The Crystal and Molecular Structure of Butein Monohydrate, Isolated from *Dahlia variabilis*

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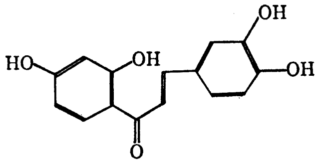
The crystals of butein monohydrate isolated from *Dahlia variabilis* are monoclinic. The unit cell, with dimensions of $a=10.89$, $b=28.88$, $c=4.29$ Å, and $\beta=96.7°$, contains four molecules, and the space group is $P2_1/n$. An approximate structure was obtained by applying the symbolic addition procedure. The structural parameters were refined by the block-diagonal least-squares method, and the final R factor for 1063 observed reflexions was 0.171. In the molecule, the C(7)–C(8) double bond and the C(9)–O(3) carbonyl group take the *s-cis* conformation with respect to the C(8)–C(9) single bond. The A phenyl group and the exocyclic atoms (C(7)∼O(3)) are nearly coplanar, and this plane makes a dihedral angle of 15.6° with that of the B phenyl group. The molecules build up a three-dimensional net through the hydrogen bonds. There is also an intramolecular hydrogen bond between O(3) and O(4).

From the experiment of feeding labelled acetate, phenylalanine, cinnamic acid, or shikimic acid to, for example, red cabbage, Neish *et al.*[1] have demonstrated conclusively that the C15-skeleton of flavonoids is biosynthesized through two separate pathways. One of the aromatic rings of flavonoids arises from the malonyl-CoA unit, whereas the other arises from the compounds in the prephenic-acid pathway. The C15-intermediate formed is then modified in various ways to give different types of flavonoid compounds. However, the problem has remained of whether the C15-intermediate is an activated flavanone or chalcone. Grisebach *et al.*[2] observed that ^{14}C-labelled chalcones are incorporated into flavonols, anthocyanins, and isoflavones, supporting the idea that chalcones are C15-intermediates of flavonoids. This is not conclusive, however, because the degree of the incorporation of chalcone is very low.



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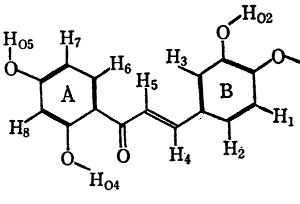

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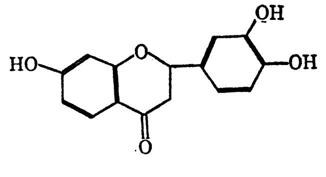

III

In order to carry out a study of flavonoids, it is necessary to have more detalied information on the structure of natural chalcones. Price[3] has reported that the chemical structure of butein from a yellow variety of species of dahlia is 3,4,2',4'-tetrahydroxychalcone (I). The present paper will deal with the X-ray structure determination of butein, isolated from the scarlet variety of the species of dahlia, as one of the major components of flavonoids.[4]

Experimental

Crystals were prepared by slow evaporation from a water-acetone mixture. They were yellow-orange needle crystals, showing a predominant (0 0 1) face. The crystal data obtained from the oscillation and Weissenberg photographs are summarized in Table 1. The reflexions were recorded, using Cu-K_α radiation, on equiinclination Weissenberg photographs for 0—3 layers around the c axis and for 0—2 layers around the b. The dimensions of the crystals used were $0.05\times0.03\times0.50$ mm. A total of 2217 independent reflexions were collected, of which 1154 were too weak to be measured, perhaps because of the small size of the crystals. Lorentz, polarization, and Phillips corrections were made as usual, but the absorption correction was omitted. The overall temperature factor obtained at this stage was 4.90 Å^2.

Table 1. Crystal data of butein monohydrate

Formula: $C_{15}H_{12}O_5\cdot H_2O$
M.W.=290.3; $F(0\ 0\ 0)=608$
Monoclinic, $a=10.89$, $b=28.88$, $c=4.29$Å
$\beta=96.7°$
Volume of the unit cell, 1393.9Å^3
Density (by flotation) 1.42 g·cm^{-3}
Density (calculated) 1.42 g·cm^{-3}
$Z=4$
Absent spectra: $h0l$ when $h+l$ is odd.
$0k0$ when k is odd.
Space group is $P2_1/n$

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[1] A. C. Neish, *Ann. Rev. Plant Physiol.*, **11**, 55 (1960).

[2] H. Grisebach, In "Chemistry and Biochemistry of Plant Pigments," ed. by T. W. Goodwin, Academic Press, London and New York (1965), pp. 279—308.

[3] J. R. Price, *J. Chem. Soc.*, **1939**, 1017.

[4] N. Saito, K. Ishizuka, and Y. Osawa, *Bot. Mag. Tokyo*, **83**, 229 (1970).

Structure Determination

The symbolic addition procedure[5] was applied for sign-determination. The starting set for applying the Σ_2 formula, in which three phases define the point of origin, is shown in Table 2. The SIGMA program was utilized to list the reflexion triplets with the associated probabilities. The signs of 161 reflexions out of 282 with $|E|\geq 1.5$ were determined, although 53 of them were later found to be incorrect. The E map computed with these signs (A+, B−) has shown the molecular skeleton clearly.

TABLE 2. STARTING SET OF THE SYMBOLIC ADDITION PROCEDURE

h	k	l	$\|E\|$	Phase or symbol
−10	6	1	4.42	+
− 7	14	1	4.93	+
− 6	11	2	3.71	+
− 8	16	2	4.88	A
− 8	15	1	3.99	B

A structure factor calculation based on this approximate structure gave an R factor of 0.46. Six cycles of block-diagonal matrix least-squares refinement decreased the R to 0.36. The water of crystallization was located from a difference Fourier synthesis.

Four subsequent cycles of refinement reduced the R to 0.23. Anisotropic thermal factors were then introduced; the R dropped to 0.183 after three cycles. At this stage, hydrogen atoms were located by assuming a suitable geometry and were included in the least-squares refinement. The R factor was reduced to 0.171 after three cycles. The atomic scattering factors were taken from International Tables for X-ray

TABLE 3. FINAL ATOMIC COORDINATES AND TEMPERATURE FACTORS
The anisotropic temperature factors are expressed in the form of
$\exp\{-(B_{11}h^2+B_{22}k^2+B_{33}l^2+B_{12}hk+B_{13}hl+B_{23}kl)\}$

Atom	x/a	y/b	z/c	B_{11} or B	B_{22}	B_{33}	B_{12}	B_{13}	B_{23}
C(1)	0.2284	0.0653	1.4473	0.00386	0.00065	−0.01087	0.00092	0.01649	0.00799
C(2)	0.3083	0.0294	1.3943	0.00816	0.00062	0.03446	−0.00026	0.03397	0.00073
C(3)	0.4145	0.0376	1.2613	0.00489	0.00030	−0.00532	−0.00031	0.01923	0.00175
C(4)	0.4369	0.0829	1.1601	0.00600	0.00072	0.00657	0.00108	0.04229	0.00151
C(5)	0.3571	0.1192	1.2022	0.00317	0.00052	0.01863	−0.00165	0.02110	−0.00227
C(6)	0.2483	0.1096	1.3240	0.00516	0.00026	0.01675	−0.00030	0.03555	−0.00024
C(7)	0.5510	0.0892	1.0270	0.00686	0.00065	−0.01462	0.00052	0.00941	−0.00184
C(8)	0.5853	0.1274	0.8762	0.00544	0.00088	0.00373	0.00294	0.02849	0.00328
C(9)	0.7048	0.1305	0.7681	0.00488	0.00047	0.04155	0.00036	0.02585	0.00303
C(10)	0.7368	0.1719	0.5978	0.00371	0.00090	−0.00591	0.00112	0.01188	0.00002
C(11)	0.6566	0.2089	0.5235	0.00420	0.00105	0.00424	0.00245	0.03271	0.00703
C(12)	0.6894	0.2476	0.3728	0.00983	0.00074	0.00240	0.00338	0.06557	−0.01009
C(13)	0.8080	0.2490	0.2859	0.00515	0.00084	−0.01893	−0.00014	0.01405	0.00459
C(14)	0.8915	0.2140	0.3441	0.00571	0.00141	−0.03526	−0.00040	0.19587	0.00615
C(15)	0.8563	0.1750	0.5019	0.00399	0.00112	0.01432	0.00335	0.02048	0.01196
O(1)	0.1231	0.0597	1.5831	0.00687	0.00080	0.03290	−0.00037	0.07234	0.00788
O(2)	0.1758	0.1461	1.3935	0.00678	0.00044	0.11271	0.00047	0.06585	−0.00071
O(3)	0.7817	0.0975	0.8151	0.00753	0.00067	0.09377	0.00402	0.03736	0.01395
O(4)	0.9441	0.1411	0.5726	0.00496	0.00084	0.11951	0.00409	0.04841	0.01865
O(5)	0.8431	0.2875	0.1269	0.00666	0.00093	0.01648	−0.00025	0.03447	0.00894
O(6)	0.8975	0.0267	1.1927	0.00788	0.00134	0.09180	0.00084	0.00546	0.01417
H(1)	0.2882	0.9977	1.4633	3.26					
H(2)	0.4851	0.0107	1.2439	5.25					
H(3)	0.3673	0.1539	1.1261	1.92					
H(4)	0.6275	0.0729	1.1200	5.24					
H(5)	0.5371	0.1529	0.8569	1.50					
H(6)	0.5704	0.2046	0.5809	0.79					
H(7)	0.6322	0.2714	0.3290	4.53					
H(8)	0.9656	0.2129	0.2329	−0.41					
H(O1)	0.1059	0.0385	1.6794	5.60					
H(O2)	0.1128	0.1442	1.4328	5.54					
H(O4)	0.8911	0.1193	0.5416	0.94					
H(O5)	0.8367	0.2848	−0.0713	5.12					
H(O6A)	0.9789	0.0324	0.3431	−1.25					
H(O6B)	0.8664	0.0489	0.1120	1.99					

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[5] J. Karle and I. L. Karle, *Acta Crystallogr.*, **21**, 849 (1966).

Crystallography.[6] The final atomic coordinates and temperature factors are given in Table 3. The observed structure factors may be obtained on request to the authors. The computations were done on a HITAC 5020E computer with programs written by Tamaichi Ashida.

Discussion

Molecular Shape. The C(7)–C(8) double bond and the C(9)–O(3) carbonyl group are in the *s-cis* conformation with respect to the C(8)–C(9) bond. A similar conformation is observed in 4-methoxychalcone[7] and chalcone[8]. This cisoidal conformation is considered to be more stable than the transoidal conformation, because it does not suffer from repulsion between H(4) and H(6).

TABLE 4. NORMAL DISTANCES FROM THE LEAST-SQUARES PLANES (Å)

	P(1)	*P*(2)	*P*(3)	*P*(4)	*P*(5)
C(1)	0.029			−0.046	
C(2)	0.288			0.021	
C(3)	0.276		0.219*	0.002	
C(4)	0.082		−0.016	0.002	
C(5)	−0.143		−0.333*	−0.028	
C(6)	−0.068			0.050	
C(7)	0.061	−0.078*	0.023		−0.014
C(8)	0.070	−0.088*	0.009		−0.038
C(9)	−0.026	−0.035*	−0.020		0.004
C(10)	0.027	−0.008	0.005		0.016
C(11)	0.208	0.009	0.095*		0.028
C(12)	0.218	−0.003			0.002
C(13)	0.066	−0.005			−0.010
C(14)	−0.090	0.005			0.003
C(15)	−0.113	0.001	−0.068*		0.013
O(1)	0.001			−0.057*	
O(2)	−0.419			−0.112*	
O(3)	−0.140		−0.049		0.048
O(4)	−0.340	−0.059*			−0.043
O(5)	0.099	0.010*			−0.010*
O(6)	−1.174				

P(1), the plane of all atoms; *P*(2), the plane of the ring A; *P*(3), the plane of the exocyclic atoms; *P*(4), the plane of the ring B; *P*(5), the plane of the ring A and exocyclic atoms. The atom with asterisk is not included in the plane evaluation.

Dihedral angle between the planes *P*(2) and *P*(3) 3.7°
P(2) and *P*(4) 15.6°
P(5) and *P*(4) 15.8°

As is shown in Table 4, the two phenyl rings, A and B, are planar within 0.01 Å and 0.05 Å respectively. The C(4), C(7), C(8), C(9), C(10), and O(3) atoms are also on a plane, within deviations of 0.05Å. The A ring and the plane of the exocyclic atoms (C(4)~O(3)) are nearly coplanar (±0.05Å). On the other hand, this plane makes a dihedral angle of 15.8° with the plane of the B phenyl group, mainly because of the rotation around the C(4)–C(7) bond. This may be due to the interaction of H(5) and H(3). The dihedral angle between the A and B rings is 15.6°. Thus, the molecule can be expressed to be nearly planar as a whole.

Bond Lengths and Angles. Figure 1 shows the bond lengths and angles in butein monohydrate calculated from the coordinates in Table 3. The estimated standard deviations are 0.02-0.03Å for the lengths and 1.0-2.0° for the angles. The average bond length in the two benzene rings is 1.39Å. The C–C single bond lengths–C(4)–C(7), 1.44, C(8)–C(9), 1.43, and C(9)–C(10), 1.47Å—are rather shorter than those in 4-methoxy chalcone (1.47, 1.49, and 1.47Å) and in chalcone (1.50,1.48, and 1.46Å). On the other hand, the doble bonds, C(7)–C(8) (1.35Å) and O(3)–C(9) (1.27Å), are somewhat long; the corresponding bond lengths are 1.33 and 1.23Å in 4-methoxychalcone, and 1.32 and 1.20Å in chalcone. The average bond length of four C–O(hydroxy) bonds is 1.37Å, which is slightly shorter than the usual value. These bond lengths and the approximate planarity of the whole molecule mentioned above suggest that the π–electrons are delocalized, to some extent, throughout the whole molecule. The fluctuation in the C–C–C angles in two benzene rings is rather large. The C(4)–C(7)–C(8) angle is quite large (126.2°); similar values, 127.2° and 127.6°, are found in 4-methoxychalcone and chalcone respectively.

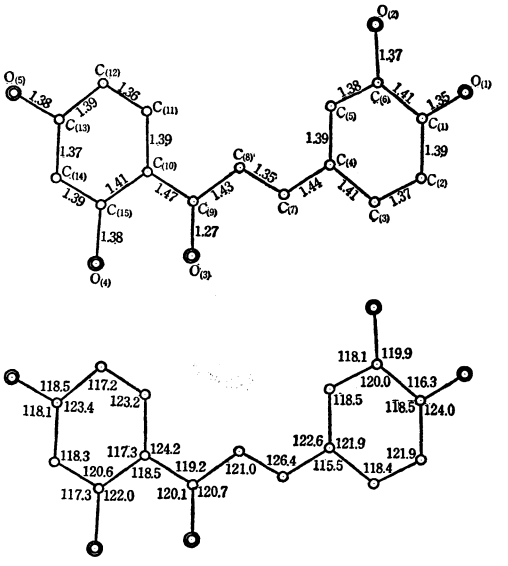

Fig. 1. Bond lengths (Å) and bond angles (°).
◎: O, ○: C

Hydrogen Bond. The O(4)–H hydroxyl group is hydrogen-bonded to the carbonyl oxygen atom, O(3), in the same molecule with the length of 2.49Å. Similar intramolecular hydrogen bonds are observed in obtusifolin (2.53Å),[9] salicylic acid (2.62Å),[10] 4-

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6) "International Tables for X-ray Crystallography," Vol. 3, Kynoch Press, Birmingham, England (1962), p. 202.

7) D. Rabinovich and G. M. J. Schmidt, *J. Chem. Soc. B*, **1970**, 6.

8) D. Rabinovich, *ibid.*, *B*, **1970**, 11.

9) P. Narayanan, K. Zechmeister, M. Rohre, and W. Hoppe, *Acta Crystallogr.*, **B27**, 718 (1971).

10) M. Sundaralingam and L. H. Jensen, *ibid.*, **18**, 1053 (1965).

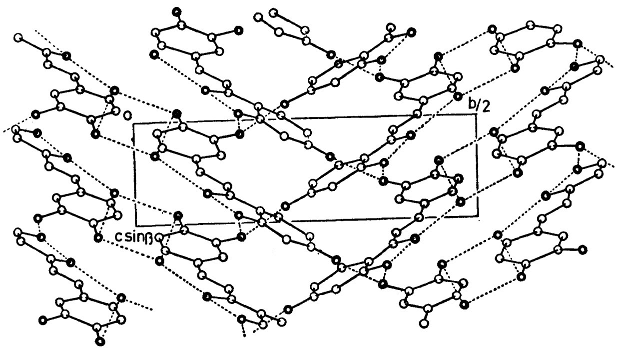
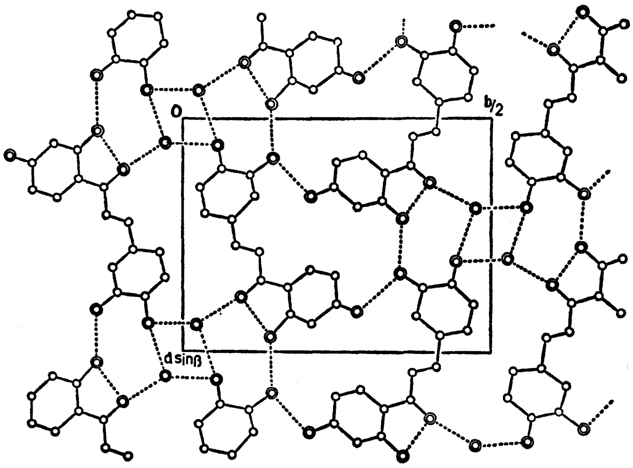


Fig. 2. The crystal structure projected along the *a* axis. The broken lines indicate the presumed hydrogen bonds.
◎: O, ○: C



– Fig. 3. The crystal structure projected along the *c* axis. The broken lines indicated the presumed hydrogen bonds.
◎: O, ○: C

aminosalicylic acid (2.62Å),[11] and salicylamide (2.49 Å).[12]

Table 5. Hydrogen bond distances

Bonds	Distance (Å)	Acceptor at
O(3)···O(6)	2.82	(x, y, z)
O(3)···O(4)	2.49	(x, y, z)
O(6)···O(1)	2.97	$(1+x, y, z)$
O(5)···O(2)	2.75	$(1/2+x, 1/2-y, -3/2+z)$
O(4)···O(2)	2.73	$(1+x, y, -1+z)$
O(6)···O(1)	2.69	$(1-x, -y, 3-z)$

The arrangements of the molecules viewed along the *a* and *c* axes are shown in Figs. 2 and 3 respectively. The presumed hydrogen bonds are indicated with broken lines and are listed in Table 5. Six hydrogen bonds connect the molecules so as to form a three-dimensional net-work.

Interconversion of Chalcone to Flavanone. As is well known, the chalcone-flavanone transformation is reversible, the equilibrium being shifted in favour of the flavanones.[13] Actually, chalcones can be converted to flavanones upon prolonged heating in an alcoholic acid or alkaline solution. From the structural characteristics revealed in the present study, the interconversion may be considered to occur through the following steps; the rotation of the A ring around the C(9)–C(10) single bond, accompanied by the breaking of the intramolecular hydrogen bond, the rotation of the A ring around the C(8)–C(9) single bond (the *s-trans* conformation (I)), and the cyclization of chalcone into flavanone (III).

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