epsilon_\alpha) \rho(U_\alpha, I_B) \quad (7)$$

Combining Eqs. (6) and (7) results in

$$\begin{aligned} G(J,+)_\alpha^\pm &= G(J,+)_\alpha^+ + G(J,+)_\alpha^- \\ &= \sum_{\ell=0}^{\infty} \sum_{S=|J-\ell_\alpha|}^{J+\ell_\alpha} \sum_{I_B=|S_\alpha-i_\alpha|}^{S_\alpha+i_\alpha} \int_0^{U_B^{\max}} dU_B T_\alpha^{\ell_\alpha}(\epsilon_\alpha) \rho(U_B, I_B, \pi) \end{aligned} \quad (8)$$

Likewise for all the other channels (i.e. the emission of neutrons, protons, deuterons)

$$G(J^+)_\alpha^\pm \begin{matrix} n^\pm \\ p^\pm \\ d^\pm \end{matrix} = \sum_b \sum_{\ell_b=0}^{\infty} \sum_{S_b=|J-\ell_b|}^{J+\ell_b} \sum_{I_B=|S_b-i_b|}^{S_b+i_b} \int_0^{U_B^{\max}} dU_B T_b^{\ell_b}(\epsilon_b) \rho(U_B, I_B, \pi) \quad (9)$$

If we now assume that the levels of opposite parity are equally populated in the compound nucleus and equally available in the residual nucleus, we can write

$$G(J^+)_\alpha^\pm \begin{matrix} n^\pm \\ p^\pm \\ d^\pm \end{matrix} = G(J^-)_\alpha^\pm \begin{matrix} n^\pm \\ p^\pm \\ d^\pm \end{matrix} \quad (10)$$

Thus the level density for a particular angular momentum and parity is given by

$$\rho(U, I, +) = \rho(U, I, -) = \rho(U, I, \pi) = \frac{\rho(U, I)}{2} \quad (11)$$

Finally, the energy width $\Gamma_J^b(U_c)$ for the decay by emission of particle b leading to a residual nucleus B is given by¹⁹

$$\Gamma_J^b(U_c) = \frac{D(U_c, J)}{2\pi} \int_0^{U_B^{\max}} dU_B \sum_{\ell_b=0}^{\ell_b} T_b^{\ell_b}(\epsilon_b) \sum_{S_b=|J-\ell_b|}^{J+\ell_b} \sum_{I_b=|S_b-i_b|}^{S_b+i_b} \rho(U_B, I_B) \quad (12)$$

where I_B = spin of the residual nucleus B ,

i_b = spin of the emitted particle b ,

S_b = exit channel spin,

$T_b^{\ell_b}(\epsilon_b)$ = optical model transmission coefficient of particle b
with orbit angular momentum ℓ_b and channel energy ϵ_b ,

$\rho(U_B, I_B)$ = level density of the residual nucleus B .

The relation between the exit channel energy ϵ_b and the maximum excitation energy of the residual nucleus is

$$\epsilon_b = U_B^{\max} - U_B \quad (13)$$

and

$$U_B^{\max} = \epsilon_a + Q_{ab} \quad (14)$$

where Q_{ab} is the ground state Q -value for the reaction. $D(U_c, J)$ is the spacing of levels with spin J of the compound nucleus at an excitation energy U_c .

C. Nuclear Level Density

The level density of a spherical nucleus for a particular value of the angular momentum I is given by

$$\rho(E, I) = \omega(E, M=I) - \omega(E, M=I+1) , \quad (15)$$

where M is the projection of I on a space-fixed axis, and $\omega(E, M)$ is the density of states of a particular projection M . Since many independent degrees of freedom contribute to M , the density of states $\omega(E, M)$ is expected to approach a normal distribution,

$$\omega(E, M) = \left[\frac{\omega(E)}{(2\pi\sigma^2(E))^{\frac{1}{2}}} \right] \exp \left[\frac{-M^2}{2\sigma^2(E)} \right] , \quad (16)$$

where $\omega(E)$ is the total state density and $\sigma^2(E)$ is defined as a spin cutoff factor. From Eqs. (15) and (16), one obtains to a good approximation the spin-dependent level density

$$\rho(E, I) = \left[\frac{(2I+1)}{(8\pi)^{\frac{1}{2}}\sigma^3(E)} \right] \omega(E) \exp \left[-\frac{I(I+1)}{2\sigma^2(E)} \right] . \quad (17)$$

The state density $\omega(E)$ is calculated with realistic sets of single particle levels^{20,21} by the grand partition function method for a system of interacting fermions. The Hamiltonian describing a system of paired fermions has been discussed by various authors.^{11,12,22-25} Such a Hamiltonian is approximately diagonalized by means of a transformation where the quasiparticle excitations are considered to be independent fermions with energy²⁶

$$E_k = [(\epsilon_k - \lambda)^2 + \Delta^2]^{\frac{1}{2}} , \quad (18)$$

where λ is the chemical potential, ϵ_k the single particle energy and Δ the gap parameter which gives a measure of the pairing correlation. For a paired system the logarithm of the grand partition function for

one type of fermion is given by²⁷

$$\ln Z(\alpha, \beta) = -\beta \sum_k (\epsilon_k - i - E_k) + 2 \sum_k \ln[1 + \exp(-\beta E_k)] - \beta \frac{\Delta^2}{G} \quad (19)$$

where G is the pairing strength and β is related to the temperature of the system, $\beta = 1/T$. If the summation is over doubly degenerate orbitals designated by k , Eq. (19) is valid only if the quantities Δ , λ and β satisfy the gap equation

$$\frac{2}{G} = \sum_k \frac{1}{E_k} \tanh(\frac{1}{2} \beta E_k) \quad (20)$$

The statistical properties of a nucleus defined in terms of its neutron and proton numbers N and Z , respectively, and the total energy are given in the grand partition function $Z(\alpha_n, \alpha_p, \beta)$. The quantities α_n , α_p and β are Lagrangian multipliers associated with the particle numbers and energy. In the framework of statistical mechanics the state density which is the inverse Laplace transform of the grand partition function, is given by

$$\omega(N, Z, E) = \left(\frac{1}{2\pi i}\right)^3 \int_{-i\infty}^{i\infty} d\alpha_n \int_{-i\infty}^{i\infty} d\alpha_p \int_{-i\infty}^{i\infty} d\beta Z(\alpha_n, \alpha_p, \beta) \exp(-\alpha_n N - \alpha_p Z + \beta E) \quad (21)$$

This integral is evaluated by the method outlined previously.¹²

The spin cutoff factor $\sigma^2(E)$ is calculated also with the microscopic theory and is given by^{12,28}

$$\sigma^2(E) = \frac{1}{2} \left\{ \sum_k m_{pk}^2 \operatorname{sech}^2(\frac{1}{2} \beta E_{pk}) + \sum_k m_{nk}^2 \operatorname{sech}^2(\frac{1}{2} \beta E_{nk}) \right\} \quad (22)$$

The additional quantity needed to solve Eqs. (21) and (22) is the ground

state gap parameter Δ which is used to fix the pairing strength G . In the present calculations we have used values of Δ_n and Δ_p obtained from Ref. 28. In addition, calculations have been done using the functional form of Δ_n and Δ_p ,²⁹

$$\Delta_p = \Delta_n = 12A^{-\frac{1}{2}}. \quad (23)$$

D. Total Energy Level Widths

The total decay width, Γ_J , of the compound nucleus with spin J , is calculated by summing the partial widths for all outgoing particles,

$$\Gamma_J = \sum_b \Gamma_J^b \quad (24)$$

The average life-time, τ , of the compound nucleus is found from a weighted sum of the life-times of the nuclei with different angular momentum, J .

Since $\tau = h/\Gamma$, one obtains

$$\frac{1}{\Gamma} = \frac{\sum_J \frac{\sigma_J}{\Gamma_J}}{\sum_J \sigma_J} \quad (25)$$

where σ_J is the cross section for formation of the compound nucleus with spin J and is given by Eq. (1).

III. CALCULATIONAL PROCEDURE

A computer code has been constructed³⁰ to compute the various partial widths, Γ_J^b , and the total width, Γ , of the compound nucleus using the formulas already discussed.

A. Input Values

Input values for the main code consisted of single particle levels, level density and transmission coefficients. A Nilsson model program was used to generate the single particle levels. The original version of the Nilsson model³¹ has been used. The parameters for the Nilsson model were chosen from Ref. 21.

Using the realistic set of single particle levels, the spin-dependent nuclear level density was calculated using the formulas outlined in Section II.C. The detail of such calculations are outlined in our previous publications.^{12,32,33} The level spacing, D , of the compound nucleus of spin J at excitation energy U_c is defined in relation to Eq. (17) by

$$D(U_c, J) = \frac{1}{\rho(U_c, J)} \quad (26)$$

The transmission coefficients of the entrance and exit channels were calculated with a GENOA computer program. The optical model parameters employed were those of Perey³⁴ for protons, Huizenga and Igo³⁵ for alpha particles, and Bjorklund and Frenbach³⁶ for neutrons.

B. Operation of Computer Program

Transmission coefficients, level density, and spin cut-off factors referring to emission of different kinds of particles and the resulting residual nuclei were calculated as described above. The calculations were done with energy bins of 0.1 MeV. The results of these calculations are then fit to a polynomial over various ranges of energy. The results from this fitting procedure were then used to calculate the partial widths, Γ_J^b , of the different particles n, p, d and α by numerical integration of Eq. (12). Knowing values of Γ_J^b and σ_J [which was calculated using Eq. (1)] the total energy level width Γ was deduced from Eq. (25). The calculations were done for many nuclei, the results of which are discussed in the following section.

IV. RESULTS AND DISCUSSION

The results of the statistical analysis are summarized in Table 1, in which both the experimental data⁴ and the results of the theoretical calculations are presented. The calculations were repeated for the two sets of pairing energies which are displayed in Fig. 2. Values of the energy width, $\Gamma_{\text{theo}}^{(1)}$, were obtained by using the initial values of the gap parameter from Ref. 28. The corresponding values, $\Gamma_{\text{theo}}^{(2)}$, were obtained by use of the gap parameter which is generated from Eq. (23).

The level density (in levels per MeV) for several doubly even nuclei considered in the calculations are plotted in Fig. 3. Values of spin cut-off factors σ^2 for the same nuclei are shown in Fig. 4. The

function Γ_J for fixed energy and variable J , for the nuclei ^{76}Se and ^{104}Pd as an example, is plotted in Figs. 5 and 6, which shows that the values of Γ_J decrease when J increases. The logarithms of the energy width listed in Table 1 versus $(A/E^*)^{1/2}$ for various nuclei are presented in Fig. 7.

An examination of the results listed in Table 1 and presented in Fig. 7 show that the energy widths obtained from the statistical model of nuclei and nuclear reactions give reasonably good agreement with the experiment. In addition, the general trend of $\ln\Gamma$ versus $(A/E^*)^{1/2}$ agree with the semi-empirical result reported previously.⁴

It is not possible to calculate the error in Γ_{theo} associated with a particular set of single particle levels. However, some estimate of the uncertainty can be made by comparing results obtained with different sets of single particle levels. Such a comparison was made for several nuclei using single particle levels of Seeger et al.²⁰ and Nilsson et al.²¹ The results agreed to within 5-10%.

It is also seen that the average value of Γ depends on the magnitude of the gap parameter. Increasing the gap parameter by 15% decreases the value of Γ_{theo} by 25-35%.

In summary, the values of the total energy width calculated with the statistical model which is based upon the shell model are in reasonable agreement with experiment. In particular, gross features of the experimental data due to nuclear shell effects are reproduced.

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FOOTNOTES AND REFERENCES

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1. R.W.Shaw, J.C.Norman, R.Vandenbosch, and J.C.Bishop, Phys. Rev. 184 (1969) 1040.
2. R.G.Stokstad, "Resonant structure in heavy ion reactions," in Proceedings of the Symposium on Heavy Ion Induced Transfer Reactions, Argonne, Illinois, 13-17 March 1973 (unpublished, but issued as Argonne Physics Division Information Report CONF-730312); also in Proceedings of the Europhysics Study Conference on Intermediate Processes in Nuclear Reactions, Plitvice, 1972 (Springer-Verlag, Berlin, 1973), Vol. 22, p.179.
3. R.Wieland, A.Gobbi, L.Chua, M.W.Sachs, D.Shapira, R.Stokstad, and D.A.Bromley, Phys. Rev. C8 (1973) 37.
4. D.Shapira, R.G.Stokstad, and D.A.Bromley, Phys. Rev. C10 (1974) 1063-1082.
5. Formulas based on equidistant model and literature references may be found in a review paper by J.R.Huizenga and L.G.Moretto, Ann. Rev. Nucl. Sci. 22 (1972) 427.
6. J.R.Huizenga, Statistical Properties of Nuclei, edited by J.B.Gary (Plenum Press, New York, 1972), p.425.
7. M.Maruyama, Nucl. Phys. A131 (1969) 145.
8. A.Ignalyuk, V.S.Stavinskii, and Yu.N.Shubin, Sov. J. Nucl. Phys. 11 (1970) 563.

9. L.G.Moretto, Nucl. Phys. A185 (1972) 145-165.
10. L.G.Moretto, Nucl. Phys. A216 (1973) 1-28.
11. A.S.Jensen and D.Damgaard, Nucl. Phys. A203 (1973) 578.
12. A.N.Behkami and J.R.Huizenga, Nucl. Phys. A217 (1973) 78.
13. F.C.Williams,Jr., G.Chan and J.R.Huizenga, Nucl. Phys. A187 (1972) 225.
14. H.Baba, Nucl. Phys. A159 (1970) 625.
15. W.Dilg, W.Schantl, H.Vonach, and M.Uhl, Nucl. Phys. A217 (1973) 269.
16. L.C.Vaz, C.C.Lu, and J.R.Huizenga, Phys. Rev. C5 (1971) 463.
17. C.C.Lu, L.C.Vaz, and J.R.Huizenga, Nucl. Phys. A190 (1972) 229.
18. C.C.Lu, L.C.Vaz, and J.R.Huizenga, Nucl. Phys. A197 (1972) 321-336.
19. L.C.Vaz, C.C.Lu, and J.R.Huizenga, UR-NSRL-54 (1972).
20. P.A.Seeger and R.C.Perisho, Los Alamos Scientific Laboratory Report LA-3761 (1957).
21. S.G.Nilsson, C.F.Tsang, A.Sobiczewski, Z.Syzmanski, S.Wycech, C.Gustafson, I.L.Lamm, P.Möller, and B.Nilsson, Nucl. Phys. A131 (1969) 1.
22. M.Sano and S.Yamasaki, Prog. Theor. Phys. Rev. 83 (1951) 243.
23. P.Decowski, W.Grochulski, A.Marcinkowski, K.Siwiek and Z.Wilhelmi, Nucl. Phys. A110 (1968) 129.
24. M.Hillman and J.R.Grover, Phys. Rev. 185 (1969) 1303.
25. L.G.Moretto, Nucl. Phys. A182 (1972) 642.
26. N.N.Bogoliubov, Nuovo Cimen. 1 (1958) 794.
27. M.Sano and S.Yamasaki, Prog. Theor. Phys. 29 (1963) 397.
28. A.Bohr and B.R.Mottelson, Nuclear Structure, Vol. 1 (Benjamin, New York, 1969) p.170.
29. P.E.Nemirowsky and Yu.V.Adamchuk, Nucl. Phys. 39 (1962) 551.

30. This code can be obtained from the author upon request.
31. S.G.Nilsson, Mat. Fys. Medd. Dan. Vid. Selsk. 29 (1955) 16.
32. J.R.Huizenga, A.N.Behkami, J.S.Sventek and R.W.Atcher, Nucl. Phys. A223 (1974) 577.
33. J.R.Huizenga, A.N.Behkami, R.W.Atcher, J.S.Sventek, H.C.Britt and H.Freiesleben, Nucl. Phys. A223 (1974) 589.
34. F.G.Perey, Phys. Rev. 131 (1963) 745.
35. J.R.Huizenga and G.Igo, Nucl. Phys. 29 (1962) 462.
36. F.Bjorklund and S.Frenbach, Phys. Rev. 109 (1958) 1295.
37. G.M.Temmer, Phys. Rev. Letters 12, 330 (1964).
38. A.D.Carlson and H.H.Barschall, Phys. Rev. 158, 1142 (1967).
39. O.Hausser, P.VonBrentano, and T.Mayer-Kuckuk, Phys. Letters 12, 226 (1964).
40. D.M.Brink and R.O.Stephen, Phys. Letters 5, 77 (1963).
41. M.Jaskola, I.M.Turkiewicz, J.Turkiewicz, and F.Gradzki, Nucl. Phys. 79, 108 (1966).
42. A.A.Katsanos, ANL-7289
43. P.VonBrentano, J.Ernst, O.Hausser, T.Mayer-Kuckuk, A.Ritcher, and W.VonWitsch, Phys. Letters 9, 48 (1964).
44. B.W.Allardyce, P.Y.Dallimore, I.Hall, N.W.Tanner, and A.Ritcher, Nucl. Phys. 80, 394 (1966).
45. D.VonEhrenstein, L.Meyer-Schutzmeister, and R.G.Allas, Nucl. Phys. 79, 625 (1966).
46. A.Ritcher, A.Bamberger, P.VonBrentano, T.Mayer-Kuckuk, and W.VonWitsch, Z.Naturfor. 21, 100 (1966).

47. H.K.Vonach and H.H.Barschall, Phys. Rev. 158, 1142 (1967).
48. P.Fessenden, W.R.Gibbs and R.B.Leachman, Phys. Rev. Letters 15, 796 (1965).

TABLE 1. Experimental and theoretical energy level widths.

Compound nucleus	Reaction	Ref.	Range of measurement (MeV)	Excitation energy (MeV)	Γ_{exp} (keV)	$\Gamma_{\text{theo}}^{(1) a}$ (keV)	$\Gamma_{\text{theo}}^{(2) b}$ (keV)
^{24}Mg	$^{23}\text{Na}(p, \alpha_0)^{20}\text{Ne}$	37	$E_p = 8 - 12$	21.4	110 ± 40	29.7	49.2
^{25}Mg	$^{24}\text{Mg} + n$	38	$E_n = 9.5 - 11.5$	17.4	28 ± 6	39.9	55.3
	$^{24}\text{Mg} + n$	38	$E_m = 11 - 12.5$	18.6	28 ± 6	57.2	86.8
^{27}Al	$^{26}\text{Mg}(p, p_0)^{26}\text{Mg}$	39	$E_p = 8.3 - 10.5$	17.4	47 ± 12	17.5	19.1
^{28}Al	$^{27}\text{Al} + n$	38	$E_n = 6.5 - 8.8$	15.1	42 ± 10	15.2	25.9
^{28}Si	$^{27}\text{Al}(p, p_0)^{27}\text{Al}$	40	$E_p = 9.36 - 11.3$	21.6	36 ± 6	21.9	17.7
^{29}Si	$^{28}\text{Si} + n$	38	$E_n = 9.5 - 11.5$	18.7	34 ± 10	64.0	98.0
^{30}Si	$^{29}\text{Si}(n, \alpha_0)^{26}\text{Mg}$	41	$E_n = 13.4 - 15$	24.4	25 ± 10	88.2	122.7
^{32}S	$^{31}\text{P}(p, \alpha_0)^{28}\text{Al}$	42	$E_p = 9 - 10$	19.0	41 ± 12	43.8	29.7
^{33}S	$^{32}\text{S} + n$	38	$E_n = 8.7 - 11.2$	18.3	30 ± 5	99.1	77.8
^{36}Ar	$^{35}\text{Cl}(p, \alpha)^{32}\text{S}$	43	$E_p = 9.6 - 10.4$	18.23	16 ± 5	13.7	10.8
^{38}Ar	$^{37}\text{Cl}(p, \alpha_0)^{34}\text{S}$	44	$E_p = 9.5 - 10.3$	19.9	12.5 ± 4	12.9	8.3
^{40}Ca	$^{39}\text{K}(p, \alpha_0)^{36}\text{Ar}$	45	$E_p = 10.5 - 11$	18.8	10 ± 5	8.4	8.5
^{46}Ti	$^{45}\text{Sc}(p, \alpha_0)^{42}\text{Ca}$	46	$E_p = 8.5 - 9.4$	19.1	6.4 ± 1	16.1	11.9
^{52}Cr	$^{51}\text{V}(p, \alpha_0)^{48}\text{Ti}$	42	$E_p = 9 - 9.66$	19.7	7.1 ± 3	9.5	13.1
	$^{51}\text{V}(p, \alpha_0)^{48}\text{Ti}$	42	$E_p = 10 - 10.66$	20.7	8.2 ± 3	15.8	21.3
^{55}Mn	$^{54}\text{Cr}(p, p_0)^{54}\text{Cr}$	46	$E_p = 9.3 - 10.11$	17.7	11 ± 3	9.1	7.5
^{56}Fe	$^{55}\text{Mn}(p, \alpha_0)^{52}\text{V}$	47	$E_p = 11.5 - 11.9$	19.7	5 ± 3	8.1	3.1
^{57}Co	$^{56}\text{Fe}(p, p_0)^{56}\text{Fe}$	46	$E_p = 11.5 - 11.9$	17.5	5 ± 1	3.4	1.7
^{60}Ni	$^{59}\text{Co}(p, \alpha_0)^{56}\text{Fe}$	47		20.4	0.63 ± 0.17	19.4	18.8
^{76}Se	$^{75}\text{As}(p, \alpha_0)^{72}\text{Ge}$	48		15.24	6.9 ± 0.3	0.31	0.44
^{90}Zr	$^{89}\text{Y}(p, \alpha_0)^{86}\text{Sr}$	49		18.8	0.176 ± 0.04	0.126	0.128
	$^{89}\text{Y}(p, \alpha_0)^{86}\text{Sr}$	49		20.86	0.173 ± 0.087	2.01	3.22
^{104}Pd	$^{103}\text{Rh}(p, \alpha_0)^{100}\text{Ru}$	48		17.72	0.233 ± 0.064	0.196	0.295
^{108}Cd	$^{107}\text{Ag}(p, \alpha_0)^{104}\text{Pd}$	48		16.35	0.088 ± 0.026	0.076	0.089

^aData derived using the pairing gaps from Ref. 28.^bData derived using the pairing gaps from Ref. 29.

Fig. 1. A schematic diagram of formation of a compound nucleus and its subsequent decay.
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Fig. 2. Pairing gap Δ_n , Δ_p plotted as a function of mass number used in the statistical model calculations.

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Fig. 3. Plot of the level density with a microscopic theory as a function of excitation energy for different nuclei using the gap parameters from Ref. 28.

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Fig. 4. Plot of the spin cut-off factors for the same nuclei and excitation energies as in Fig. 3.

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Fig. 5. Behavior of the partial width $\Gamma_J^b(E)$ versus J for the compound nucleus ^{76}Se and ^{104}Pd at excitation energy of 17.0 MeV.

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Fig. 6. Behavior of the partial width $\Gamma_J^b(E)$ versus J for the compound nucleus ^{76}Se and ^{104}Pd at excitation energy of 17.0 MeV.

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Fig. 7. The dependence of energy level widths on $\sqrt{A/E^*}$. A and E^* are the mass (amu) and excitation energy (MeV), respectively.

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