

Elles sont reliées dans la direction **a**, par l'intermédiaire des octaèdres des ions  $\text{Co}(2)$ . Chacun de ces derniers partagent un sommet avec deux octaèdres entourant les ions  $\text{Co}(1)$  comme l'indique la Fig. 2.

Les octaèdres d'oxygène des ions uranium joignent les chaînes de  $\text{Co}(1)$  séparées par la translation  $\frac{1}{2}\frac{1}{2}0$ .

### Conclusion

La résolution de la structure de  $\text{Co}_3\text{U}_2\text{O}_8$  a mis en évidence l'existence de deux types d'ions cobalt et d'un seul type d'ion uranium. L'examen des coordinences octaédriques de ces cations permet de prévoir la présence d'ions  $\text{Co}^{2+}$  et  $\text{U}^{5+}$ . Les mesures magnétiques en cours préciseront définitivement l'état de valence des cations.

Des essais de préparation des composés hypothétiques  $\text{M}_3\text{U}_2\text{O}_8$  ( $\text{M}=\text{Fe}, \text{Ni}, \text{Mn}$ ) selon la méthode utilisée pour  $\text{Co}_3\text{U}_2\text{O}_8$  (Bacmann, 1971) sont restés

infructueux. Dans tous les cas, on note la formation d'un oxyde double  $\text{MU}_2\text{O}_6$  ( $\text{M}=\text{Fe}, \text{Ni}, \text{Mn}$ ) de structure cubique type fluorine déjà décrite pour  $\text{MnU}_2\text{O}_6$  (Kemmler-Sack & Rudorff, 1967).

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## Polymorphism of Phenobarbitone: The Crystal Structure of 5-Ethyl-5-phenylbarbituric Acid Monohydrate

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Unit-cell constants have been obtained for five of the reported polymorphs of phenobarbitone, 5-ethyl-5-phenylbarbituric acid,  $\text{C}_{12}\text{H}_{13}\text{O}_3\text{N}_2$ . Of these, form XIII has been shown to be a monohydrate. Cell constants of form XIII are  $a = 7.157$  (1),  $b = 30.879$  (4),  $c = 10.870$  (1) Å, *Pbca*,  $Z = 8$ . Diffractometer intensity data from the hydrate have been used to determine and refine the structure to a conventional *R* value of 0.050. The pyrimidine ring of the phenobarbitone molecule is markedly non-planar, and adopts an envelope conformation with C(5) lying 0.43 Å out of the plane defined by other atoms in the ring. The crystal structure is characterized by sheets, normal to the *y* axis, of hydrophilic character alternating with parallel lipophilic sheets. Within the hydrophilic sheets, each pyrimidine ring is hydrogen-bonded to four water molecules, and each water to four phenobarbitone molecules. The phenobarbitone molecules do not form homo-molecular hydrogen bonds, but associate in pairs through a dipole-dipole interaction. Packing of the phenyl groups in the lipophilic layers is analogous to that found in benzene.

### Introduction

The high degree of polymorphism existing in the drug-active barbituric acids has been noted and studied by a number of workers (*e.g.* Fischer, 1932; Fischer & Köfler, 1932; Brandstätter, 1942; Cleverley & Williams 1959; Brandstätter-Kuhnert & Aepkers, 1961). Of the large number of barbituric acids studied, the 5-ethyl-5-phenyl derivative has been found to exhibit the greatest number of polymorphs. Brandstätter-Kuhnert & Aepkers (1961) reported eleven forms, many of which were observed only in binary mixed crystals containing other barbituric acids. Mesley, Clements, Flaherty &

Goodhead (1968) re-investigated the series, and reported two further forms, making a total of thirteen polymorphs. There is still considerable doubt as to how many of these forms can be made from pure phenobarbitone, but it is certain that at least six, and possibly three more, can.

Various studies of crystal structures of barbituric acids and related compounds (*e.g.* Singh, 1965; Bolton, 1963; Craven, Vizzini & Rodrigues, 1969; Craven & Vizzini, 1969) have revealed a variety of intermolecular hydrogen-bonding schemes, and it has been shown, for example, in barbital (5,5-diethylbarbituric acid) (Craven, Vizzini & Rodrigues, 1969; Craven &

Vizzini, 1971) that different polymorphs of a barbituric acid can show quite different hydrogen-bonding schemes. The high degree of polymorphism shown by

phenobarbitone suggested this compound as a subject for detailed study in the expectation that a wide variety of hydrogen-bonding schemes would be encountered.

### Polymorphs of phenobarbitone

Systematic efforts were made to prepare crystals suitable for structural X-ray study of as many polymorphs of pure phenobarbitone as possible. The methods used included crystallization from solutions, from melts at various temperatures, and by sublimation on to surfaces at various temperatures. Forms I, II, III, V, and XIII were readily obtained in a good form. [The numbering of the polymorphs adopted by Mesley, Clements, Flaherty & Goodhead (1968) has been used throughout this work.] The crystal data for each of these forms are given in Table 1. Form IV was also prepared by crystallization from a melt, in the form of short needles, and was identified from its powder diffraction pattern. However, this preparation proved to be unstable, and did not last long enough for single-crystal measurements to be made.

Form XIII was originally reported as a polymorph of phenobarbitone by Cleverley & Williams (1959), and called by them form V. It is unusual among drug barbituric acids in showing absorption bands in the infrared near  $3500\text{ cm}^{-1}$ , which were attributed to some degree of enolization in the pyrimidine ring by Cleverley & Williams (1959), and by Mesley *et al.* (1968). Mesley *et al.* also considered the possibility that these absorption bands resulted from the presence of water of crystallization, but rejected this hypothesis in favour of enolization. The unit-cell dimensions for phenobarbitone XIII in Table 1 gave a low value of  $D_{\text{calc}}$ , if only eight molecules of phenobarbitone were included in the unit cell, and measurements of weight loss of the material at  $100^\circ\text{C}$  showed conclusively that phenobarbitone XIII is in fact a monohydrate.

Phenobarbitone XIII can now be definitely identified with the monohydrate for which crystal data were presented by Ghose, Jeffrey, Craven & Warwicker (1960). Thus, this form should strictly be excluded from the list of known polymorphs of phenobarbitone. It seems likely that form XII of phenobarbitone (Mesley *et al.*, 1968) and form III of thialbarbitone (Kemithal, 5-alkyl, 5- $\Delta^2$ -cyclohexenyl barbituric acid) (Cleverley & Williams, 1959), both of which also show O-H stretching bands in the infrared, are also hydrates.

Phenobarbitone XIII is the first reported, and so far

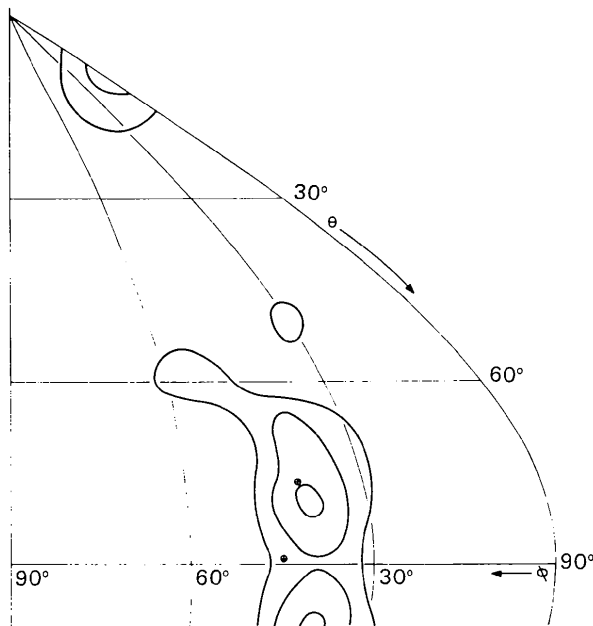


Fig. 1. The  $I(\theta, \phi)$  plot for phenobarbitone XIII. The small crosses mark the refined positions of the normals to the two planar groups.

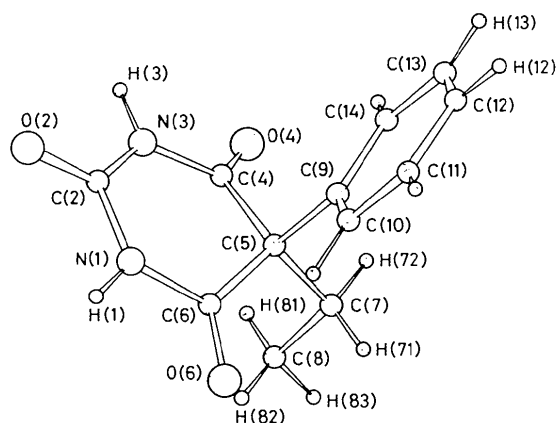


Fig. 2. The conformation and atom-numbering system for the phenobarbitone molecule. Phenyl hydrogen atoms have the same number as the carbon to which they are attached. O(1) in the tables is the water oxygen.

Table 1. Crystal data for phenobarbitone polymorphs

The density of form XIII is calculated for the monohydrate

| Polymorphic form | <i>a</i> | <i>b</i> | <i>c</i> | $\alpha$ | $\beta$ | $\gamma$ | Space group | <i>Z</i> | $D_c$ |
|------------------|----------|----------|----------|----------|---------|----------|-------------|----------|-------|
| I                | 6.800    | 47.174   | 10.695   | 90       | 94.18   | 90       | $P2_1/n$    | 12       | 1.352 |
| II               | 6.784    | 23.537   | 10.741   | 91.89    | 94.43   | 89.03    | $P\bar{1}$  | 6        | 1.354 |
| III              | 9.534    | 11.855   | 10.794   | 90       | 111.56  | 90       | $P2_1/c$    | 4        | 1.360 |
| V                | 12.66    | 6.75     | 27.69    | 90       | 106.9   | 90       | $P2_1/c$    | 8        | 1.362 |
| XIII             | 7.157    | 30.879   | 10.870   | 90       | 90      | 90       | $Pbca$      | 8        | 1.384 |

the only well established crystalline hydrate of a barbituric acid drug. Crystal structures have been obtained for a number of hydrates of similar compounds (e.g. Craven & Sabine, 1969; Mootz & Jeffrey, 1965; Jeffrey, Ghose & Warwicker, 1961), and it was thought to be of interest to obtain a complete crystal structure of phenobarbitone XIII in order to determine the

hydrogen-bonding scheme and compare it with the schemes in similar hydrates.

Determination of the crystal structure

Large well formed prismatic crystals of the monohydrate were obtained by evaporating to dryness a

Table 2. Observed and calculated structure amplitudes ( $\times 10$ )

| h | k | l | Obs  | Calc | h | k | l | Obs  | Calc | h | k | l | Obs  | Calc | h | k | l | Obs  | Calc | h | k | l | Obs  | Calc |
|---|---|---|------|------|---|---|---|------|------|---|---|---|------|------|---|---|---|------|------|---|---|---|------|------|
| 0 | 0 | 0 | 2.67 | 2.67 | 0 | 0 | 0 | 2.67 | 2.67 | 0 | 0 | 0 | 2.67 | 2.67 | 0 | 0 | 0 | 2.67 | 2.67 | 0 | 0 | 0 | 2.67 | 2.67 |
| 0 | 0 | 1 | 1.81 | 1.81 | 0 | 0 | 1 | 1.81 | 1.81 | 0 | 0 | 1 | 1.81 | 1.81 | 0 | 0 | 1 | 1.81 | 1.81 | 0 | 0 | 1 | 1.81 | 1.81 |
| 0 | 0 | 2 | 1.33 | 1.33 | 0 | 0 | 2 | 1.33 | 1.33 | 0 | 0 | 2 | 1.33 | 1.33 | 0 | 0 | 2 | 1.33 | 1.33 | 0 | 0 | 2 | 1.33 | 1.33 |
| 0 | 0 | 3 | 0.85 | 0.85 | 0 | 0 | 3 | 0.85 | 0.85 | 0 | 0 | 3 | 0.85 | 0.85 | 0 | 0 | 3 | 0.85 | 0.85 | 0 | 0 | 3 | 0.85 | 0.85 |
| 0 | 0 | 4 | 0.37 | 0.37 | 0 | 0 | 4 | 0.37 | 0.37 | 0 | 0 | 4 | 0.37 | 0.37 | 0 | 0 | 4 | 0.37 | 0.37 | 0 | 0 | 4 | 0.37 | 0.37 |
| 0 | 1 | 0 | 1.81 | 1.81 | 0 | 1 | 0 | 1.81 | 1.81 | 0 | 1 | 0 | 1.81 | 1.81 | 0 | 1 | 0 | 1.81 | 1.81 | 0 | 1 | 0 | 1.81 | 1.81 |
| 0 | 1 | 1 | 1.33 | 1.33 | 0 | 1 | 1 | 1.33 | 1.33 | 0 | 1 | 1 | 1.33 | 1.33 | 0 | 1 | 1 | 1.33 | 1.33 | 0 | 1 | 1 | 1.33 | 1.33 |
| 0 | 1 | 2 | 0.85 | 0.85 | 0 | 1 | 2 | 0.85 | 0.85 | 0 | 1 | 2 | 0.85 | 0.85 | 0 | 1 | 2 | 0.85 | 0.85 | 0 | 1 | 2 | 0.85 | 0.85 |
| 0 | 1 | 3 | 0.37 | 0.37 | 0 | 1 | 3 | 0.37 | 0.37 | 0 | 1 | 3 | 0.37 | 0.37 | 0 | 1 | 3 | 0.37 | 0.37 | 0 | 1 | 3 | 0.37 | 0.37 |
| 0 | 1 | 4 | 0.00 | 0.00 | 0 | 1 | 4 | 0.00 | 0.00 | 0 | 1 | 4 | 0.00 | 0.00 | 0 | 1 | 4 | 0.00 | 0.00 | 0 | 1 | 4 | 0.00 | 0.00 |
| 0 | 2 | 0 | 1.81 | 1.81 | 0 | 2 | 0 | 1.81 | 1.81 | 0 | 2 | 0 | 1.81 | 1.81 | 0 | 2 | 0 | 1.81 | 1.81 | 0 | 2 | 0 | 1.81 | 1.81 |
| 0 | 2 | 1 | 1.33 | 1.33 | 0 | 2 | 1 | 1.33 | 1.33 | 0 | 2 | 1 | 1.33 | 1.33 | 0 | 2 | 1 | 1.33 | 1.33 | 0 | 2 | 1 | 1.33 | 1.33 |
| 0 | 2 | 2 | 0.85 | 0.85 | 0 | 2 | 2 | 0.85 | 0.85 | 0 | 2 | 2 | 0.85 | 0.85 | 0 | 2 | 2 | 0.85 | 0.85 | 0 | 2 | 2 | 0.85 | 0.85 |
| 0 | 2 | 3 | 0.37 | 0.37 | 0 | 2 | 3 | 0.37 | 0.37 | 0 | 2 | 3 | 0.37 | 0.37 | 0 | 2 | 3 | 0.37 | 0.37 | 0 | 2 | 3 | 0.37 | 0.37 |
| 0 | 2 | 4 | 0.00 | 0.00 | 0 | 2 | 4 | 0.00 | 0.00 | 0 | 2 | 4 | 0.00 | 0.00 | 0 | 2 | 4 | 0.00 | 0.00 | 0 | 2 | 4 | 0.00 | 0.00 |
| 0 | 3 | 0 | 1.81 | 1.81 | 0 | 3 | 0 | 1.81 | 1.81 | 0 | 3 | 0 | 1.81 | 1.81 | 0 | 3 | 0 | 1.81 | 1.81 | 0 | 3 | 0 | 1.81 | 1.81 |
| 0 | 3 | 1 | 1.33 | 1.33 | 0 | 3 | 1 | 1.33 | 1.33 | 0 | 3 | 1 | 1.33 | 1.33 | 0 | 3 | 1 | 1.33 | 1.33 | 0 | 3 | 1 | 1.33 | 1.33 |
| 0 | 3 | 2 | 0.85 | 0.85 | 0 | 3 | 2 | 0.85 | 0.85 | 0 | 3 | 2 | 0.85 | 0.85 | 0 | 3 | 2 | 0.85 | 0.85 | 0 | 3 | 2 | 0.85 | 0.85 |
| 0 | 3 | 3 | 0.37 | 0.37 | 0 | 3 | 3 | 0.37 | 0.37 | 0 | 3 | 3 | 0.37 | 0.37 | 0 | 3 | 3 | 0.37 | 0.37 | 0 | 3 | 3 | 0.37 | 0.37 |
| 0 | 3 | 4 | 0.00 | 0.00 | 0 | 3 | 4 | 0.00 | 0.00 | 0 | 3 | 4 | 0.00 | 0.00 | 0 | 3 | 4 | 0.00 | 0.00 | 0 | 3 | 4 | 0.00 | 0.00 |
| 0 | 4 | 0 | 1.81 | 1.81 | 0 | 4 | 0 | 1.81 | 1.81 | 0 | 4 | 0 | 1.81 | 1.81 | 0 | 4 | 0 | 1.81 | 1.81 | 0 | 4 | 0 | 1.81 | 1.81 |
| 0 | 4 | 1 | 1.33 | 1.33 | 0 | 4 | 1 | 1.33 | 1.33 | 0 | 4 | 1 | 1.33 | 1.33 | 0 | 4 | 1 | 1.33 | 1.33 | 0 | 4 | 1 | 1.33 | 1.33 |
| 0 | 4 | 2 | 0.85 | 0.85 | 0 | 4 | 2 | 0.85 | 0.85 | 0 | 4 | 2 | 0.85 | 0.85 | 0 | 4 | 2 | 0.85 | 0.85 | 0 | 4 | 2 | 0.85 | 0.85 |
| 0 | 4 | 3 | 0.37 | 0.37 | 0 | 4 | 3 | 0.37 | 0.37 | 0 | 4 | 3 | 0.37 | 0.37 | 0 | 4 | 3 | 0.37 | 0.37 | 0 | 4 | 3 | 0.37 | 0.37 |
| 0 | 4 | 4 | 0.00 | 0.00 | 0 | 4 | 4 | 0.00 | 0.00 | 0 | 4 | 4 | 0.00 | 0.00 | 0 | 4 | 4 | 0.00 | 0.00 | 0 | 4 | 4 | 0.00 | 0.00 |
| 1 | 0 | 0 | 1.81 | 1.81 | 1 | 0 | 0 | 1.81 | 1.81 | 1 | 0 | 0 | 1.81 | 1.81 | 1 | 0 | 0 | 1.81 | 1.81 | 1 | 0 | 0 | 1.81 | 1.81 |
| 1 | 0 | 1 | 1.33 | 1.33 | 1 | 0 | 1 | 1.33 | 1.33 | 1 | 0 | 1 | 1.33 | 1.33 | 1 | 0 | 1 | 1.33 | 1.33 | 1 | 0 | 1 | 1.33 | 1.33 |
| 1 | 0 | 2 | 0.85 | 0.85 | 1 | 0 | 2 | 0.85 | 0.85 | 1 | 0 | 2 | 0.85 | 0.85 | 1 | 0 | 2 | 0.85 | 0.85 | 1 | 0 | 2 | 0.85 | 0.85 |
| 1 | 0 | 3 | 0.37 | 0.37 | 1 | 0 | 3 | 0.37 | 0.37 | 1 | 0 | 3 | 0.37 | 0.37 | 1 | 0 | 3 | 0.37 | 0.37 | 1 | 0 | 3 | 0.37 | 0.37 |
| 1 | 0 | 4 | 0.00 | 0.00 | 1 | 0 | 4 | 0.00 | 0.00 | 1 | 0 | 4 | 0.00 | 0.00 | 1 | 0 | 4 | 0.00 | 0.00 | 1 | 0 | 4 | 0.00 | 0.00 |
| 1 | 1 | 0 | 1.81 | 1.81 | 1 | 1 | 0 | 1.81 | 1.81 | 1 | 1 | 0 | 1.81 | 1.81 | 1 | 1 | 0 | 1.81 | 1.81 | 1 | 1 | 0 | 1.81 | 1.81 |
| 1 | 1 | 1 | 1.33 | 1.33 | 1 | 1 | 1 | 1.33 | 1.33 | 1 | 1 | 1 | 1.33 | 1.33 | 1 | 1 | 1 | 1.33 | 1.33 | 1 | 1 | 1 | 1.33 | 1.33 |
| 1 | 1 | 2 | 0.85 | 0.85 | 1 | 1 | 2 | 0.85 | 0.85 | 1 | 1 | 2 | 0.85 | 0.85 | 1 | 1 | 2 | 0.85 | 0.85 | 1 | 1 | 2 | 0.85 | 0.85 |
| 1 | 1 | 3 | 0.37 | 0.37 | 1 | 1 | 3 | 0.37 | 0.37 | 1 | 1 | 3 | 0.37 | 0.37 | 1 | 1 | 3 | 0.37 | 0.37 | 1 | 1 | 3 | 0.37 | 0.37 |
| 1 | 1 | 4 | 0.00 | 0.00 | 1 | 1 | 4 | 0.00 | 0.00 | 1 | 1 | 4 | 0.00 | 0.00 | 1 | 1 | 4 | 0.00 | 0.00 | 1 | 1 | 4 | 0.00 | 0.00 |
| 1 | 2 | 0 | 1.81 | 1.81 | 1 | 2 | 0 | 1.81 | 1.81 | 1 | 2 | 0 | 1.81 | 1.81 | 1 | 2 | 0 | 1.81 | 1.81 | 1 | 2 | 0 | 1.81 | 1.81 |
| 1 | 2 | 1 | 1.33 | 1.33 | 1 | 2 | 1 | 1.33 | 1.33 | 1 | 2 | 1 | 1.33 | 1.33 | 1 | 2 | 1 | 1.33 | 1.33 | 1 | 2 | 1 | 1.33 | 1.33 |
| 1 | 2 | 2 | 0.85 | 0.85 | 1 | 2 | 2 | 0.85 | 0.85 | 1 | 2 | 2 | 0.85 | 0.85 | 1 | 2 | 2 | 0.85 | 0.85 | 1 | 2 | 2 | 0.85 | 0.85 |
| 1 | 2 | 3 | 0.37 | 0.37 | 1 | 2 | 3 | 0.37 | 0.37 | 1 | 2 | 3 | 0.37 | 0.37 | 1 | 2 | 3 | 0.37 | 0.37 | 1 | 2 | 3 | 0.37 | 0.37 |
| 1 | 2 | 4 | 0.00 | 0.00 | 1 | 2 | 4 | 0.00 | 0.00 | 1 | 2 | 4 | 0.00 | 0.00 | 1 | 2 | 4 | 0.00 | 0.00 | 1 | 2 | 4 | 0.00 | 0.00 |
| 1 | 3 | 0 | 1.81 | 1.81 | 1 | 3 | 0 | 1.81 | 1.81 | 1 | 3 | 0 | 1.81 | 1.81 | 1 | 3 | 0 | 1.81 | 1.81 | 1 | 3 | 0 | 1.81 | 1.81 |
| 1 | 3 | 1 | 1.33 | 1.33 | 1 | 3 | 1 | 1.33 | 1.33 | 1 | 3 | 1 | 1.33 | 1.33 | 1 | 3 | 1 | 1.33 | 1.33 | 1 | 3 | 1 | 1.33 | 1.33 |
| 1 | 3 | 2 | 0.85 | 0.85 | 1 | 3 | 2 | 0.85 | 0.85 | 1 | 3 | 2 | 0.85 | 0.85 | 1 | 3 | 2 | 0.85 | 0.85 | 1 | 3 | 2 | 0.85 | 0.85 |
| 1 | 3 | 3 | 0.37 | 0.37 | 1 | 3 | 3 | 0.37 | 0.37 | 1 | 3 | 3 | 0.37 | 0.37 | 1 | 3 | 3 | 0.37 | 0.37 | 1 | 3 | 3 | 0.37 | 0.37 |
| 1 | 3 | 4 | 0.00 | 0.00 | 1 | 3 | 4 | 0.00 | 0.00 | 1 | 3 | 4 | 0.00 | 0.00 | 1 | 3 | 4 | 0.00 | 0.00 | 1 | 3 | 4 | 0.00 | 0.00 |
| 1 | 4 | 0 | 1.81 | 1.81 | 1 | 4 | 0 | 1.81 | 1.81 | 1 | 4 | 0 | 1.81 | 1.81 | 1 | 4 | 0 | 1.81 | 1.81 | 1 | 4 | 0 | 1.81 | 1.81 |
| 1 | 4 | 1 | 1.33 | 1.33 | 1 | 4 | 1 | 1.33 | 1.33 | 1 | 4 | 1 | 1.33 | 1.33 | 1 | 4 | 1 | 1.33 | 1.33 | 1 | 4 | 1 | 1.33 | 1.33 |
| 1 | 4 | 2 | 0.85 | 0.85 | 1 | 4 | 2 | 0.85 | 0.85 | 1 | 4 | 2 | 0.85 | 0.85 | 1 | 4 | 2 | 0.85 | 0.85 | 1 | 4 | 2 | 0.85 | 0.85 |
| 1 | 4 | 3 | 0.37 | 0.37 | 1 | 4 | 3 | 0.37 | 0.37 | 1 | 4 | 3 | 0.37 | 0.37 | 1 | 4 | 3 | 0.37 | 0.37 | 1 | 4 | 3 | 0.37 | 0.37 |
| 1 | 4 | 4 | 0.00 | 0.00 | 1 | 4 | 4 | 0.00 | 0.00 | 1 | 4 | 4 | 0.00 | 0.00 | 1 | 4 | 4 | 0.00 | 0.00 | 1 | 4 | 4 | 0.00 | 0.00 |
| 2 | 0 | 0 | 1.81 | 1.81 | 2 | 0 | 0 | 1.81 | 1.81 | 2 | 0 | 0 | 1.81 | 1.81 | 2 | 0 | 0 | 1.81 | 1.81 | 2 | 0 | 0 | 1.81 | 1.81 |
| 2 | 0 | 1 | 1.33 | 1.33 | 2 | 0 | 1 | 1.33 | 1.33 | 2 | 0 | 1 | 1.33 | 1.33 | 2 | 0 | 1 | 1.33 | 1.33 | 2 | 0 | 1 | 1.33 | 1.33 |
| 2 | 0 | 2 | 0.85 | 0.85 | 2 | 0 | 2 | 0.85 | 0.85 | 2 | 0 | 2 | 0.85 | 0.85 | 2 | 0 | 2 | 0.85 | 0.85 | 2 | 0 | 2 | 0.85 | 0.85 |
| 2 | 0 | 3 | 0.37 | 0.37 | 2 | 0 | 3 | 0.37 | 0.37 | 2 | 0 | 3 | 0.37 | 0.37 | 2 | 0 | 3 | 0.37 | 0.37 | 2 | 0 | 3 | 0.37 | 0.37 |
| 2 | 0 | 4 | 0.00 | 0.00 | 2 | 0 | 4 | 0.00 | 0.00 | 2 | 0 | 4 | 0.00 | 0.00 | 2 | 0 | 4 | 0.00 | 0.00 | 2 | 0 | 4 | 0.00 | 0.00 |
| 2 | 1 | 0 | 1.81 | 1.81 | 2 | 1 | 0 | 1.81 | 1.81 | 2 | 1 | 0 | 1.81 | 1.81 | 2 | 1 | 0 | 1.81 | 1.81 | 2 | 1 | 0 | 1.81 | 1.81 |
| 2 | 1 | 1 | 1.33 | 1.33 | 2 | 1 | 1 | 1.33 | 1.33 | 2 | 1 | 1 | 1.33 | 1.33 | 2 | 1 | 1 | 1.33 | 1.33 | 2 | 1 | 1 | 1.33 | 1.33 |
| 2 | 1 | 2 | 0.85 | 0.85 | 2 | 1 | 2 | 0.85 | 0.85 | 2 | 1 | 2 | 0.85 | 0.85 | 2 | 1 | 2 | 0.85 | 0.85 | 2 | 1 | 2 | 0.85 | 0.85 |
| 2 | 1 | 3 | 0.37 | 0.37 | 2 | 1 | 3 | 0.37 | 0.37 | 2 | 1 | 3 | 0.37 | 0.37 | 2 | 1 | 3 | 0.37 | 0.37 | 2 | 1 | 3 | 0.37 | 0.37 |
| 2 | 1 | 4 | 0.00 | 0.00 | 2 | 1 | 4 | 0.00 | 0.00 | 2 | 1 | 4 | 0.00 | 0.00 | 2 | 1 | 4 | 0.00 | 0.00 | 2 | 1 | 4 | 0.00 | 0.00 |
| 2 | 2 | 0 | 1.81 | 1.81 | 2 | 2 | 0 | 1.81 | 1.81 | 2 | 2 | 0 | 1.81 | 1.81 | 2 | 2 | 0 | 1.81 | 1.81 | 2 | 2 | 0 | 1.81 | 1.81 |
| 2 | 2 | 1 | 1.33 | 1.33 | 2 | 2 | 1 | 1.33 | 1.33 | 2 | 2 | 1 | 1.33 | 1.33 | 2 | 2 | 1 | 1.33 | 1.33 | 2 | 2 | 1 | 1.33 | 1.33 |
| 2 | 2 | 2 | 0.85 | 0.85 | 2 | 2 | 2 | 0.85 | 0.85 | 2 | 2 | 2 | 0.85 | 0.85 | 2 | 2 | 2 | 0.85 | 0.85 | 2 | 2 | 2 | 0.85 | 0.85 |
| 2 | 2 | 3 | 0.37 | 0.37 | 2 | 2 | 3 | 0.37 | 0.37 | 2 | 2 | 3 |      |      |   |   |   |      |      |   |   |   |      |      |

solution of phenobarbitone in aqueous alcohol. The first crop of crystals from this solvent are of form II, and the hydrate crystallizes in the later stages. The crystals are approximately equidimensional, many-faceted orthorhombic prisms, which readily grow to a size of 1–2 mm. Precession photographs were taken to obtain approximate unit-cell dimensions, and the observed systematic absences ( $0kl$ ,  $k$  odd;  $h0l$ ,  $l$  odd;  $hk0$ ,  $h$  odd) established the space group unambiguously as *Pbca*.

Two complete data sets were collected at different times. The first was obtained by using Mo  $K\alpha$  radiation and a relatively small crystal. About 65% of the reflexions measured were very weak [ $I < 3\sigma(I)$ ] and although this data set yielded a solution of the structure, it was not able to provide a well refined result. Therefore, after the structure was solved, a further data set was obtained, with Cu  $K\alpha$  radiation and a rather larger crystal (*ca.*  $0.25 \times 0.25 \times 0.25$  mm). The refinement was completed with this new data set.

Both sets of data were obtained on Hilger and Watts Y290 PDP-8 controlled four-circle diffractometers. The mosaic spread of both crystals was small (about  $0.1^\circ$ ), and the standard reflexions showed no reduction in intensity with time. The crystal parameters and the orientation matrix for the diffractometer were determined simultaneously from an iterative least-squares procedure based on observations made on 12 high-angle reflexions (Cu  $K\alpha$ :  $\lambda = 1.54178$ ; Mo  $K\alpha$ :  $\lambda = 0.7093$  Å). The normal data-conversion and averaging processes were carried out, but no corrections were made for absorption on either data set [ $\mu(\text{Mo}) = 1.34$ ;  $\mu(\text{Cu}) = 10.9$  cm $^{-1}$ ]. Standard deviations were assigned to the corrected intensities with the method suggested by Grant, Killean & Lawrence (1969) for a constant-time experiment, with a value for  $c$  of 0.05.

The structure was partly solved by the symbolic-addition procedure. A Fourier map computed from the resulting signed  $E$ 's with values greater than 1.7 gave

plausible atomic positions for a molecule lying in a pseudo mirror plane at  $z=0$ . The normals to both the pyrimidine and phenyl rings lay in the  $xy$  plane. This structure failed to refine, and some of the bond lengths were far from satisfactory. However, it was noticed that all the  $E$ 's to which signs had been assigned in the symbolic-addition procedure belonged to only four of the eight possible parity groups. Reflexions of the type  $h+l$  odd were not represented among the signed  $E$ 's, thus introducing an apparent  $B$ -centring condition and forcing the symmetry of the  $E$ -map to comply with space group *Bbcm* (= *Cmca*, No. 64). This space group has a mirror plane at  $z=0$ , and the phenobarbitone molecules are constrained to lie in it. Further progress could be achieved only by breaking this pseudo-symmetry and calculating non-zero amplitudes for reflexions with  $h+l$  odd.

The symmetry of the model was broken by considering the  $I(\theta, \varphi)$  synthesis developed by Tollin & Cochran (1964). This synthesis gives maxima at the polar coordinates of normals to planar groups of atoms in a crystal structure. The  $I(\theta, \varphi)$  synthesis for phenobarbitone XIII, calculated from about 200 strong reflexions is shown in Fig. 1. The angle  $\theta$  corresponds to a rotation about the crystallographic  $y$  direction, and  $\varphi$  to rotation about  $z$ .

The model obtained from the  $E$  map would require the  $I(\theta, \varphi)$  synthesis to show a maximum at  $\theta=90^\circ$ , and about  $\varphi=40^\circ$ , arising from two overlapping peaks corresponding to the pyrimidine and benzene rings. Fig. 1 shows such a single peak at the expected  $\varphi$  angle, but at a  $\theta$  value of about  $80^\circ$ . The phenyl group was arbitrarily chosen to be rotated approximately  $20^\circ$  away from its previous position about the C(5)–C(9) bond. The phenyl group was specified as a rigid group (Doedens, 1969), and this model refined smoothly to a conventional  $R$  of about 0.12. The final position of the planar part of the pyrimidine ring and the phenyl group are shown on Fig. 1.

Table 3. Fractional atomic coordinates and thermal parameters

Thermal parameters are multiplied by  $10^4$ .

|       | $x/a$         | $y/b$        | $z/c$         | $U_{11}$ | $U_{22}$ | $U_{33}$  | $U_{12}$  | $U_{13}$  | $U_{23}$  |
|-------|---------------|--------------|---------------|----------|----------|-----------|-----------|-----------|-----------|
| O(1)  | −0.00186 (20) | 0.00165 (4)  | 0.31336 (15)  | 643 (11) | 585 (10) | 372 (10)  | 179 (8)   | −5 (7)    | 4 (7)     |
| O(2)  | −0.21441 (21) | 0.01862 (5)  | 0.00210 (12)  | 414 (8)  | 456 (10) | 486 (11)  | −86 (7)   | 2 (6)     | 3 (7)     |
| O(4)  | 0.19631 (22)  | 0.09821 (5)  | −0.21428 (14) | 562 (10) | 715 (10) | 337 (10)  | −106 (9)  | 82 (8)    | −12 (7)   |
| O(6)  | 0.18823 (24)  | 0.10397 (6)  | 0.20734 (14)  | 662 (12) | 880 (10) | 338 (11)  | −222 (10) | −64 (8)   | −43 (9)   |
| N(1)  | −0.02274 (24) | 0.06420 (5)  | 0.10536 (14)  | 438 (10) | 480 (10) | 293 (10)  | −70 (8)   | 29 (8)    | −8 (7)    |
| N(3)  | −0.02093 (23) | 0.06176 (5)  | −0.10760 (14) | 414 (10) | 427 (10) | 288 (10)  | −39 (7)   | −39 (8)   | −3 (7)    |
| C(2)  | −0.09469 (27) | 0.04723 (6)  | −0.00010 (16) | 322 (9)  | 380 (10) | 377 (14)  | 4 (8)     | −5 (9)    | −3 (9)    |
| C(4)  | 0.11465 (27)  | 0.09311 (6)  | −0.11842 (19) | 355 (10) | 438 (10) | 327 (13)  | 7 (9)     | −7 (10)   | 40 (9)    |
| C(5)  | 0.14502 (30)  | 0.12153 (7)  | −0.00589 (16) | 339 (10) | 419 (10) | 347 (13)  | −30 (8)   | 4 (9)     | −28 (9)   |
| C(6)  | 0.11069 (28)  | 0.09611 (7)  | 0.11114 (19)  | 401 (11) | 513 (14) | 310 (13)  | −38 (9)   | 5 (10)    | −75 (9)   |
| C(7)  | 0.34431 (29)  | 0.14017 (8)  | −0.00642 (18) | 345 (11) | 507 (14) | 473 (15)  | −65 (10)  | −10 (10)  | −10 (10)  |
| C(8)  | 0.49686 (33)  | 0.10625 (10) | −0.00177 (19) | 351 (11) | 705 (14) | 542 (17)  | 19 (11)   | −14 (10)  | −28 (12)  |
| C(9)  | 0.00103 (30)  | 0.15871 (7)  | −0.01336 (20) | 353 (11) | 396 (10) | 610 (16)  | −29 (9)   | −32 (11)  | −57 (10)  |
| C(10) | −0.09901 (37) | 0.17201 (8)  | 0.08922 (28)  | 508 (13) | 510 (14) | 894 (21)  | −25 (11)  | 124 (15)  | −188 (14) |
| C(11) | −0.22629 (40) | 0.20631 (10) | 0.07841 (41)  | 523 (15) | 588 (14) | 1516 (35) | 18 (13)   | 177 (20)  | −348 (30) |
| C(12) | −0.25208 (49) | 0.22692 (10) | −0.03189 (45) | 588 (18) | 514 (14) | 1763 (39) | 121 (13)  | −250 (23) | −156 (32) |
| C(13) | −0.15334 (53) | 0.21353 (10) | −0.13328 (38) | 938 (23) | 629 (19) | 1225 (29) | 207 (18)  | −394 (23) | 80 (19)   |
| C(14) | −0.02679 (39) | 0.17937 (9)  | −0.12496 (27) | 699 (17) | 587 (14) | 728 (19)  | 137 (13)  | −144 (15) | 21 (14)   |

Table 3 (cont.)

|                | <i>x/a</i>   | <i>z/c</i>   | <i>z/c</i>   | <i>B</i> |
|----------------|--------------|--------------|--------------|----------|
| H(1)           | -0.0551 (42) | 0.0520 (9)   | 0.1817 (27)  | 2.0 (6)  |
| H(3)           | -0.0558 (42) | 0.0493 (9)   | -0.1801 (27) | 2.4 (6)  |
| H(10)          | -0.0805 (53) | 0.1594 (10)  | 0.1755 (30)  | 5.4 (9)  |
| H(11)          | -0.3027 (54) | 0.2124 (12)  | 0.1552 (33)  | 6.4 (8)  |
| H(12)          | -0.3495 (54) | 0.2520 (12)  | -0.0330 (31) | 5.0 (10) |
| H(13)          | -0.1580 (52) | 0.2287 (10)  | -0.2179 (32) | 5.4 (8)  |
| H(14)          | 0.0423 (37)  | 0.1725 (8)   | -0.2019 (25) | 3.0 (6)  |
| H(71)          | 0.3551 (38)  | 0.1578 (8)   | 0.0704 (26)  | 2.6 (6)  |
| H(72)          | 0.3593 (36)  | 0.1552 (8)   | -0.0855 (24) | 2.1 (5)  |
| H(81)          | 0.4846 (50)  | 0.0907 (10)  | -0.0738 (32) | 4.5 (8)  |
| H(82)          | 0.4864 (51)  | 0.0948 (11)  | 0.0791 (32)  | 4.2 (8)  |
| H(83)          | 0.6199 (80)  | 0.1221 (16)  | -0.0072 (29) | 2.5 (14) |
| H <i>W</i> (1) | -0.0879 (56) | -0.0080 (11) | 0.3736 (32)  | 5.1 (9)  |
| H <i>W</i> (2) | 0.0865 (56)  | 0.0105 (12)  | 0.3757 (32)  | 4.7 (9)  |

A search for hydrogen atoms in a difference synthesis at this point failed to reveal any clear maxima. Some bond lengths and temperature factors appeared to be unsatisfactory, and it became clear that the intensity data were inadequate. The second data set was therefore collected at this stage. All hydrogen atoms were clearly indicated on a difference synthesis calculated from the second data set when *R* was about 0.10. Hydrogen-atom positions and isotropic temperature factors were refined through two full-matrix least-squares cycles. Analysis of the weighting scheme showed that it was satisfactory, but showed a small effect due to secondary extinction. A parameter (Zachariassen, 1963, 1967) was included in the refine-

ment to allow for this effect. Anisotropic full-matrix refinement of all non-hydrogen atoms converged at *R* = 0.050 for data with *F* > 3σ(*F*). Structure factors are given in Table 2 and dispositional and thermal parameters in Table 3.

### Discussion of the structure

#### Molecular geometry

A representation of the molecule, showing the atom numbering system is shown in Fig. 2. Bond lengths and angles (Table 4) in the molecule show no sur-

Table 4. Bond lengths (Å) and interbond angles (°)

|             |           |                     |           |
|-------------|-----------|---------------------|-----------|
| N(1)—C(2)   | 1.362 (2) | C(13)—C(14)         | 1.393 (4) |
| C(2)—O(2)   | 1.231 (2) | C(14)—C(9)          | 1.385 (3) |
| C(2)—N(3)   | 1.359 (2) | N(1)—H(1)           | 0.94 (3)  |
| N(3)—C(4)   | 1.376 (2) | N(3)—H(3)           | 0.91 (3)  |
| C(4)—O(4)   | 1.205 (2) | C(7)—H(71)          | 1.00 (3)  |
| C(4)—C(5)   | 1.521 (3) | C(7)—H(72)          | 0.98 (3)  |
| C(5)—C(7)   | 1.538 (3) | C(8)—H(81)          | 0.92 (3)  |
| C(5)—C(9)   | 1.545 (3) | C(8)—H(82)          | 0.95 (3)  |
| C(5)—C(6)   | 1.515 (3) | C(8)—H(83)          | 1.01 (6)  |
| C(6)—O(6)   | 1.209 (3) | C(10)—H(10)         | 1.02 (3)  |
| C(6)—N(1)   | 1.374 (2) | C(11)—H(11)         | 1.02 (4)  |
| C(7)—C(8)   | 1.514 (3) | C(12)—H(12)         | 1.04 (4)  |
| C(9)—C(10)  | 1.387 (3) | C(13)—H(13)         | 1.03 (4)  |
| C(10)—C(11) | 1.402 (4) | C(14)—H(14)         | 1.00 (3)  |
| C(11)—C(12) | 1.370 (6) | O(1)—H <i>W</i> (1) | 0.95 (4)  |
| C(12)—C(13) | 1.373 (5) | O(1)—H <i>W</i> (2) | 0.97 (4)  |

Table 4 (cont.)

|                   |           |                                  |           |
|-------------------|-----------|----------------------------------|-----------|
| C(6)—N(1)—C(2)    | 125.3 (2) | C(7)—C(5)—C(9)                   | 109.9 (2) |
| N(1)—C(2)—O(2)    | 121.5 (2) | C(5)—C(6)—N(1)                   | 116.5 (2) |
| N(1)—C(2)—N(3)    | 116.7 (2) | C(5)—C(6)—O(6)                   | 123.2 (2) |
| O(2)—C(2)—N(3)    | 121.6 (2) | N(1)—C(6)—O(6)                   | 120.2 (2) |
| C(2)—N(3)—C(4)    | 125.5 (2) | C(5)—C(7)—C(8)                   | 114.2 (2) |
| N(3)—C(4)—O(4)    | 120.5 (2) | C(5)—C(9)—C(10)                  | 121.5 (2) |
| N(3)—C(4)—C(5)    | 116.0 (2) | C(5)—C(9)—C(14)                  | 119.0 (2) |
| C(5)—C(4)—O(4)    | 123.4 (2) | C(10)—C(9)—C(14)                 | 119.6 (2) |
| C(4)—C(5)—C(6)    | 110.7 (2) | C(9)—C(10)—C(11)                 | 119.5 (3) |
| C(4)—C(5)—C(7)    | 110.2 (2) | C(10)—C(11)—C(12)                | 120.8 (3) |
| C(4)—C(5)—C(9)    | 106.9 (2) | C(11)—C(12)—C(13)                | 119.6 (3) |
| C(6)—C(5)—C(7)    | 110.3 (2) | C(12)—C(13)—C(14)                | 120.7 (3) |
| C(6)—C(5)—C(9)    | 108.7 (2) | C(13)—C(14)—C(9)                 | 119.9 (3) |
| C(2)—N(1)—H(1)    | 120 (2)   | C(9)—C(14)—H(14)                 | 125 (2)   |
| C(6)—N(1)—H(1)    | 115 (2)   | C(5)—C(7)—H(71)                  | 106 (2)   |
| C(2)—N(3)—H(3)    | 120 (2)   | C(5)—C(7)—H(72)                  | 106 (2)   |
| C(4)—N(3)—H(3)    | 115 (2)   | C(8)—C(7)—H(71)                  | 107 (2)   |
| C(9)—C(10)—H(10)  | 124 (2)   | C(8)—C(7)—H(72)                  | 106 (2)   |
| C(11)—C(10)—H(10) | 117 (2)   | H(71)—C(7)—H(72)                 | 118 (2)   |
| C(10)—C(11)—H(11) | 115 (2)   | C(7)—C(8)—H(81)                  | 105 (2)   |
| C(12)—C(11)—H(11) | 124 (2)   | C(7)—C(8)—H(82)                  | 103 (2)   |
| C(11)—C(12)—H(12) | 116 (2)   | C(7)—C(8)—H(83)                  | 107 (2)   |
| C(13)—C(12)—H(12) | 124 (2)   | H(81)—C(8)—H(82)                 | 126 (3)   |
| C(12)—C(13)—H(13) | 124 (2)   | H(81)—C(8)—H(83)                 | 107 (3)   |
| C(14)—C(13)—H(13) | 115 (2)   | H(82)—C(8)—H(83)                 | 108 (3)   |
| C(13)—C(14)—H(14) | 115 (2)   | H <i>W</i> (1)—O1—H <i>W</i> (2) | 92 (3)    |

| Hydrogen bonds      |   |           |                                    |            |
|---------------------|---|-----------|------------------------------------|------------|
| O(1)—O(2 <i>a</i> ) | ( $\frac{1}{2} + x, y, \frac{1}{2} - z$ )   | 2.921 (2) | O(2 <i>a</i> )—O(1)—O(2 <i>b</i> ) | 92.59 (7)  |
| O(1)—O(2 <i>b</i> ) | ( $-\frac{1}{2} - x, -y, \frac{1}{2} + z$ ) | 2.954 (2) | O(2 <i>a</i> )—O(1)—N(1)           | 116.14 (7) |
| O(1)—N(1)           | ( $x, y, z$ )                               | 2.977 (2) | O(2 <i>a</i> )—O(1)—N(3)           | 126.54 (8) |
| O(1)—N(3)           | ( $-x, -y, -z$ )                            | 2.977 (2) | O(2 <i>b</i> )—O(1)—N(1)           | 129.08 (8) |
|                     |   |           | O(2 <i>b</i> )—O(1)—N(3)           | 114.84 (7) |
|                     |   |           | N(1)—O(1)—N(3)                     | 81.89 (7)  |

prising features, except for the bonds in the phenyl ring of 1.37 Å, between C(11)–C(12) and C(12)–C(13). The pyrimidine ring is very symmetric about the median plane through C(5), C(2) and O(2), there being no significant differences between corresponding bond lengths and angles on either side of this plane.

The pyrimidine ring is very markedly non-planar, in contrast with the approximately planar conformation of the ring in most of the other barbituric acids studied. The equation of the best plane through the planar part of the ring is given in Table 5. The pyrimidine ring is envelope shaped, with the 'flap', having C(5) at its apex, directed towards the phenyl group. The angle between the lines C(5)–C(12) and C(2)–O(2) is thus reduced to 94° from the value of 125.4° that would be expected if the pyrimidine ring were approximately planar.

Table 5. *Planar groups*

|  |
|--|
| Plane (1): [O(2), C(2), N(1), N(3), C(4), C(6)]      |
| $5.05948x - 21.81944y + 0.33584z + 1.4935 = 0.$      |
| r.m.s. deviation: 0.0091 Å.                          |
| Plane (2): [C(9), C(10), C(11), C(12), C(13), C(14)] |
| $5.20787x + 19.99514y + 2.45989z - 3.1429 = 0.$      |
| r.m.s. deviation: 0.0026 Å.                          |
| <i>x, y, z</i> are fractional coordinates.           |

|      | Distance from (1) |       | Distance from (2) |
|------|-------------------|-------|-------------------|
| N(1) | 0.013 Å           | C(9)  | 0.003 Å           |
| C(2) | -0.016            | C(10) | 0.000             |
| O(2) | 0.003             | C(11) | -0.003            |
| N(3) | 0.004             | C(12) | 0.003             |
| C(4) | 0.002             | C(13) | 0.000             |
| C(6) | -0.006            | C(14) | -0.003            |
| C(5) | -0.426            | C(5)  | 0.027             |
| O(4) | 0.272             |       |                   |
| O(6) | 0.247             |       |                   |

By far the majority of the approximately planar pyrimidine rings that have been found in barbituric acids occur in compounds wherein the C(5) substituents are such that an *n*-pentane configuration (all *trans*) centred on C(5) may occur. All barbituric acids so far studied in which one of the C(5) substituents is phenyl have been found to have the envelope conformation shown here, *e.g.* 5-methyl-5-phenyl (Bravic, Housty & Bideau, 1968); *N*-methyl-5-methyl-5-phenyl (Bideau, Marley & Housty, 1969); phenobarbitone complexed with adenine (Kim & Rich, 1968).

The phenyl ring is rotated about the C(5)–C(9) bond. If the normal to the planar part of the pyrimidine ring is defined as the base vector of a spherical coordinate system, then the spherical coordinates of the normal to the phenyl ring are  $\varphi = 86.0^\circ$ ,  $\theta = 13.8^\circ$ , where  $\varphi$  is the rotation in the median plane of the pyrimidine ring towards C(2). The angle  $\varphi$  is thus related to the dihedral angle of 29.6° of the 'flap' on the pyrimidine ring.

#### Hydrogen bonding

Inclusion of water into the crystal structure has apparently inhibited the formation of hydrogen bonds between molecules of phenobarbitone. Although crystal structures of pure barbituric acids have invariably shown strong hydrogen bonding between molecules, it has occasionally been observed that if an alternative molecule is available in the structure, bonding occurs from the barbituric acid molecule only to the non-barbituric acid (Kim & Rich, 1968; Craven & Gartland, 1970).

The hydrogen-bonding scheme is shown in Fig. 3. Each water molecule is bonded to four phenobarbitone molecules, through the C(2) atoms of two of the

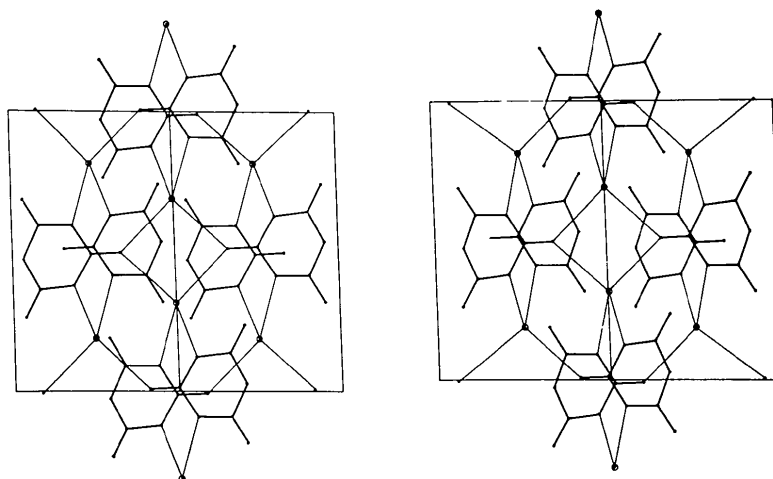


Fig. 3. The hydrogen-bonding scheme in the hydrophilic layers. The C(5) substituents have been omitted for clarity. The water oxygen atom is encircled. The view of the layer is approximately down the *y* axis, the *z* axis being vertical. The pseudo mirror plane at  $z = 0$  is clearly apparent.

molecules, and the N(1) and the N(3) atoms of the other two. Each phenobarbitone molecule is similarly bonded to four water molecules, two of the bonds being from O(2) to water, and the remaining two from the nitrogen atoms. The O(4) and O(6) atoms are not involved in hydrogen bonding at all. This arrangement results in the formation of infinite sheets of hydrogen-bonded molecules parallel to the  $xz$  plane of the crystal.

Although the H(1) and H(3) atoms lie close to plane 1 defined in Table 5, the water oxygen, O(1), lies 1.56 Å away from it. Consequently, the hydrogen bonds N-H...O(1) are 'bent' (angle at H is 146.5° in both bonds), the hydrogen atoms lying about 0.4 Å from the nitrogen-oxygen vector. This is a relatively large distortion for a non-bifurcated hydrogen bond (Hamilton & Ibers, 1968), but not so exceptional as to throw doubt upon the hydrogen-bonding scheme. The bonds from O(1) to O(2) are much more linear, the O-H-O angles being 170.2 and 170.8°.

The phenobarbitone molecules in the hydrogen bonded sheets are arranged in pairs (Fig. 4), the two members of the pair being related by a centre of symmetry. The C(2) carbonyl groups of the two molecules are therefore parallel, and aligned so that the carbon of one group lies opposite the oxygen of the other. This arrangement clearly results from a strong dipole-dipole interaction between the carbonyl groups, resulting in a non-bonded carbon-oxygen distance of only 3.00 Å. Such an arrangement has been noted before (Craven & Mascarenhas, 1964; Craven, Martinez-Carrera & Jeffrey, 1964; Mootz & Jeffrey, 1965), and in some structures may well be as important

in controlling molecular packing as is hydrogen bonding.

The C(2) carbonyl group is thus involved in a dipole-dipole interaction, and in two hydrogen bonds to water molecules. The C(4) and C(6) carbonyls are not involved in any intermolecular interactions, and this fact accounts for the significant (about  $8\sigma$ ) elongation of the C(2)-O(2) bond compared with the C(4)-O(4) and C(6)-O(6) bonds.

The hydrophilic sheets, involving the hydrogen-bonding network are separated by parallel lipophilic sheets composed of packed phenyl rings. The packing of the phenyl rings within the lipophilic sheets is similar to that observed in benzene (Cox, 1958), and in many other aromatic compounds. The hydrogen atom attached to C(12) lies almost equidistant (2.93 to 3.01 Å) from all the carbon atoms in the phenyl ring at position  $(x - \frac{1}{2}, \frac{1}{2} - y, -z)$ . The ethyl groups lie at the boundaries of the hydrophilic and lipophilic layers, and do not interfere with the efficient packing of the phenyl rings. It is probable that the packing requirements in the lipophilic layer govern the degree of rotation of the phenyl group about the C(5)-C(9) bond.

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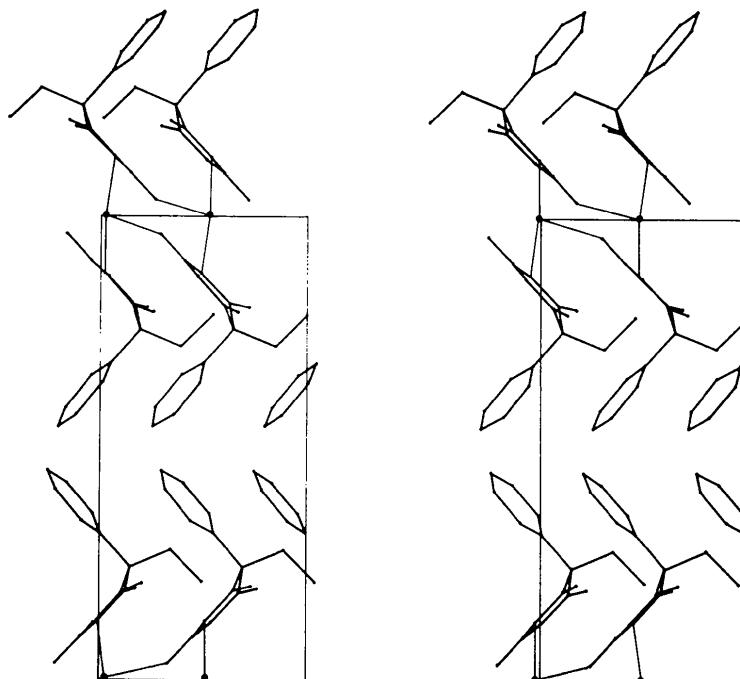


Fig. 4. The molecular packing viewed down the  $z$  axis. The  $x$  axis is horizontal and the  $y$  axis vertical.

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## Comparison of Two Independent Structure Determinations of Acetylene Dicarboxylic Acid\*

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The results of two independent structure determinations of acetylene dicarboxylic acid are compared through the use of half-normal probability plots. A systematic error of unknown origin is indicated in one or both structure determinations.

In our study of electron-cloud distortions due to bonding using generalized scattering factors (Stewart, 1969; Cromer & Larson, 1973; Larson & Cromer, 1973), we determined the crystal structure of acetylene dicarboxylic acid (ADA). Upon completing this analysis we found that Benghiat, Leiserowitz & Schmidt (1972) (hereinafter BLS) had previously determined this crystal structure. In this note we make use of half-normal probability plots (Abrahams & Keve, 1971) to compare the results of these two quite independent crystal structure determinations.

The structure is interesting because the hydrogen-bonded carboxylic acid pairs are disordered and there

appear to be two half hydrogen atoms in each of the hydrogen bonds. The carboxylic acid groups are randomly rotated by 180°. Fig. 1 shows the atom numbering scheme used by BLS, which is used here also.

Our crystals were grown from absolute ethanol and were stable in our laboratory atmosphere for the time required to collect the data, but they later decomposed. BLS grew crystals from nitromethane and report them to be extremely hygroscopic; hence their data were collected with the crystal enclosed in a Lindemann-glass tube.

Table 1 summarizes the two sets of experimental data. Refinement in both cases was carried out by means of full-matrix least-squares analysis. In both refinements the weights were derived from  $\sigma_I$  as de-

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