^{31}P(pol d,p),(d,p) 1989Ec03,1986So01

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Full Evaluation	Jun Chen	NDS 201,1 (2025)	31-Oct-2024

$J^\pi(^{31}P$ g.s.)=1/2$^+$.

Also includes (d,pγ) by 1968Me05 for half-life measurement of 78-keV level.

(pol d,p):

1989Ec03: E=20 MeV polarized deuteron beam was produced from the Munich MP tandem accelerator laboratory. Target was 81 μg/cm^2 ^{31}P on a 10 μg/cm^2 carbon backing. Reaction products were momentum-analyzed with a Q3D spectrograph (FWHM=5-7 keV) and detected with single wire proportional counters and plastic scintillators. Measured vector analyzing powers, $\sigma(E_p,\theta)$ with θ_{cm}=0° to 50°. Deduced levels, J, π, L-transfers from DWBA analysis. Comparisons with available data. Report 104 levels up to 8363.

(d,p):

1986So01: E=3 MeV from an electrostatic accelerator. Reaction products were momentum-analyzed with a magnetic spectrograph. Measured proton spectra and cross sections. Deduced levels. Report 34 levels between 3700 and 7000.

1978Co21: E=1.5-2.5 MeV at the Atomic Energy Establishment, Egypt. Measured $\sigma(E_p,\theta)$, θ_{cm}=20° to 150°. Deduced levels, J, π, L-transfers and spectroscopic factors from DWBA analysis.

1973Va13: E=10 MeV deuterons from the Utrecht 6 MV tandem Van de Graaff generator. Protons were analyzed in a split-pole magnetic spectrograph (FWHM=6-10 keV) and detected using a focal plane position sensitive detector. Measured $\sigma(E_p,\theta)$, θ_{cm}=0° to 140°. Deduced levels, J, π, L-transfers and spectroscopic factors from DWBA analysis. Report 22 levels up to 4160.

1968Me05: E=2.5 MeV deuterons from the University of Iowa type-CN Van de Graaff accelerator. GaP target. Silicon surface barrier detector. Lifetime of first excited state determined using the third moment about the centroid of the photopeak.

1965Ba27: E=1.3-2.5 MeV deuterons from the 2.5-MeV electrostatic accelerator of the UAR Atomic Energy Establishment. Reaction products were momentum-analyzed with a magnetic analyzer. Measured $\sigma(E_p,\theta)$, θ=15° to 150°. Deduced levels, L-transfers and deformation parameters from Butler curve analysis. Report 10 proton groups.

1962Ho09: E=7.8 MeV deuterons from the University of Michigan cyclotron. Reaction products were momentum-analyzed with a high-resolution magnetic spectrometer (FWHM=15-20 keV) and detected in nuclear emulsion plates. Measured $\sigma(E_d,\theta)$, $\theta_{c.m.}$=0° to 90°. Deduced levels, J, π, relative reduced widths and L-transfers from Butler curves analysis. Report 58 levels up to 6710.

1960Pi05: E=6 MeV deuterons from MIT-NOR electrostatic generator. Silver phosphorus targets. Magnetic spectrograph and photographic emulsion. Measured proton groups. Deduced levels. Report 52 excited levels up to 6200.

Others: 1976We29, 1977Hu07, 1977Ba75, 1983Ye01.

^{32}P Levels

For spectroscopic factors (2J+1)S under comments, two values from 1978Co21 are obtained by using ordinary exponential wave function for the deuteron and by using a Hulthen wave function, respectively.

E(level)[†]	J$^\pi$[†]	$T_{1/2}$	L[#]	dσ/dΩ (μb/sr)[@]	Comments
0	1$^+$		0+2	474	L: also from 1962Ho09 and 1973Va13; (0)+2 from 1978Co21. (2J+1)S: <0.07 for $s_{1/2}$ and 3.0 for $d_{3/2}$ (1973Va13); 3.17 and 2.07 for $d_{3/2}$ for 0+78 doublet (1978Co21).
78.1 *12*	2$^+$	360 ps *+62−35*	2	664	E(level): others: 77 *3* (1960Pi05), 77 (1962Ho09). $T_{1/2}$: from delayed-coincidence in 1968Me05. L: also from 1962Ho09 and 1978Co21. (2J+1)S: 4.7 for $d_{3/2}$ (1973Va13); 3.17 and 2.07 for 0+78 doublet (1978Co21).
511.6 *12*	0$^+$		0	360	E(level): others: 516 *3* (1960Pi05), 516 (1962Ho09). L: also from 1962Ho09, 1973Va13, 1978Co21. (2J+1)S: 0.32 for $s_{1/2}$ (1973Va13); 0.34 and 0.22 (1978Co21).
1151.2 *17*	1$^+$		0	659	E(level): others: 1149 *3* (1960Pi05), 1149 (1962Ho09). L: from 1978Co21, 1973Va13, 1962Ho09. Other: 0+2 (1989Ec03). (2J+1)S: 0.53 for $s_{1/2}$ (1973Va13); 1.16 and 0.76 (1978Co21).

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^{31}P(pol d,p),(d,p) 1989Ec03,1986So01 (continued)

^{32}P Levels (continued)

E(level)[†]	Jπ[†]	L[#]	dσ/dΩ (μb/sr)[@]	Comments
1327.6 *15*		2	8	E(level): others: 1322 *4* (1960Pi05), 1322 (1962Ho09). L: from 1978Co21. (2J+1)S: 0.51 and 0.33 for $d_{3/2}$ (1978Co21).
1510? *20*				E(level): from 1962Ho09.
1756.1 *28*	3^+	2	22	E(level): others: 1755 *4* (1960Pi05), 1755 (1962Ho09). L: from 1978Co21. Others: 2+4 (1989Ec03), (2) (1973Va13). (2J+1)S: (0.07) for $d_{5/2}$ (1973Va13); 1.21 and 0.79 (1978Co21).
2175.8 *20*	$(3)^+$	2+4	12	E(level): others: 2177 *4* (1960Pi05), 2177 (1962Ho09). (2J+1)S: 0.45 and 0.30 for $s_{1/2}$, 0.33 and 0.22 for $d_{3/2}$ for unresolved triplet 2180+2220+2230 in 1978Co21.
2221.9 *13*	2^+	2	46	E(level): others: 2223 *4* (1960Pi05), 2223 (1962Ho09). L: others: 0+2 (1962Ho09), 2 (1973Va13), 2 (1978Co21). (2J+1)S: 0.13 for $s_{1/2}$ and 0.40 for $d_{3/2}$ (1973Va13); see comments for 2176 level.
2229.5 *30*	$(1)^+$	0+2	241	L: also from 1973Va13 and 1978Co21. (2J+1)S: 0.32 for $s_{1/2}$ (1973Va13); 0.34 and 0.22 (1978Co21).
2658.0 *6*	2^+	2	49	E(level): others: 2657 *5* (1960Pi05), 2657 (1962Ho09). L: others: (2,3) (1962Ho09), (1,2,3) (1973Va13), 2 (1978Co21). (2J+1)S: (0.22) for $d_{3/2}$, (0.01) for $p_{1/2}$, (0.40) for $f_{5/2}$ (1973Va13); 0.02 and 0.01 for $s_{1/2}$ (1978Co21).
2738.3 *12*	$(1,2)^+$	2	13[&]	E(level): others: 2743 *5* (1960Pi05), 2743 (1962Ho09). L: others: 2 (1962Ho09), 0+2 (1973Va13 and 1978Co21). (2J+1)S: 0.003 for $s_{1/2}$ and 0.04 for $d_{3/2}$ (1973Va13); 0.15 and 0.10 for $d_{3/2}$ (1978Co21).
3001.7 *12*	$(3)^+$	2(+4)	52	E(level): others: 3007 *5* (1960Pi05), 3007 (1962Ho09). L: others: (2,3) (1962Ho09), (2) (1973Va13). (2J+1)S: (0.22) for $d_{3/2}$ (1973Va13).
3144.4 *11*			2[&]	E(level): other: 3148 (1962Ho09).
3263.9 *7*	$(1,2)^-$	1	647	E(level): others: 3265 *5* (1960Pi05), 3265 (1962Ho09). L: also from 1962Ho09 and 1973Va13. (2J+1)S: 1.1 for $p_{1/2}$ (1973Va13).
3319.1 *6*	$(2,4)^-$	3	1807	E(level): others: 3324 *5* (1960Pi05), 3324 (1962Ho09). L: others: 3,(2) (1962Ho09), 3 (1973Va13). (2J+1)S: 3.1 for $f_{7/2}$ (1973Va13).
3443.5 *7*	4^-	3	4044[&]	E(level): others: 3447 *5* (1960Pi05), 3447 (1962Ho09). L: from 1973Va13. Others: 3,(2) (1962Ho09), 3(+5) (1989Ec03). (2J+1)S: 7.0 for $f_{7/2}$ (1973Va13).
3795.0 *12*	$(1)^+$	0+2	7	E(level): others: 3798 *6* (1960Pi05), 3798 (1962Ho09). L: other: L=3 from 1973Va13 is in disagreement. (2J+1)S: 0.13 for $f_{7/2}$ (1973Va13).
3880.9 *6*	2^+	2	86	E(level): others: 3879.6 *6* (1986So01), 3890 *6* (1960Pi05), 3890 (1962Ho09). L: also from 1973Va13. (2J+1)S: 0.28 for $d_{3/2}$ (1973Va13).
3989.9 *7*	$(1,3)^+$	(0)+2	94[a]	Jπ: 1989Ec03 point out that 3^+ gives a better agreement with theoretical spectroscopic factors. E(level): others: 3994 *6* (1960Pi05), 3994 (1962Ho09).
4010.0 *20*	$(2)^-$	1	1488[a]	E(level): others: 4010 *6* (1960Pi05), 4010 (1962Ho09). L: from 1962Ho09. Other: 1+3 (1989Ec03 and 1973Va13). (2J+1)S: 0.33 for $p_{1/2}$ and 0.63 for $f_{5/2}$ (1973Va13).
4035.1 *12*	$(1,2)^-$	1	6060[a]	E(level): others: 4040 *6* (1960Pi05), 4040 (1962Ho09). L: others: 1,(2) (1962Ho09), 1 (1973Va13). (2J+1)S: 1.3 for $p_{1/2}$ (1973Va13).
4149.8 *14*	4^-	3	121[&]	E(level): others: 4158 *6* (1960Pi05), 4158 (1962Ho09). L: from 1973Va13. Other: 3(+5) (1989Ec03).

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^{31}P(pol d,p),(d,p) 1989Ec03,1986So01 (continued)

^{32}P Levels (continued)

E(level)†	Jπ†	L#	dσ/dΩ (μb/sr)@	Comments
				(2J+1)S: 0.18 for $f_{7/2}$ (1973Va13).
4204.3 *6*	1^+	0+2	113	E(level): others: 4204.9 *7* (1986So01), 4209 *6* (1960Pi05), 4209 (1962Ho09). L: from 1962Ho09. Other: 0+2 (1989Ec03).
4275.1 *30*			22	E(level): others: 4280 *6* (1960Pi05), 4280 (1962Ho09).
4316.6 *14*	$(3)^+$	2(+4)	13	E(level): others: 4316 *6* (1960Pi05), 4316 (1962Ho09).
4409.8 *12*	$(0,1)^-$	1	36	E(level): others: 4409.1 *7* (1986So01), 4412 *6* (1960Pi05), 4412 (1962Ho09). L: other: 1,(2) (1962Ho09).
4554.7 *6*	2^+	2	29	E(level): other: 4560 (1962Ho09).
4613.1 *18*	$(3)^+$	2+4	20	E(level): others: 4608.6 *18* (1986So01), 4615 *7* (1960Pi05), 4615 (1962Ho09).
4661.4 *14*	$(1,2)^-$	1	2533[a]	E(level): others: 4664 *7* (1960Pi05), 4664 (1962Ho09). L: other: 1,(2) (1962Ho09).
4697.0 *17*	$(3)^+$	(2)+4	14	
4710.2 *19*	$(1)^+$	0+2	40	E(level): other: 4709.4 *6* (1986So01).
4743 *4*	(3^+)	(2)+4	5[b]	
4847.5 *11*			3[b]	E(level): other: 4849.4 *7* (1986So01).
4874.1 *30*	$(1,2)^-$	1	267	E(level): others: 4878 *7* (1960Pi05), 4878 (1962Ho09). L: other: 1,(2) (1962Ho09).
4940.7 *25*			3[b]	E(level): others: 4942.5 *9* (1986So01), 4944 *7* (1960Pi05), 4944 (1962Ho09).
5011.8 *30*			23[&]	E(level): others: 5006.2 *10* (1986So01), 5010 *7* (1960Pi05), 5010 (1962Ho09).
5080.5 *13*	$(4)^-$	3(+5)	715[&]	E(level): others: 5077 *7* (1960Pi05), 5077 (1962Ho09). L: other: 3,(2) (1962Ho09).
5129.4 *15*			10[&]	E(level): others: 5124.5 *10* (1986So01), 5129 *7* (1960Pi05), 5129 (1962Ho09).
5233.5 *14*	$(2)^-$	1(+3)	16	E(level): others: 5234.8 *11* (1986So01), 5232 *7* (1960Pi05), 5237 (1962Ho09).
5350.3 *6*	$(1,2)^-$	1	558	E(level): others: 5346 *7* (1960Pi05), 5346 (1962Ho09). L: other: 1,(2) (1962Ho09).
5396.4 *12*			2[b]	E(level): others: 5395.6 *14* (1986So01), 5394 *7* (1960Pi05), 5394 (1962Ho09).
5497.8 *34*		>2	219[&]	E(level): other: 5493.2 *7* (1986So01).
5510.0 *9*	$(0,1)^-$	1	448[&]	E(level): others: 5510 *6* (1960Pi05), 5510 (1962Ho09). L: other: 1,(2) (1962Ho09).
5554.4 *12*			10[&]	E(level): others: 5554.2 *18* (1986So01), 5550 *8* (1960Pi05), 5550 (1962Ho09).
5587.9‡ *22*				
5663.4 *15*			30[&]	E(level): others: 5661.6 *11* (1986So01), 5657 *8* (1960Pi05), 5657 (1962Ho09).
5673.5 *15*	$(1,2)^+$	2	8[b]	E(level): other: 5673.6 *10* (1986So01).
5704.3 *20*	$(1,2)^-$	1	13[b]	E(level): others: 5703.4 *7* (1986So01), 5700 *8* (1960Pi05), 5700 (1962Ho09). L: other: 1+3 (1962Ho09).
5724.8 *9*	(4^-)	3(+5)	12[b]	E(level): others: 5725.7 *8* (1986So01), 5724 *8* (1960Pi05), 5724 (1962Ho09). L: other: 1+3 (1962Ho09).
5778.2 *10*	1^-	1	65[b]	E(level): others: 5775 *8* (1960Pi05), 5775 (1962Ho09). L: other: 1,(2) (1962Ho09).
5815.2 *16*	$(3,4)^-$	3	170[a]	E(level): others: 5816.0 *26* (1986So01), 5813 *8* (1960Pi05), 5813 (1962Ho09).
5830.1‡ *9*				E(level): others: 5835 *8* (1960Pi05), also seen in 1962Ho09.
5860.2 *11*	(2^-)	1(+3)	252[a]	E(level): others: 5858 *8* (1960Pi05), 5858 (1962Ho09).
5968.7 *22*			25	E(level): others: 5968.0 *14* (1986So01), 5964 *8* (1960Pi05), 5964 (1962Ho09).
5971.8 *21*			68	
5989? *8*				E(level): from 1960Pi05, also seen in 1962Ho09.

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^{31}P(pol d,p),(d,p) 1989Ec03,1986So01 (continued)

^{32}P Levels (continued)

E(level)[†]	Jπ[†]	L[#]	dσ/dΩ (μb/sr)[@]	Comments
6026.2 *10*	(2,3,4)$^-$	3	43	E(level): others: 6024 *8* (1960Pi05), 6024 (1962Ho09).
6062.7 *9*	1$^-$	1	244	E(level): others: 6062 *8* (1960Pi05), 6062 (1962Ho09). L: other: 1,(2) (1962Ho09).
6104.8 *8*	(3)$^+$	2+4	22	E(level): others: 6103.4 *15* (1986So01), 6096 *8* (1960Pi05), 6096 (1962Ho09).
6147.2 *22*	(1,2,3)$^+$	2	19[&]	E(level): others: 6131 *8* (1960Pi05), 6131 (1962Ho09).
6160? *8*				E(level): from 1960Pi05 also seen in 1962Ho09.
6197.2 *10*	(0,1)$^-$	1	168	E(level): others: 6195.2 *14* (1986So01), 6196 *8* (1960Pi05), 6196 (1962Ho09). L: other: 1,(2) (1962Ho09).
6278.7 *23*			9[b]	E(level): other: 6275.0 *14* (1986So01).
6298.1[‡] *14*				
6310.7 *19*		>1	22[b]	E(level): other: 6310.9 *14* (1986So01).
6332.9 *15*		0	11[b]	E(level): others: 6329.3 *14* (1986So01), 6340 *20* (1962Ho09). L: from 1962Ho09.
6378.0[‡] *15*				
6396.2 *27*			8	E(level): other: 6393.1 *18* (1986So01).
6413.0 *6*			4	
6434.1 *32*			15	
6477.0 *27*	(4$^-$)	3(+5)	24	
6530.7 *22*		3	357[a]	E(level): others: 6531.7 *15* (1986So01), 6530 *20* (1962Ho09). L: from 1962Ho09. Other: <3 (1989Ec03).
6553.0 *26*		<3	255[&]	
6581.9 *5*		3	984[a]	E(level): others: 6583.5 *17* (1986So01), 6580 *20* (1962Ho09). L: from 1962Ho09. Other: <3 (1989Ec03).
6682.3 *33*		(2+3)	83[&]	
6685.0 *20*			40[&]	
6705.3 *12*			153[&]	
6707.8 *15*			138[&]	E(level): other: 6710 *20* (1962Ho09).
6733.8 *10*			18[&]	
6738.1 *11*			9[&]	
6780.5[‡] *21*				
6858.0 *12*			399[&]	E(level): other: 6856.8 *22* (1986So01).
6996.9 *33*			37	
7067 *3*			52	
7339.8 *20*			70[&]	
7343.1 *18*			122[&]	
7392.7 *23*		>1	247[&]	
7655.4 *34*			11	
7679.0 *14*			23	
7767.2 *25*			75	
7806.6 *26*	(2,3,4)$^-$	3	63	
7810.2 *34*	(4$^-$)	3(+5)	77	
7851.7 *20*	(2,3,4)$^-$	3	36	
7875.3 *36*	(3,4,5)$^-$	4	131	
7925.5 *20*			17	
7939.6 *20*			17	
7957.9 *28*		>2	65	
7963.1 *32*			44	
7990.5 *28*		>2	35	
8018.1 *27*	(2,3,4)$^-$	3	109	

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^{31}P(pol d,p),(d,p) 1989Ec03,1986So01 (continued)

^{32}P Levels (continued)

E(level)†	Jπ†	L#	dσ/dΩ (μb/sr)@	E(level)†	Jπ†	L#	dσ/dΩ (μb/sr)@
8036.7 *33*	$(1,2)^+$	2	29	8165.7 *34*			33
8042.2 *33*			32	8202.5 *33*	$(2,3,4)^-$	3	68
8076.7 *36*			22	8247.4 *28*			15
8082.6 *18*			21	8337.2 *29*	$(1,2)^+$	2	37
8098.7 *21*		>3	95	8363.1 *26*			30&
8158.1 *26*	$(2,3,4)^-$	3	74				

† From 1989Ec03, unless otherwise noted. Spin-parities are deduced based on measured $\sigma(\theta)$ and analyzing powers.
‡ From 1986So01.
# From 1989Ec03, unless otherwise noted. Values from 1989Ec03 are in good agreement with values from other work as given under comments.
@ At 30° (1989Ec03), unless otherwise stated.
& At 20° (1989Ec03).
a At 10° (1989Ec03).
b At 50° (1989Ec03).