Scattering factors used are those of Cromer & Waber (1974). Investigation used *XTAL*/PC (Hall & Stewart, 1990; Grossie, 1990). Table 1* presents the final atomic coordinates and equivalent isotropic thermal parameters. Selected derived values in the form of interatomic distances and angles are tabulated in Table 2. A drawing of the molecular structure is shown in Fig. 1.

Related literature. The structures of other sydnones have been reported by Barnighausen, Jellinek, Munnik & Vos (1963), Hope & Thiessen (1969) and King, Preston, Suffolk & Turnbull (1979). The sydnone ring in the title compound is virtually identical (within errors) to the other sydnones reported even though there should be considerable structural strain from the ring fusion.

* Lists of structure factors, anisotropic thermal parameters, H-atom parameters, dihedral angles and least-squares planes have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 54519 (18 pp.). Copies may be obtained through The Technical Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England. [CIF reference: ST0533]

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References

BARNIGHAUSEN, H., JELLINEK, F., MUNNIK, J. & VOS, A. (1963). *Acta Cryst.* **16**, 471–475.

CROMER, D. T. & WABER, J. T. (1974). *International Tables for X-ray Crystallography*, Vol. IV, Table 2.2B. Birmingham: Kynoch Press. (Present distributor Kluwer Academic Publishers, Dordrecht.)

GROSSIE, D. A. (1990). *Desktop Crystallography: XTAL for the Personal Computer*. International Union of Crystallography Meeting, Bordeaux, France.

HALL, S. R. & STEWART, J. M. (1990). *Editors. XTAL*3.0 *Reference Manual*. Univs. of Western Australia, Australia, and Maryland, USA.

HOPE, H. & THIESSEN, W. E. (1967). *J. Am. Chem. Soc.* **89**, 5977–5978.

HOPE, H. & THIESSEN, W. E. (1969). *Acta Cryst.* B**25**, 1237–1247.

KING, T. J., PRESTON, P. N., SUFFOLK, J. S. & TURNBULL, K. (1979). *J. Chem. Soc. Perkin Trans.* 2, pp. 1751–1757.

LOWE, J. D. & TURNBULL, K. (1986). *J. Heterocycl. Chem.* **23**, 125–128.

ROBERTSON, B. E. & WANG, H. (1990). *REGWT. XTAL*3.0 *Reference Manual*, edited by S. R. HALL & J. M. STEWART. Univs. of Western Australia, Australia, and Maryland, USA. Perth: Lamb.

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Structure of the Anti-Malarial Drug Primaquine Diphosphate

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Abstract. 8-(4-Amino-1-methylbutylamino)-6-methoxyquinoline bis(dihydrogenphosphate), $C_{15}H_{23}N_3O^{2+}.2(H_2PO_4)^-$, $M_r = 455.35$, triclinic, $P\bar{1}$, $Z = 2$, $a = 7.389$ (6), $b = 8.862$ (4), $c = 16.055$ (10) Å, $\alpha = 97.57$ (2), $\beta = 100.21$ (3), $\gamma = 77.01$ (2)°, $V = 1003.6$ (5) Å^3, $D_m = 1.495$ (by flotation), $D_x = 1.507$ g cm^{-3}, λ(Cu $K\alpha$) = 1.5418 Å, μ(Cu $K\alpha$) = 24.48 cm^{-1}, $F(000) = 480$, room temperature, $R = 0.068$ for 3448 observed reflections. The above working cell is related to the reduced cell with angles $\alpha = 82.43$, $\beta = 79.79$ and $\gamma = 77.01$° by the transformation (-1 0 0/0 -1 0/0 0 1). Primaquine diphosphate was crystallized in the dicationic form with protonation on the quinoline ring nitrogen atom and on the terminal amino group. One dihydrogenphosphate anion is chelated by the quinoline ring and the butylamino side chain. The other dihydrogenphosphate anion is hydrogen bonded to the terminal amino group. The C(14) atom is nearly in the plane of the quinoline ring with a C(9)—C(8)—N(13)—C(14) torsion angle of 169°. The butyl-diamino side chain is kinked by rotation about the C(14)—C(16) bond with a N(13)—C(14)—C(16)—C(17) torsion angle of -59°. The C(15) methyl substituent is inline with the rest of the butyl chain. The terminal amino group N(19) is hydrogen bonded to three symmetry-related phosphate groups while N(1) and N(13) are 'chelated' to a fourth phosphate group.

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Experimental. Primaquine diphosphate (Sigma Chemical Co.) was crystallized from an acidic aqueous ethanol solution (pH 2.5) in the form of orange rods. Data were collected using a 0.15 × 0.2 × 0.5 mm crystal on an Enraf–Nonius CAD-4 diffractometer using ω–2θ scans. 15 centered reflections in the θ range 20–30° were used to determine the unit-cell constants. Out of a total of 3793 reflections collected up to a 2θ limit of 140° ($h = 0 \rightarrow +9$, $k = -10 \rightarrow +10$, $l = -19 \rightarrow +19$), 3448 reflections with $I/\sigma(I) > 2$ were considered observed and used for the structure analysis. Three reflections were monitored every 2 h during data collection and showed a variation of 5% in intensity. No corrections for absorption were made.

The structure was solved by the Patterson method and refined by full-matrix least squares based on $|F_o|$. A difference Fourier map revealed all the H atoms including the one bound to N(1) of the quinoline ring. Anisotropic thermal parameters of the heavy atoms and isotropic thermal parameters of H atoms were refined. The H-atom coordinates were not refined. $R = 0.068$, $wR = 0.096$, $S = 2.69$, weight $= 1/[\sigma^2(F) + (0.03F_o)^2]$, max $\Delta/\sigma = 0.05$, max. excursion in the final difference map $= -0.7$ to $+1.0$ e Å^{-3}. Scattering factors for non-H atoms from Cromer & Waber (1965) and for H atoms from Stewart, Davidson & Simpson (1965). A locally modified version of the *SDP* program package from Enraf–Nonius (Frenz, 1982) was used.

The positional parameters are listed in Table 1.* A thermal ellipsoid drawing of the structure is given in Fig. 1 and a packing diagram in Fig. 2. Bond lengths, angles and torsion angles are given in Table 2 and hydrogen-bond distances in Table 3.

Related literature. Primaquine is the drug of choice for the treatment of *Plasmodium vivax* malaria (Webster, 1985). It inhibits protein biosynthesis (Olenick & Hahn, 1972; Olenick, 1975) by binding to DNA (Whichard, Morris, Smith & Holbrook, 1968) and this may be its mode of action. The primaquine dication contains two different functional groups known to bind nucleic acids. The N(1) protonated quinoline ring is analogous to the planar heterocyclic cationic acridine and phenanthroline dyes such as proflavin and ethidium which can intercalate

* Lists of structure factors and anisotropic thermal parameters have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 54537 (14 pp.). Copies may be obtained through The Technical Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England. [CIF reference: CR0331]

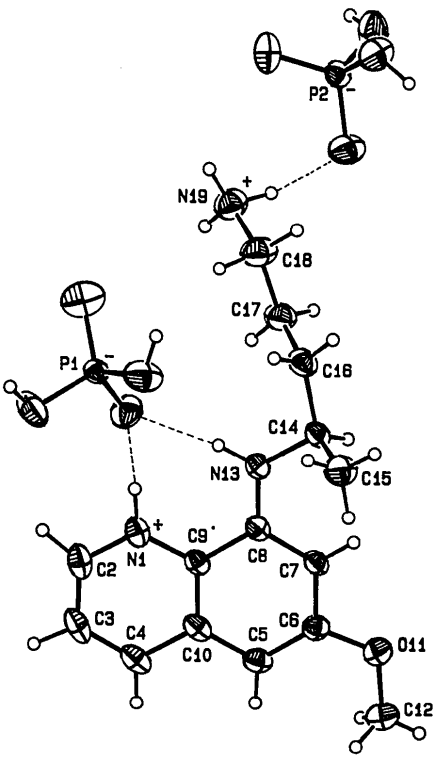

Fig. 1. Primaquine diphosphate with non-H atoms drawn as 50% probability ellipsoids and H atoms drawn as spheres of arbitrary size. The nitrogen atoms N(1) and N(19) are positively charged while the two phosphate groups are negatively charged.

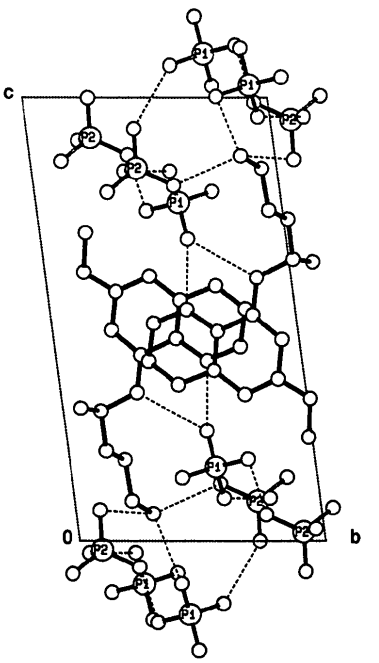

Fig. 2. Packing of the primaquine diphosphate structure viewed down a^*. Notice how the aromatic dications stack and the NH groups are involved in hydrogen-bonding interactions with the neighboring phosphate groups. A similar mode of interaction can be envisioned of two primaquine dications with adjacent sugar-phosphate strands of a DNA in the groove.

Table 1. *Fractional positional parameters for all atoms of primaquine diphosphate*

$B_{eq} = (4/3)\sum_i\sum_j \beta_{ij}\mathbf{a}_i.\mathbf{a}_j$.

	x	y	z	B_{eq} or B(Å^2)
N(1)	0.2469 (3)	0.5713 (3)	0.4248 (2)	2.36 (6)
C(2)	0.2876 (5)	0.7068 (4)	0.4589 (2)	3.00 (9)
C(3)	0.3169 (5)	0.7421 (4)	0.5460 (2)	3.10 (10)
C(4)	0.3052 (4)	0.6349 (4)	0.5979 (2)	2.85 (7)
C(5)	0.2400 (4)	0.3809 (4)	0.6147 (2)	2.50 (7)
C(6)	0.1944 (4)	0.2448 (3)	0.5765 (2)	2.27 (7)
C(7)	0.1692 (4)	0.2118 (3)	0.4875 (2)	2.19 (7)
C(8)	0.1867 (4)	0.3152 (3)	0.4332 (2)	1.98 (6)
C(9)	0.2300 (4)	0.4601 (3)	0.4733 (2)	1.99 (7)
C(10)	0.2575 (4)	0.4910 (3)	0.5624 (2)	2.18 (7)
O(11)	0.1663 (4)	0.1301 (3)	0.6181 (1)	3.13 (7)
C(12)	0.1863 (5)	0.1545 (4)	0.7088 (2)	3.25 (9)
N(13)	0.1614 (4)	0.2839 (3)	0.3476 (2)	2.51 (7)
C(14)	0.1511 (4)	0.1280 (3)	0.3052 (2)	2.33 (7)
C(15)	0.3375 (6)	0.0162 (4)	0.3242 (2)	3.40 (9)
C(16)	0.0999 (5)	0.1362 (4)	0.2106 (2)	2.82 (8)
C(17)	−0.0834 (5)	0.2402 (4)	0.1775 (2)	3.12 (9)
C(18)	−0.0875 (6)	0.2476 (5)	0.0837 (2)	3.80 (10)
N(19)	−0.2516 (5)	0.3542 (4)	0.0435 (2)	3.54 (8)
P(1)	0.2787 (1)	0.5426 (1)	0.1858 (1)	2.03 (2)
O1(P1)	0.4097 (4)	0.3785 (3)	0.1698 (2)	4.06 (7)
O2(P1)	0.4183 (4)	0.6542 (3)	0.2138 (2)	4.00 (8)
O3(P1)	0.1851 (4)	0.5417 (3)	0.2611 (1)	3.40 (7)
O4(P1)	0.1490 (3)	0.5832 (3)	0.1062 (1)	4.92 (7)
P(2)	−0.6551 (1)	0.1979 (1)	−0.0656 (1)	2.19 (2)
O1(P2)	−0.8639 (4)	0.1811 (3)	−0.0870 (2)	4.18 (9)
O2(P2)	−0.5466 (4)	0.0472 (3)	−0.1121 (1)	3.66 (7)
O3(P2)	−0.6288 (3)	0.3362 (3)	−0.1026 (2)	3.48 (6)
O4(P2)	−0.5860 (4)	0.1971 (3)	0.0285 (1)	3.89 (7)
H(N1)	0.230	0.555	0.366	5 (1)
H(C2)	0.280	0.776	0.415	3 (1)
H(C3)	0.340	0.845	0.567	4 (1)
H(C4)	0.324	0.654	0.658	4 (1)
H(C5)	0.261	0.407	0.673	3 (1)
H(C7)	0.141	0.124	0.464	4 (1)
H1(C12)	0.184	0.081	0.734	5 (1)
H2(C12)	0.110	0.241	0.724	4 (1)
H3(C12)	0.290	0.191	0.734	5 (1)
H(N13)	0.166	0.359	0.315	3 (1)
H(C14)	0.055	0.104	0.330	2 (1)
H1(C15)	0.338	−0.074	0.301	5 (1)
H2(C15)	0.375	0.014	0.386	4 (1)
H3(C15)	0.408	0.054	0.296	5 (1)
H1(C16)	0.096	0.053	0.180	4 (1)
H2(C16)	0.182	0.163	0.189	5 (1)
H1(C17)	−0.184	0.204	0.187	4 (1)
H2(C17)	−0.089	0.325	0.211	5 (1)
H1(C18)	−0.084	0.144	0.053	4 (1)
H2(C18)	0.027	0.299	0.086	13 (3)
H1(N19)	−0.259	0.433	0.076	6 (1)
H2(N19)	−0.230	0.371	−0.012	4 (1)
H3(N19)	−0.345	0.294	0.045	9 (2)
H(O1P1)	0.384	0.333	0.117	6 (1)
H(O2P1)	0.449	0.677	0.176	9 (2)
H(O1P2)	−0.944	0.261	−0.096	5 (1)
H(O2P2)	−0.502	−0.030	−0.078	4 (1)

Table 2. *Bond distances* (Å) *and angles* (°) *in the primaquine diphosphate structure*

N(1)—C(2)	1.328 (4)	N(13)—C(14)	1.469 (4)
N(1)—C(9)	1.373 (4)	C(14)—C(15)	1.513 (5)
C(2)—C(3)	1.381 (4)	C(14)—C(16)	1.506 (4)
C(3)—C(4)	1.369 (5)	C(16)—C(17)	1.510 (5)
C(4)—C(10)	1.419 (4)	C(17)—C(18)	1.511 (5)
C(5)—C(6)	1.364 (4)	C(18)—N(19)	1.465 (6)
C(5)—C(10)	1.409 (4)	P(1)—O1(P1)	1.573 (3)
C(6)—C(7)	1.408 (4)	P(1)—O2(P1)	1.556 (3)
C(6)—O(11)	1.358 (4)	P(1)—O3(P1)	1.497 (2)
C(7)—C(8)	1.386 (4)	P(1)—O4(P1)	1.488 (2)
C(8)—C(9)	1.435 (4)	P(2)—O1(P2)	1.556 (3)
C(8)—N(13)	1.354 (4)	P(2)—O2(P2)	1.566 (3)
C(9)—C(10)	1.408 (4)	P(2)—O3(P2)	1.494 (3)
O(11)—C(12)	1.430 (4)	P(2)—O4(P2)	1.507 (2)
C(2)—N(1)—C(9)	122.4 (3)	C(5)—C(10)—C(9)	120.7 (3)
N(1)—C(2)—C(3)	121.1 (4)	C(6)—O(11)—C(12)	117.3 (3)
C(2)—C(3)—C(4)	119.3 (4)	C(8)—N(13)—C(14)	122.9 (3)
C(3)—C(4)—C(10)	120.3 (4)	N(13)—C(14)—C(15)	110.6 (3)
C(6)—C(5)—C(10)	118.1 (3)	N(13)—C(14)—C(16)	109.6 (3)
C(5)—C(6)—C(7)	121.7 (3)	C(15)—C(14)—C(16)	109.5 (3)
C(5)—C(6)—O(11)	125.0 (3)	C(14)—C(16)—C(17)	118.2 (3)
C(7)—C(6)—O(11)	113.4 (3)	C(16)—C(17)—C(18)	107.8 (4)
C(6)—C(7)—C(8)	122.6 (3)	C(17)—C(18)—N(19)	114.3 (4)
C(7)—C(8)—C(9)	115.8 (3)	O1(P1)—P(1)—O2(P1)	103.9 (2)
C(7)—C(8)—N(13)	122.6 (3)	O1(P1)—P(1)—O3(P1)	108.6 (2)
C(9)—C(8)—N(13)	121.7 (3)	O1(P1)—P(1)—O4(P1)	109.7 (2)
N(1)—C(9)—C(8)	120.1 (3)	O2(P1)—P(1)—O3(P1)	106.4 (2)
N(1)—C(9)—C(10)	118.7 (3)	O2(P1)—P(1)—O4(P1)	112.4 (2)
C(8)—C(9)—C(10)	121.2 (3)	O3(P1)—P(1)—O4(P1)	115.2 (2)
C(4)—C(10)—C(5)	121.1 (3)	O1(P2)—P(2)—O2(P2)	103.7 (2)
C(4)—C(10)—C(9)	118.2 (3)	O1(P2)—P(2)—O3(P2)	110.6 (2)
		O1(P2)—P(2)—O4(P2)	111.2 (2)
		O2(P2)—P(2)—O3(P2)	108.7 (2)
		O2(P2)—P(2)—O4(P2)	108.4 (2)
		O3(P2)—P(2)—O4(P2)	113.8 (2)

Table 3. *Hydrogen-bonding distances* (Å) *in the primaquine diphosphate structure*

A—H···*B*	Sym.	Trans.			*A*···*B*
N(1)—H(N1)···O3(P1)	1	0	0	0	2.575 (4)
N(13)—H(N13)···O3(P1)	1	0	0	0	2.878 (3)
N(19)—H1(N19)···O3(P2)	2	−1	1	0	2.780 (4)
N(19)—H2(N19)···O4(P1)	2	0	1	0	2.801 (4)
N(19)—H3(N19)···O4(P2)	1	0	0	0	3.058 (4)
O1(P1)—H(O1P1)···O4(P2)	1	1	0	0	2.603 (4)
O2(P1)—H(O2P1)···O3(P2)	2	0	1	0	2.588 (4)
O1(P2)—H(O2P2)···O4(P1)	2	−1	1	0	2.619 (3)
O2(P2)—H(O4P2)···O4(P2)	2	−1	0	0	2.607 (4)

Symmetry codes: (1) x, y, z; (2) $-x, -y, -z$.

between the base pairs of double helical nucleic acids (Berman & Young, 1981). The butyl-diamino side chain of primaquine is similar in structure to the aliphatic amine putrescine (Woo, Seeman & Rich, 1979) and the central segment of spermine (Jain, Zon & Sundaralingam, 1989), which can bind to the phosphodiester groups of the nucleic acid backbone. The crystal structure of the related antimalarial drug, chloroquine, which is also in the bis(dihydrogen-phosphate) form, has been determined (Karle & Karle, 1988; Preston & Stewart, 1970).

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References

BERMAN, H. M. & YOUNG, P. R. (1981). *Ann. Bio. Biophys. BioEng.* **10**, 87–114.

CROMER, D. T. & WABER, J. T. (1965). *Acta Cryst.* **18**, 104–109.

FRENZ, B. A. (1982). *The Enraf–Nonius CAD4-SDP. A Real-Time System for Concurrent X-ray Data Collection and Crystal Structure Solution.* In *Computing in Crystallography*, edited by H. SCHENK, R. OLTHOF-HAZEKAMP, H. VAN KONINGSVELD & G. C. BASSI. Delft Univ. Press.
JAIN, S., ZON, G. & SUNDARALINGAM, M. (1989). *Biochemistry*, **28**, 2360–2364.
KARLE, J. M. & KARLE, I. L. (1988). *Acta Cryst.* C**44**, 1605–1608.
OLENICK, J. G. (1975). *Antibiotics*, **3**, 516–520.
OLENICK, J. G. & HAHN, F. E. (1972). *Antimicrobial Agents Chemotherapy*, **1**, 259–264.
PRESTON, H. S. & STEWART, J. M. (1970). *Chem Commun.* pp. 1142–1143.
STEWART, R. F., DAVIDSON, E. R. & SIMPSON, W. T. (1965). *J. Chem. Phys.* **42**, 3175–3187.
WEBSTER, L. T. (1985). *The Pharmacological Basis of Therapeutics*, 7th edition, edited by G. GILMAN, L. S. GOODMAN, T. W. RALL & F. MURAD, pp. 1051–1054.
WHICHARD, L. P., MORRIS, C. R., SMITH, J. M. & HOLBROOK, D. J. (1968). *Mol. Pharmacol.* **4**, 630–639.
WOO, N. H., SEEMAN, N. C. & RICH, A. (1979). *Biopolymers*, **18**, 539–545.

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Structure of 2-Chloro-7,12-dihydropyrido[3,2-*b*:5,4-*b'*]diindole

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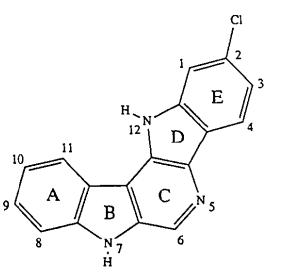
Abstract. $C_{17}H_{10}ClN_3$, $M_r = 291.74$, trigonal, $P3_1$, $a = 8.3291\ (5)$, $c = 17.1142\ (14)$ Å, $V = 1028.2\ (1)$ Å^3, $Z = 3$, $D_x = 1.413$ Mg m^{-3}, λ(Cu $K\alpha$) = 1.54178 Å, $\mu = 2.44$ mm^{-1}, $F(000) = 450$, $T = 293$ K, $R = 0.038$ for 1287 unique observed reflections. The pyridodiindole skeleton is planar (r.m.s. = 0.039 Å and $\chi^2 = 0.62$ for 20 atoms). In the crystal, the molecules stack in pairs with the terminal *A* and *E* rings of adjacent molecules (x, y, z and $x+1$, $y+1$, z) above one another at a distance of 3.44 (7) Å. The other intermolecular interaction in this structure is a hydrogen bond between the indole N(12)—H(12) group and the pyridine N(5) atom from a symmetry-related molecule at $-x+y$, $1-x$, $-\frac{1}{3}+z$; the N···N distance is 2.874 (5) Å, the H···N distance is 1.92 (5) Å and the angle N—H···N is 162 (4)°. Interestingly, the other hydrogen-donor group, the indole N(7)—H(7) group, is not involved in hydrogen bonding. The C—Cl bond length is 1.728 (4) Å.

Experimental. The title compound (I) was prepared by Trudell, Basile, Shannon, Skolnick & Cook (1987). Single crystals were obtained by slow evaporation from methanol/ethyl acetate solution. A rectangular solid of dimensions 0.44 × 0.20 × 0.08 mm was used for data collection on an Enraf–Nonius CAD-4F diffractometer with Ni-filtered Cu $K\alpha$ radiation. Accurate unit-cell parameters were obtained from a least-squares refinement of the angles of 25 reflections with $31 < \theta < 45°$. An ω–2θ scan mode was used; three standards measured every 2000 s indicated no crystal deterioration [003 682 (17), $2\bar{4}5$ 482 (18), $3\bar{1}2$ 237 (7)]; intensities for 4360 reflections were collected [h: $-10\rightarrow10$, k: $-10\rightarrow10$, l: $-21\rightarrow0$; maximum $(\sin\theta/\lambda) = 0.6257$ Å^{-1}]; 1470 unique reflections ($R_{int} = 0.076$) of which 183 were regarded as unobserved [$I < 2.5\sigma(I)$]. No absorption correction was applied.



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