Carbohydrate Research
Elsevier Publishing Company, Amsterdam
Printed in Belgium

PHENYLHYDRAZONO–PHENYLAZO TAUTOMERISM.

PART II. STRUCTURES OF 2-OXO-1,3-BIS(PHENYLHYDRAZONO) COMPOUNDS* AND RELATED COMPOUNDS

Alexander J. Fatiadi and Horace S. Isbell
Division of Analytical Chemistry, Institute for Materials Research, National Bureau of Standards, Washington, D. C. 20234 (U. S. A.)

(Received May 27th, 1967; in revised form, July 15th, 1967)

INTRODUCTION

In prior publications[1,2], we reported the preparation, from *myo*-inositol, of *xylo*-4,5,6-trihydroxy-2-oxo-1,3-bis(phenylhydrazono)cyclohexane (**1**) and showed that it exists in a red form and in a yellow form. In the preceding paper[2], we pointed out that certain previously known, crystalline, oxo-bis(phenylhydrazono) compounds, when prepared under mild conditions, are yellow, but change to dark red on standing or on heating in toluene, and we suggested that **1** and also these other compounds undergo a tautomeric reaction such as that depicted in Fig. 1. We further suggested that the red forms have an enolic, phenylhydrazono–phenylazo resonance-structure (**1b**), whereas the yellow forms have a normal phenylhydrazono structure (**1a**).

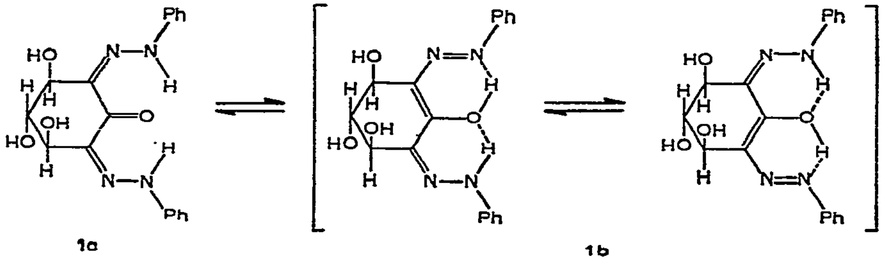


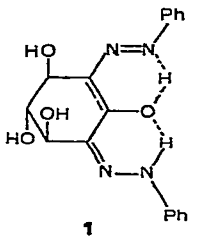
Fig. 1. Tautomerism of 2-oxo-1,3-bis(phenylhydrazones).

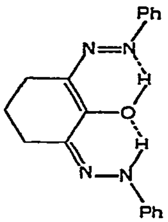
We have now prepared and studied the following, previously known oxo-bis(phenylhydrazono) compounds: 2-oxo-1,3-bis(phenylhydrazono)cyclohexane[3] (**2**), 2-oxo-1,3-bis(phenylhydrazono)cyclopentane[4] (**3**), 3-oxo-2,4-bis(phenylhydrazono)cyclohexane-1-carboxylic acid[5] (**4**), 2-oxo-1,3-bis(phenylhydrazono)indan[6] (**5**), and 2-oxo-1,3-bis(phenylhydrazono)propane[7,8,9] (**6**). The structures and properties of oxo-bis(phenylhydrazono) compounds have been the subject of numerous prior investigations[3–18], but heretofore, the structures of **1**–**6** have not been rigorously determined.

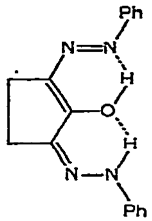
---

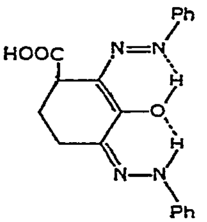
*For purposes of comparison, the compounds are considered as 2-oxo-1,3-bis(phenylhydrazono) derivatives, even though, in their systematic names, the groups may be otherwise designated.

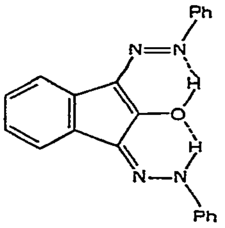
In fact, **3** has been reported[19], without proof, to be a 3-oxo-1,2-bis(phenylhydrazono) compound, rather than a 2-oxo-1,3-bis(phenylhydrazono) compound. In the present paper, the structures of the compounds were studied by measurement of n.m.r. spectra and by comparison of their u.v. and visible spectra with those of compounds of known structure. Certain parameters for correlation of spectra and structure have been found, and specific structures have been assigned to the compounds of interest. For simplicity of representation, only one enolic structure for each of the compounds **1**–**6** is shown, although all possible enolic resonance forms corresponding to **1b** should be considered possible for the compounds.

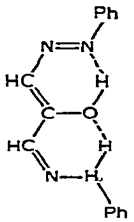

1

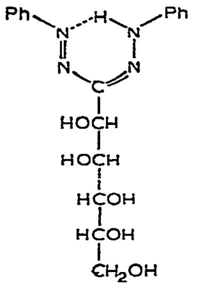

2

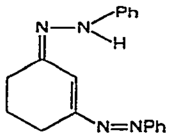

3


4


5


6


7


8

DISCUSSION

Red and yellow forms of 2-oxo-1,3-bis(phenylhydrazono) compounds

The u. v. and visible spectra of the red forms of compounds **1**–**6**, given in Table I, show three main regions of absorption*, namely, at 243–251 nm (ε ~20,000), 282–289 nm (ε ~5,000), and 432–488 nm (ε ~35,000). The similarity of the absorption spectra indicates that all of the compounds have like chromophores, and consequently, similar structures for the phenylhydrazono moieties.

The deep-red color of the compounds, and especially the high intensity of the absorption band at 432–488 nm cannot be explained by the presence of a phenylhydrazono, or a simple phenylazo, chromophore[20]. The spectra suggest that each of the compounds has a phenylhydrazono group and a phenylazo group in a conjugated resonance structure. The diphenylformazans of sugars[21] have a phenylhydrazono

---

*The ultraviolet peaks are given as the wavelength (λ) in nanometers (nm), formerly called millimicrons (mμ); 1 nm = 10^{-9} m.

TABLE I

ULTRAVIOLET AND VISIBLE ABSORPTION BANDS[a], AND THEIR INTENSITIES, FOR PHENYLHYDRAZONO-PHENYLAZO COMPOUNDS AND RELATED COMPOUNDS

Compound	*Solvent*	λ_{max} *(in nm) and* ε_{max}[b]			
		Phenylhydrazono-phenylazo compounds			
1	EtOH	251 (18,800)		286 (sh) (6,000)	487 (34,300)
2	MeOH	249 (24,000)		289 (sh) (5,000)	470 (36,800)
3	MeOH	243 (18,000)	262 (sh) (12,500)	285 (sh) (4,200)	462 (54,800)
4	MeOH	250 (21,500)		282 (sh) (5,500)	470 (34,000)
5[c]	MeOH	233 (24,000)	263 (sh) (18,900)	288 (15,800)	488 (28,700)
6	MeOH	250 (20,200)		288 (sh) (6,000)	432 (3,300)
7	EtOH	257 (16,700)		292 (sh) (7,200)	441 (18,500)
8	EtOH	253 (22,000)		292 (sh) (8,100)	487 (30,000)
		Phenylhydrazono compounds			
9	EtOH	278 (23,500'; 302 (sh) (10,200)			
10	MeOH	247 (sh) (9,700); 302 (10,500); 372 (48,600)			
11	MeOH	259 (24,200); 318 (10,800); 399 (21,900)			
14	MeOH	249 (16,700); 255 (sh) (15,100); 295 (24,500); 315 (28,700); 418 (23,500)			
		Phenylazo compounds			
12	MeOH	361 (4,500); 375 (4,400); 398 (sh) (2,250); 466 (sh) (1,500)			
13	MeOH	233 (11,000); 227 (12,600); 233 (10,800); 302 (23,800); 425 (350)			
		Tris(phenylhydrazono) compounds			
18	EtOH	238 (sh) (20,200); 261 (27,000); 296 (30,000); 322 (sh) (21,900); 392 (27,500); 455 (sh) (9,400)			
19	EtOH	258 (28,300); 293 (31,200); 316 (sh) (18,700); 418 (37,700); 465 (sh) (16,700)			
20	EtOH	237 (sh) (22,300); 261 (20,300); 291 (21,200); 324 (sh) (15,600); 390 (16,400); 452 (sh) (6,700)			
21	EtOH	237 (sh) (17,200); 251 (17,900); 302 (22,700); 344 (24,000); 408 (29,400)			

---

[a] The spectra were recorded 30 min after the sample had dissolved. [b] The molecular extinction coefficient is given in parentheses. [c] The spectrum of **5** is complicated by the existence of the polycyclic indan ring, but the bands at 233–263, 288, and 488 nm clearly indicate that the compound has the characteristic phenylhydrazono-phenylazo structure. In addition to the bands listed, the compound shows bands at 355 ($\varepsilon \sim 30{,}700$) and 430 nm (sh) ($\varepsilon \sim 15{,}100$).

group and a phenylazo group attached to the *same* carbon atom, presumably in a resonance state. Because of the similarity of the resonance structures, the 2-oxo-1,3-bis(phenylhydrazones) and the diphenylformazans of sugars would be expected to show similar u.v. and visible absorption. In agreement with this expectation, D-mannose *N*,*N*-diphenylformazan (**7**) gave three intense absorption bands in the regions characteristic of the red forms of compounds **1**–**6** (see Table I). The marked similarity in the absorption spectra of the 2-oxo-1,3-bis(phenylhydrazono) compounds and of the formazans clearly supports the enolic, phenylhydrazono–phenylazo structure proposed. The structure was further supported by comparison of the u. v. and visible spectra of the compounds with the spectrum of 1-phenylazo-3-phenylhydrazono-1-cyclohexene (**8**). This compound was originally prepared by Merling[22], who suggested that it has a phenylhydrazono group in conjugation with a phenylazo group. We have repeated the preparation of **8** and find that it shows u. v. and visible absorption bands similar to those listed for D-mannose *N*,*N*-diphenylformazan and for the red forms of compounds **1**–**6**.

Product **2**, prepared from 1,2,3-cyclohexanetrione and phenylhydrazine under mild conditions, crystallized from aqueous ethyl alcohol in the form of a yellow hydrate (**2a**). A freshly prepared, ice-cold solution of **2a** in aqueous ethyl alcohol shows an absorption band at about 400 nm that shifts rapidly to a longer wavelength (about 470 nm). The solution, after equilibration and evaporation, yields red crystals of **2b**. We could not obtain crystalline hydrates of other 2-oxo-bis(phenylhydrazono) compounds, but, in each instance, the product prepared under mild conditions was yellow or orange, and became dark red on recrystallization. The relative stability of the red and yellow forms of the several 2-oxo-1,3-bis(phenylhydrazones) seems to vary widely.

The bis(phenylhydrazone) of 1,2,3-cyclopentanetrione (**3**) separated from aqueous ethyl alcohol in orange-colored, anhydrous crystals, slightly soluble in toluene. The freshly prepared toluene solution is yellow-orange, but turns red on standing. Evaporation of the red solution gives dark-red crystals of the enolic form, **3b**. The products obtained by recrystallization from ethyl alcohol varied widely and appeared to be mixtures.

It has been reported by others[23–25] that the phenylhydrazono structure is ordinarily favored over the phenylazo structure. In solution, however, the relative stability of the two forms may depend on the formation of complexes and on the polarity of the solvent[26].

A comparison of the infrared spectra of the yellow hydrate **2a** and the red form **2b** reveals significant differences; thus, **2a** shows the following characteristic absorption bands*: 2.82 μm (O-H); 3.00 μm (N-H); 6.10 μm (C=N); and 6.48 μm (N-H bending). In marked contrast, **2b** does not show these bands, but shows a new band at 6.36 μm which may be attributed to the -N=N- vibration[27,30]. This absorp-

---

*The infrared absorption bands are given as the wavelength (λ) in micrometers (μm), formerly called microns (μ); 1 μm = 10^{-6} m.

tion band and the lack of absorption bands characteristic of C=O, C=N, and N-H (bending) support the enolic, phenylhydrazono–phenylazo structure proposed for **2b**.

The infrared spectra of the red forms of **1** and **3**–**6** all show a band at 6.32 to 6.44 μm, attributed to the -N=N- vibration, but they also show weak bands at 2.88 to 3.00 μm, corresponding to N-H vibrations, at 6.45 to 6.58 μm attributed to N-H bending[31,33], and a band at 6.10 μm (C=N). These bands are not shown by **2b** (in which the normal N-H vibrations may be restricted by the highly stable, chelate structure). It thus appears that **2b** was isolated in the pure, chelate form, whereas compounds **1** and **3**–**6** contain minute proportions of the hydrazono form.

The structure of compound **2** is particularly favorable for chelation, because the phenylhydrazono and oxo groups are in position to form a resonance structure without steric hindrance or ring strain. The steric factors are not quite so favorable for compounds **1**, **3**, **4**, **5**, and **6**, and this fact may account for the presence of N-H bands in their i.r. spectra. With compound **2**, the resonance energy may be sufficient to

TABLE II

NUCLEAR MAGNETIC RESONANCE SPECTRA OF 2-OXO-1,3-BIS(PHENYLHYDRAZONO) COMPOUNDS AND RELATED COMPOUNDS[a]

Compound	*Solvent*	*Chelated* N-H	*Nonchelated* N-H	*Other pertinent signals*
1	*p*-dioxane	14.30		
		12.32		
1	Me$_2$SO	14.40	10.86	
		14.28	11.42	
2	CDCl$_3$	13.98		
2	Me$_2$SO	14.46	10.00	
		14.12		
3	Me$_2$SO	13.70	10.30	
4	Me$_2$SO	14.30	10.43	10.20 (CO$_2$H)
		14.00		
5	Me$_2$SO	12.80		
6	*p*-dioxane	13.90	9.91	7.90 (methine)
7	*p*-dioxane	12.64		
10	Me$_2$SO	(12.60)[b]	10.45	7.83 (methine)
			(11.50)[b]	
11	Me$_2$SO	12.86	10.40	
14	*p*-dioxane	13.20	9.40	8.10 (methine)
				9.50 (aldehyde)
14	Me$_2$SO	13.25	10.90	8.18 (methine)
				9.50 (aldehyde)
18	CDCl$_3$	13.54		
		12.75		
19	*p*-dioxane	12.55	10.80	
		11.85		
20	Me$_2$SO	13.75	10.80	9.91 (CO$_2$H)
		12.80		
21	CDCl$_3$	(13.34)[b]		8.20 (methine)

[a] All resonance positions are given as p.p.m. downfield from internal tetramethylsilane (δ-scale); the average deviation is ±0.1 p.p.m. [b] Signal observed after equilibration.

hybridize the phenylhydrazono–phenylazo moieties completely. Presumably, the electron-withdrawing power of the carbonyl group is a driving force for the formation of the resonance structure depicted in **1b**.

To obtain additional information concerning the structures, the n.m.r. spectra of the 2-oxo-1,3-bis(phenylhydrazono) compounds were compared with the spectra of compounds having somewhat similar features (see Table II). In each instance, the spectrum in *p*-dioxane, chloroform-*d*, or methyl sulfoxide shows a strong signal (12.55 to 14.46 p.p.m.) indicative of a chelated N-H group. Compound **2** was studied in considerable detail, because it does not have substituent groups that complicate interpretation of the spectrum, and it is readily prepared and purified.

The n.m.r. spectrum of compound **2** in chloroform-*d* (see Fig. 2) shows multiplets centered at 1.9 p.p.m. (the four protons on C-4 and C-6), at 2.62 p.p.m. (the two nonequivalent protons on C-5), and at 7.28 p.p.m. (the protons on the phenyl ring). The nonequivalence of protons on C-5 probably arises from axial and equatorial attachment and the spin–spin interaction with the protons on neighboring atoms C-4 and C-6. The spectrum also shows a strong signal at 13.98 p.p.m., indicative of an intramolecular bond between the imino hydrogen atom of the phenylhydrazono group and the carbonyl oxygen atom. The spectrum does not, however, show any signals typical of a free imino proton. This fact and the absence, in the infrared spectrum of **2**, of absorption characteristic of N-H, C=O, or O-H groups support the enolic phenylhydrazono–phenylazo structure in which the imino hydrogen atoms of the phenylhydrazono groups are alternately joined with the oxygen atom. An approximate calculation of the intensity of the n.m.r. signal of **2** at 13.98 p.p.m. in chloroform-*d* suggests that the two protons are involved but cannot be resolved. In a polar solvent, however, the two forms of the compound may exist as separate entities. In fact, the n.m.r. spectrum of **2** in methyl sulfoxide shows two low-field signals; a relatively strong signal at 14.46 and a weaker signal at 14.12 p.p.m. This result is in accordance with the chelate rings depicted in the structures shown in Fig. 1. Addition of a few drops of methyl sulfoxide to a probe of **2** in chloroform-*d* produces (by means of a solvent shift) two distinct peaks from the (otherwise submerged) low-field signal observed at 13.98 p.p.m. for **2** in chloroform-*d*.

Related phenylhydrazono and phenylazo compounds

Further insight into the structures of compounds **1–6** was obtained by study of certain compounds having related phenylhydrazono and phenylazo structures (formulas **9–14**).

myo-Inosose-2 phenylhydrazone (**9**) (a typical phenylhydrazone) shows two absorption bands in the u.v., and none in the visible region. Glyoxal bis(phenylhydrazone) (**10**), the simplest acyclic bis(phenylhydrazone), shows two bands in the u.v. region and one in the visible region at 372 nm[33,34]. The cyclic compound, D-*myo*-inosose-1 phenylosazone (**11**) also shows three bands, but at somewhat longer wavelengths than those for the acyclic compound **10**.

Simple phenylazo compounds give a low-intensity band at 380 to 415 nm

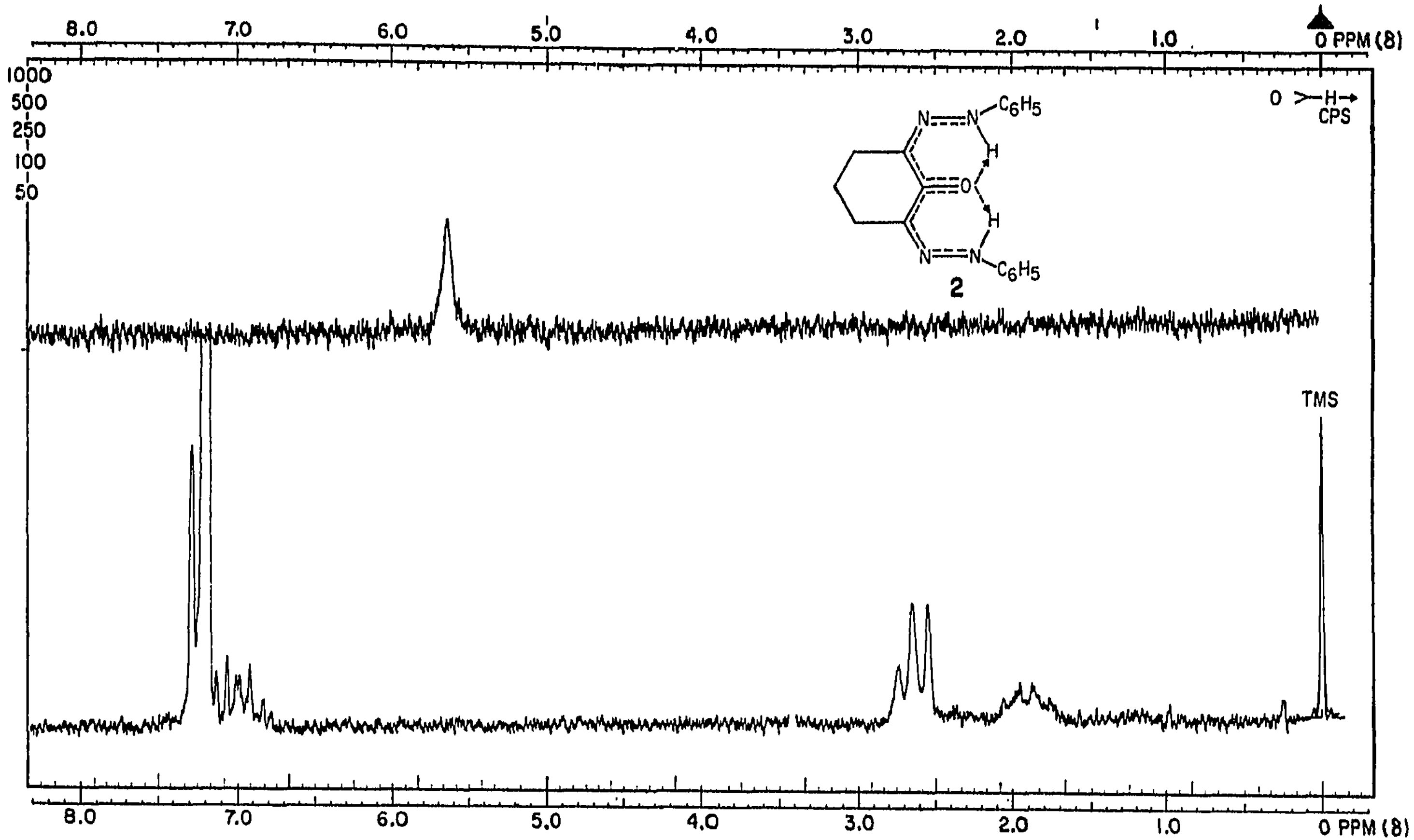
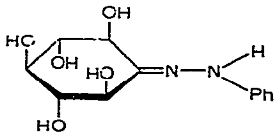
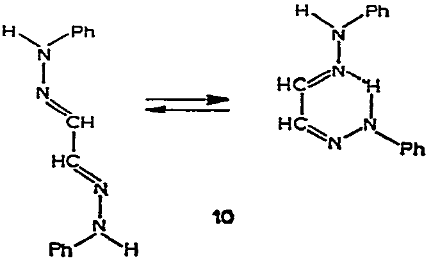
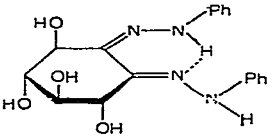


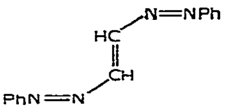
Fig. 2. N.m.r. spectrum of 2-oxo-1,3-bis(phenylhydrazono)cyclohexane (2) in chloroform-*d* at 60 MHz and 500-Hz sweep-width, with tetramethylsilane as internal standard. The upper trace is at a sweep-offset of 500 Hz.

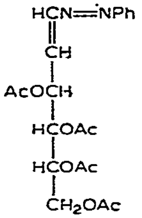
(ε ~10–250), but the presence of a conjugated double bond causes a bathochromic shift and an increase in the extinction coefficient. Thus, phenylazomethane and 1,2-diphenyl-1,2-bis(phenylazo)ethane[35] absorb at 403 and 404 nm, respectively. In marked contrast, 1,2-bis(phenylazo)ethylene[36] (**12**) gives a high-intensity band at 466 nm (ε ~1,500). This is in accordance with the observations that the azo group is iso-π-electronic with the vinyl group[37] and that the conjugation of two electronically equivalent chromophores gives rise to a high-intensity band (K band)[38]. A conjugated phenylazo chromophore in compounds **1**–**6** may account, in like manner, for the high-intensity absorption band at 430–490 nm.

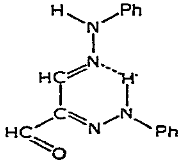

9


10


11


12


13


14

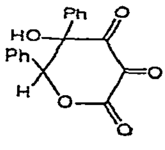
Comparison of the u.v. spectrum of the acyclic compound **6** with the spectra of the cyclic compounds **1**–**5** reveals that conjugation of a phenylazo group in the acyclic compound **6** produces less bathochromic shift and a lower extinction coefficient than conjugation in the cyclic compounds. Other conjugated azo structures show similar effects. Thus, the acyclic compound **13**, first prepared by Wolfrom and co-workers[39], shows a band at 425 nm (ε ~350), whereas the cyclic compound **8** shows a band at 487 nm (ε ~30,000). Likewise, in the visible region, compound **6** shows lower absorption than cyclic compounds **1**–**5**. In the latter compounds, the phenylhydrazono groups are held in a fixed and favorable position for forming a resonance structure, whereas, in the acyclic compound **6**, the phenylhydrazono groups may assume a less favorable position. Hence, the effect of conjugation is greater for the cyclic compounds.

In addition to a u.v. absorption band at 302 nm (previously reported for **13** by Wolfrom and co-workers[39]) and the band at 425 nm reported here, compound **13** shows a characteristic triplet: $\lambda_{\max}^{\mathrm{MeOH}}$ 222.5 (ε~11,000), 227.5 (ε ~12,600), and 233 nm (ε ~10,800). These characteristic bands may be used for detection of the structure $-C{=}C{-}N{=}N{-}Ph$ in other compounds.

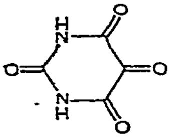
The n.m.r. spectrum of **10** after equilibration (see Table II), in agreement with the observations of Chapman and co-workers[40], gave evidence for the existence of a chelated and a nonchelated N-H group. The n.m.r. spectrum of **11** in methyl sulfoxide shows a signal at 12.86 p.p.m., thus confirming the chelate ring-structure, analogous to the structures reported for the phenylosazones of the sugars[40–42].

The points of attachment of the phenylhydrazono groups in compounds **1** and **6** had previously been established[2,8,9] by reliable chemical methods; the phenylhydrazono groups in compounds **2**, **3**, **4**, and **5** are now assigned to C-1 and C-3 from the similarity of the spectra of the compounds to the spectra of compounds **1** and **6**. The compounds were prepared by treatment of the triones with phenylhydrazine and, in each instance, the phenylhydrazono groups could have entered at C-1 and C-2, or at C-1 and C-3. It was, therefore, of interest to study the spectra of a 3-oxo-1,2-bis(phenylhydrazono) derivative. For this purpose, we prepared mesoxalaldehyde 1,2-bis(phenylhydrazone) (**14**), a compound originally reported by Chargaff and Magasanik[43] and investigated by El Khadem and Abdel Rahman[44]. The u.v. and visible spectra of **14** were found to be in agreement with those reported by the above authors, except for a broad band at 251 nm not reported by them [44]. The spectrum of **14** in the visible region shows absorption bands at 315 and 418 nm, whereas the spectra of the 2-oxo-1,3-bis(phenylhydrazono) derivatives show a single band at 432–487 nm. The two bands at lower wavelength, instead of one band at higher wavelength, serve to distinguish the 3-oxo-1,2-bis(phenylhydrazono) from the 2-oxo-1,3-bis(phenylhydrazono) derivatives. The n.m.r. spectrum of **14** in methyl sulfoxide (and in *p*-dioxane) agreed with that of El Khadem and Abdel Rahman[44].

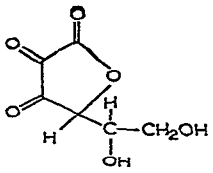
The properties of **14** are of particular interest with reference to certain phenylhydrazono compounds of unknown structure prepared from the following heterocyclic triones: tetrahydro-5-hydroxy-5,6-diphenylpyran-2,3,4-trione (**15**), alloxan **16**), and dehydro-L-ascorbic acid (**17**).



15



16



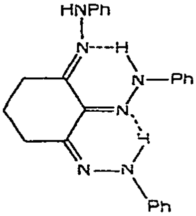
17

The red bis(phenylhydrazone) of **15** melted at 231–232°, as reported[16]; it showed λ_{max}^{EtOH} 238 ($\varepsilon \sim 19,300$), 261 ($\varepsilon \sim 21,600$), 293 ($\varepsilon \sim 18,700$), 356 ($\varepsilon \sim 9,800$), and 456 nm ($\varepsilon \sim 16,500$). However its i.r. spectrum showed strong carbonyl absorption at 5.82 and 5.98 μm. Treatment of the bis(phenylhydrazone) with phenylhydrazine at 130° produced a slightly pinkish, crystalline product, m.p. 268–270°, that differed widely from the yellow tris(phenylhydrazones) prepared from 1,2,3-triones (compounds **18**–**21**). Thus, the bis(phenylhydrazone) of **15** must have a structure different from the enolic phenylhydrazono–phenylazo structure of the red forms of compounds **1**–**6**.

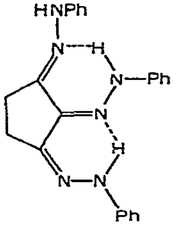
Treatment of alloxan with phenylhydrazine gave a rearranged product presumably similar to the ring-contraction products reported to result from the reaction of alloxan with aliphatic or aromatic amines[45]. Treatment of dehydro-L-ascorbic acid with phenylhydrazine gave two products, in agreement with reported work[46]. Neither of these was analogous to the 1,3-bis(phenylhydrazones) **1**–**6**.

Tris(phenylhydrazono) compounds

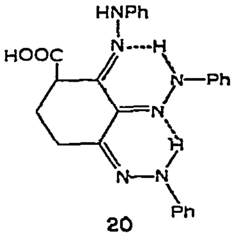
To obtain a more complete understanding of chelated phenylhydrazono structures, the tris(phenylhydrazono) derivatives depicted were prepared. These derivatives are related, respectively, to the 2-oxo-1,3-bis(phenylhydrazono) compounds **2**–**4**, and **6**.



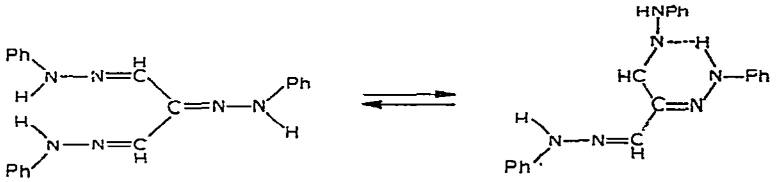
18



19



20



21 a

21 b

The n.m.r. spectrum of **18** in chloroform-*d* (see Fig. 3) shows two low-field signals, at 13.54 and 12.75 p.p.m., that are slowly exchangeable with deuterium (D_2O); these results indicate the presence of two chelated rings, as depicted in the formula. In chloroform-*d*, the signal for the free imino proton was submerged with the signals for the protons of the phenyl group.

The n.m.r. spectrum of **19** in *p*-dioxane shows signals at 12.55 and 11.85 p.p.m., ascribed to two chelate rings, and a signal at 10.80 p.p.m. readily exchangeable with deuterium at room temperature, which is ascribed to the nonchelated, imino proton. Compound **20** in methyl sulfoxide shows signals at 13.75 and 12.80 p.p.m. ascribed to the presence of two chelate rings, and a signal at 10.80 p.p.m. ascribed to a nonchelated, imino proton. The signal at 9.91 p.p.m. readily exchangeable with deuterium (D_2O) is ascribed to the proton of the carboxyl group.

El Khadem and Abdel Rahman[44] have reported that 1,2,3-tris(phenylhydrazono)propane (**21**) gives n.m.r. signals in methyl sulfoxide at 10.22, 10.83, and 12.51 p.p.m. corresponding, respectively, to the presence of two nonchelated, imino protons and one chelated proton. We find that the n.m.r. spectrum of **21** in chloroform-*d* does not show any low-field signals immediately after dissolution, but, after

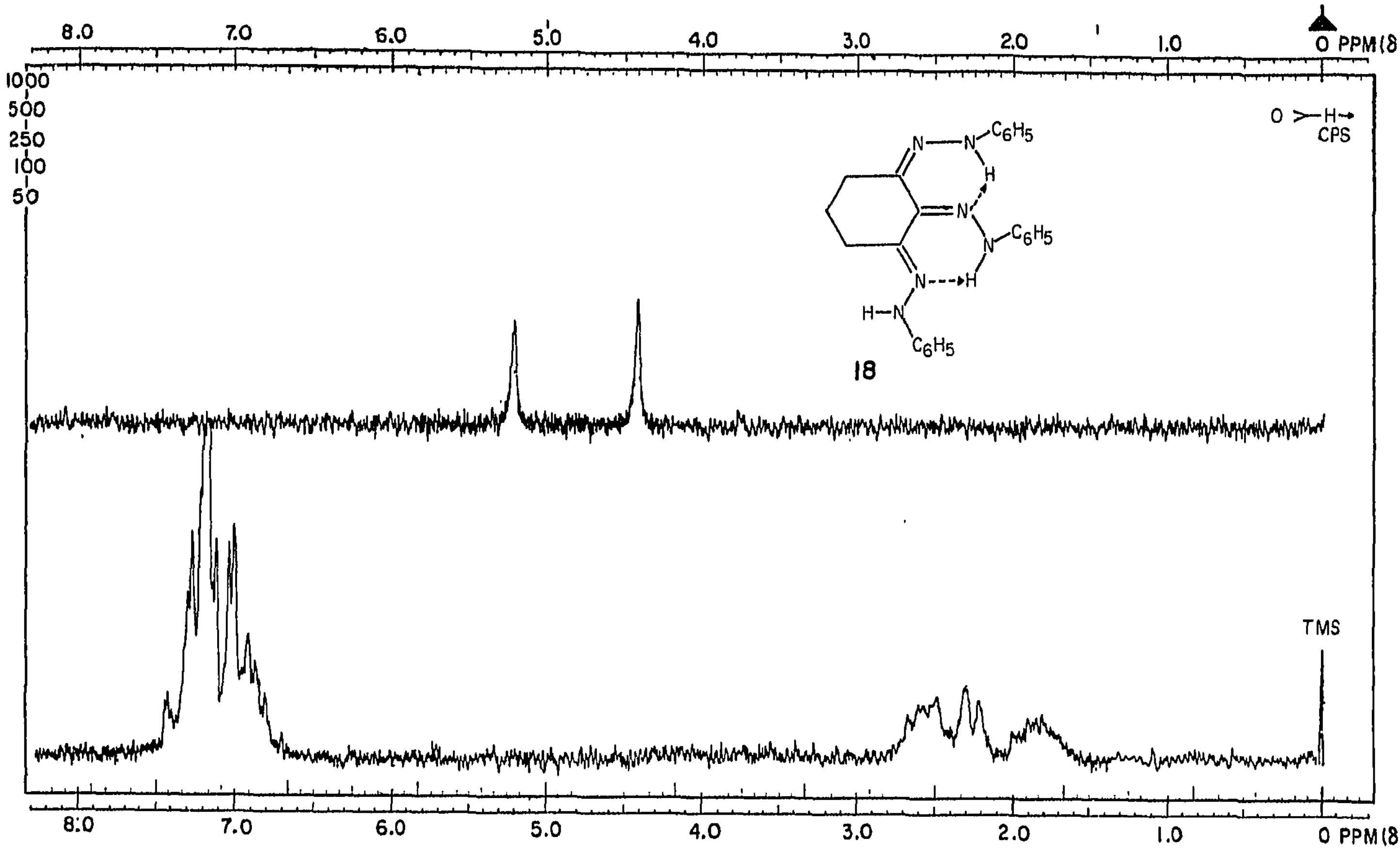


Fig. 3. N.m.r. spectrum of 1,2,3-tris(phenylhydrazono)cyclohexane (**18**) in chloroform-*d* at 60 MHz and 500-Hz sweep-width, with tetramethylsilane as internal standard. The upper trace is at a sweep-offset of 500 Hz.

a few minutes of equilibration, a weak, low-field signal develops at 13.34 p.p.m., indicating chelate-ring formation. The signal is not readily exchangeable with deuterium (D_2O) at room temperature; this suggests that **21** in chloroform-*d* may establish an equilibrium containing forms **21a** and **21b**, analogous to equilibrium mixtures reported by Chapman and co-workers[40] for certain 1,2-bis(phenylhydrazones).

The visible spectrum of **21** in ethanol shows a strong absorption band at 408 nm (see Table II) that may indicate that the compound undergoes further isomerization in polar solvents.

EXPERIMENTAL

Prior to analysis, all compounds were dried for 4 h at 25°/0.1 mm over phosphorus pentaoxide, unless otherwise stated. Melting points were observed in Pyrex* capillary tubes and are uncorrected. Ultraviolet and visible spectra were recorded with a Beckman DK-2 recording spectrophotometer*. Infrared spectra were determined in potassium chloride pellets, and in Nujol* or fluorocarbon mulls by use of a Perkin–Elmer "Infracord" Spectrophotometer, Model 137*; they are reproduced in a separate publication[47].

The n.m.r. spectra were measured with a Varian A-60 spectrophotometer* (sample temperature, 25–35°); all resonances are expressed as p.p.m. downfield from internal-reference tetramethylsilane (TMS) (δ-scale). *p*-Dioxane (commercial grade) was distilled from a small proportion of lithium aluminum hydride, and stored over molecular sieves prior to use. Methyl sulfoxide (reagent grade) was dried over molecular sieves for at least a week prior to use. Chloroform-*d* (commercial, spectrographic grade) and deuterium oxide were used without purification.

xylo-*4,5,6-Trihydroxy-2-oxo-1,3-bis(phenylhydrazono)cyclohexane* (**1**). — Compound **1** was prepared from "*xylo*-4,5,6-trihydroxycyclohexenediolic acid" by a procedure reported elsewhere[1,2]. Compound **1** failed to produce the expected tris(phenylhydrazone) when heated with phenylhydrazine for 90 min at 145° by the procedure described for compound **18**.

2-Oxo-1,3-bis(phenylhydrazono)cyclohexane (red form) (**2b**). — To a solution of dihydropyrogallol (2,3-dihydroxy-2-cyclohexen-1-one, prepared by catalytic reduction of pyrogallol[3,48]) in 300 ml of 4% aqueous acetic acid was added a saturated solution of iodine [prepared from iodine and 1:4 (v/v) glacial acetic acid–methanol] until a trace of free iodine remained. The excess of iodine was removed by cautious addition of a small quantity of the parent compound, and the solution was filtered through a thin layer of a decolorizing carbon. The colorless solution, containing 1,2,3-cyclohexanetrione, was treated with 10 ml of phenylhydrazine in 10 ml of methanol at 60–70°. The resulting, cherry-red product was twice recrystallized from warm methanol.

---

*Mention in this article of certain commercial instruments or chemical compounds does not constitute endorsement by the National Bureau of Standards.

The yield of **2b**, as lustrous, dark-red prisms, was 0.35 g, m.p. 132–133°; lit.[3] m.p. 131–132.5°.

Anal. Calc. for $C_{18}H_{18}N_4O$: C, 70.56; H, 5.92; N, 18.29. Found: C, 70.28; H, 5.85; N, 18.09.

Hydrated 2-oxo-1,3-bis(phenylhydrazono)cyclohexane (**2a**). — Dihydropyrogallol (5 g) was dissolved in 300 ml of 4% aqueous acetic acid and oxidized with iodine by the procedure given for the preparation of **2b**. The colorless solution containing 1,2,3-cyclohexanetrione was cooled to 0°, and 15 ml of phenylhydrazine in 15 ml of methanol, and 8 g of sodium acetate triacetate in 50 ml of cold water, were added with stirring. After 30 min at 0°, the light-orange precipitate was removed, and washed with cold water. The damp, crude product was quickly dissolved in warm, 95% ethanol, and the solution was filtered, and cooled quickly. The resulting, light-yellow needles were collected by filtration, washed with cold, 50% aqueous ethanol, and dried for 3 h at 25°/0.1 mm; yield 7 g; m.p. 130° (red melt, apparently anhydrous **2b**).

Anal. Calc. for $C_{18}H_{20}N_4O_2$: C, 66.65; H, 6.22; N, 17.27. Found: C, 66.67; H, 6.18; N, 17.40.

Recrystallization of the hydrate **2a** from hot ethanol yielded red, anhydrous **2b**. Stored in a closed bottle, the crystalline hydrate retained its yellow color for months without appreciable loss of water of crystallization or change in i.r. spectrum.

1,2,3-Tris(phenylhydrazono)cyclohexane (**18**). — A suspension of 0.15 g of crude **2b** and 2 ml of phenylhydrazine, in a test tube protected from the atmosphere, was heated in an oil bath for 1 h at 130–140°. The brownish yellow solution was then cooled, diluted with 2 ml of ethanol, and poured (with stirring) into 150 ml of cold, 4% aqueous acetic acid. The resulting bright-yellow precipitate was stirred for 1 h, filtered off, and washed with cold, 25% aqueous ethanol, to yield 100–200 mg of **18**; it was recrystallized from ethanol, or aqueous ethanol, and dried in a vacuum desiccator to constant weight; yellow needles, m.p. 185–186°, lit[3]. m.p. 186°.

Anal. Calc. for $C_{24}H_{24}N_6$: C, 72.70; H, 6.10; N, 21.20. Found: C, 72.77; H, 6.02; N, 21.04.

2-Oxo-1,3-bis(phenylhydrazono)cyclopentane (red form) (**3b**). — Reductic acid (2,3-dihydroxycyclopenten-1-one) (1 g) in 100 ml of 5% aqueous acetic acid was oxidized with iodine by essentially the procedure given for preparing **2**. The colorless solution containing 1,2,3-cyclopentanetrione was treated at 65–75° with 2 g of sodium acetate trihydrate and 2 ml of phenylhydrazine in 2 ml of methanol. The resulting 2-oxo-1,3-bis(phenylhydrazono)cyclopentane, brownish red leaflets, was recrystallized twice from hot ethanol and once from hot toluene. The product was dried for 2 h at 100°/0.1 mm; yield 1.1 g of lustrous, reddish bronze leaflets, m.p. 247–249°; lit.[4] m.p. 247.5–248.5°.

Anal. Calc. for $C_{17}H_{16}N_4O$: C, 69.84; H, 5.52; N, 19.17. Found: C, 69.70; H, 5.62; N, 19.42.

On heating compound **3b** with phenylhydrazine for 1 h at 145° by the procedure described for the preparation of **18**, 1,2,3-tris(phenylhydrazono)cyclopentane (**19**) was formed; yellow-orange prisms, m.p. 206–208°; lit.[4] m.p. 207–208°.

2-Oxo-1,3-bis(phenylhydrazono)cyclopentane (*orange-yellow form*) (3*). — Reductic acid (2 g) in 75 ml of 4% aqueous acetic acid was oxidized with iodine by the procedure used for preparing the red form, **3b**. The clear solution containing 1,2,3-cyclopentanetrione was cooled to 0°, and 150 ml of crushed ice, 3 ml of phenylhydrazine in 3 ml of methanol, and 3 g of sodium acetate trihydrate, were successively added with continuous stirring. After 15 min at 0°, the orange-yellow crystals were separated by filtration, washed with aqueous methanol, and dried for 3 h at 25°/0.1 mm; the yield of **3*** was 3–3.5 g.

Anal. Calc. for $C_{17}H_{16}N_4O$: C, 69.84; H, 5.52; N, 19.17. Found: C, 69.68; H, 5.47; N, 19.35.

The i.r. spectrum of the orange-yellow form of **3*** was found to be essentially the same as that of the reddish bronze form **3b** (see Table II).

3-Oxo-2,4-bis(phenylhydrazono)cyclohexane-1-carboxylic acid (**4**). —The starting material, dihydrogallic acid, was prepared according to the procedure of Mayer and co-workers[5], except for the isolation of the product, which was conducted as follows. The crude product (80–85 g) obtained by reduction of 100 g of gallic acid was suspended in 150 ml of ice–water, and the suspension was vigorously stirred for 20 min at 3–5°, and filtered. The filtrate, on being kept for 24 h at 3°, deposited crystals. The process was repeated with the original, crude mixture in 150 ml of ice–water. The crystalline product from two extractions was combined, and dissolved in 150–175 ml of warm water; the solution was decolorized with carbon, the suspension filtered, and the filtrate kept for 24–48 h at room temperature. The thick prisms of dihydrogallic acid that separated were washed with ice-cold water, and dried *in vacuo* at room temperature; yield 6–8 g, m.p. 192–193°; lit.[5] m.p. 192–193°. By concentration of the mother liquor and further extraction, the yield of product was raised to 10–12 g.

For the preparation of **4**, 1 g of dihydrogallic acid was oxidized with iodine, and the resulting trione was condensed with phenylhydrazine at 80–90° by the procedure given for the preparation of **2**. The resulting, orange-red product (1.3 g) was recrystallized twice from warm ethyl acetate; m.p. 222–223°; lit.[5] m.p. 221–223°.

Anal. Calc. for $C_{19}H_{18}N_4O_3$: C, 65.15; H, 5.18; N, 15.98. Found: C, 65.20; H, 5.10; N, 15.88.

On heating compound **4** with phenylhydrazine for 90 min at 155–160°, 2,3,4-tris(phenylhydrazono)cyclohexanecarboxylic acid (**20**) was formed; yellow prisms (ethanol), m.p. 232–234°; lit.[5] m.p. 234–235°.

Anal. Calc. for $C_{25}H_{24}N_6O_2$: C, 68.16; H, 5.49; N, 19.08. Found: C, 68.28; H, 5.66; N. 19.32.

(*2-Oxo-1,3-bis(phenylhydrazono)indan* (**5**). — Compound **5** was prepared by the reaction of ninhydrin (1,2,3-indantrione monohydrate) with phenylhydrazine in 75% aqueous acetic acid by the method of Ruhemann[6]. Crude **5** was twice recrystallized from hot ethanol (950 ml per g); orange-red needles, m.p. 207–209°; lit.[6] 207–208°.

---

*Possibly a mixture of two anhydrous forms.

Anal. Calc. for $C_{21}H_{16}N_4O$: C, 74.10; H, 4.74; N, 16.46. Found: 74.04; H, 4.60; N, 16.60.

When heated with phenylhydrazine for 90 min. at 155°, compound **5** failed to give the expected tris(phenylhydrazone).

2-Oxo-1,3-bis(phenylhydrazono)propane (**6**). — 3-Oxoglutaric acid, prepared by the method of Adams and co-workers[49], was oxidized with benzenediazonium chloride by published procedures with slight modification. An ice-cold solution of benzenediazonium chloride (from 18.7 g of aniline, 80 ml of 6N hydrochloric acid, and 14 g of sodium nitrite in 400 ml of water) was added dropwise, with stirring at 0°, to 16 g of 3-oxoglutaric acid in 80 ml of water. Sodium acetate trihydrate (55 g) in 100 ml of water was then added, and the temperature was slowly raised to 50°. Rapid evolution of carbon dioxide occurred, followed by crystallization of **6**. For analysis, and study of its spectra, the compound was recrystallized from acetone; m.p. 174–175°; lit.[7] m.p. 171–173°, lit.[9] m.p. 175–176°.

Anal. Calc. for $C_{15}H_{14}N_4O$: C, 67.65; H, 5.30; N, 21.04. Found: C, 67.85; H 5.45; N, 21.20.

When compound **6** was heated with phenylhydrazine for 1 h at 130°, 1,2,3-tris(phenylhydrazono)propane (**21**) was formed; after recrystallization from ethanol, it had m.p. 166°; lit.[43] m.p. 167°, lit.[44] m.p. 168°.

D-*Mannose diphenylformazan* (**7**). — This compound, m.p. 174–175°, was prepared and purified according to the procedure of Mester[21].

1-Phenylazo-3-phenylhydrazonocyclohexene (**8**). — The compound was prepared by the procedure of Merling[22], and purified by column chromatography [silica gel, 1:1 (v/v) acetic acid–benzene].

myo-*Inosose-2 phenylhydrazone* (**9**). — The compound was prepared by treatment of *myo*-inosose-2 with phenylhydrazine by the procedure of Posternak[50]; recrystallization from methanol yielded colorless crystals, m.p. 174–176°; lit.[51] m.p. 174–176°.

Glyoxal 1,2-bis(phenylhydrazone) (**10**). — The compound was prepared by the standard method from commercial, 50% aqueous glyoxal and phenylhydrazine at room temperature. The crude product was recrystallized several times from methanol; lustrous crystals, m.p. 169–170°; lit.[51] m.p. 169–170°.

D-myo-*Inosose-1 phenylosazone* (**11**). — D-*myo*-Inosose-1 was prepared by catalytic oxidation of *levo*-inositol[52], and converted into D-*myo*-inosose-1 phenylhydrazone. From the latter compound, the phenylosazone was prepared by oxidation with air in the presence of phenylhydrazinium acetate, as described by Carter and co-workers[53] and by Magasanik and Chargaff[54] for the preparation of the corresponding L isomer. The crude product was purified by recrystallization from 2:1:5 (v/v) water–pyridine–2-methoxyethanol, to give yellow needles, m.p. 207–209°; lit.[54] m.p. 217°; 210°.

1,2-Bis(phenylazo)ethylene (**12**). — Compound **12** was prepared by a slight modification of the procedure of von Pechmann[55]. A mixture of 5 g of **10**, 6 g of potassium dichromate, and 5 ml of glacial acetic acid in 50 ml of water was rapidly heated to 95°, and kept at this temperature for 5 min. Heating was discontinued, and the reaction mixture was kept for 24 h at room temperature. The dark product was filtered off, washed with water, and dried. It was triturated with cold acetone (25 ml), and the suspension was filtered, to yield 0.8–1.0 g of crude product. Purification by column chromatography (neutral alumina, chloroform), followed by recrystallization from methanol and acetone, yielded lustrous, dark-red plates, m.p. 149–150°; lit.[55] m.p. 152°, lit.[36] m.p. 150°.

*6-Phenylazo-*trans*-5-hexene-*D-lyxo*-1,2,3,4-tetrol tetraacetate* (**13**) (D-arabino-*3,4,5,6-tetraacetoxy-1-phenylazo-*trans*-1-hexene*). — This compound was prepared by the procedure of Wolfrom and co-workers[28].

Mesoxalaldehyde 1,2-bis(phenylhydrazone) (**14**). — The compound was prepared according to the procedure of Chargaff and Magasanik[43], and was recrystallized from aqueous ethanol, to give light-orange–yellow needles, m.p. 196–198° (dec), lit.[43] m.p. 198°.

Bis(phenylhydrazone) of tetrahydro-5-hydroxy-5,6-diphenylpyran-2,3,4-trione. — The bis(phenylhydrazone) of **15**, having an unknown structure, was prepared, by the method of Dahn and Hauth[16], from **15** and phenylhydrazine. The reddish orange product was purified by recrystallization from absolute ethanol, to give orange-red crystals, m.p. 230–231° (dec); lit.[16] m.p. 230–232°.

Anal. Calc. for $C_{29}H_{24}N_4O_3$: C, 73.09; H, 5.08; N, 11.76. Found: C, 72.90; H, 5.22; N, 11.70.

SUMMARY

The structures of *xylo*-4,5,6-trihydroxy-2-oxo-1,3-bis(phenylhydrazono)cyclohexane (**1**), 2-oxo-1,3-bis(phenylhydrazono)cyclohexane (**2**), 2-oxo-1,3-bis(phenylhydrazono)cyclopentane (**3**), 3-oxo-2,4-bis(phenylhydrazono)cyclohexane-1-carboxylic acid (**4**), 2-oxo-1,3-bis(phenylhydrazono)indan (**5**), and 2-oxo-1,3-bis(phenylhydrazono)propane (**6**) were studied by comparison of their n.m.r., u.v., visible, and i.r. spectra with the spectra of reference compounds of known structures. The results showed that compounds **1**–**6** exist in two forms. The red forms have an enolic (chelated) phenylhydrazono–phenylazo structure. A similarity of the compounds to the diphenylformazans is noted, and substantiated by a comparison of absorption spectra. Compound **2** crystallizes from aqueous ethyl alcohol in the form of a yellow hydrate shown to have a phenylhydrazono structure. On dehydration, the yellow hydrate yields the red enolic form.

The n.m.r. spectra of 1,2,3-tris(phenylhydrazono) derivatives of cyclohexane, cyclopentane, and cyclohexanecarboxylic acid show two low-field signals indicative of two chelated rings. Tris(phenylhydrazono)propane in chloroform-*d* shows no low-field n.m.r. signals immediately after dissolution, but, after equilibration, shows a weak, low-field signal; this suggests that the substance may establish an equilibrium analogous to the equilibria reported by others for phenylosazones.

ACKNOWLEDGMENT

The authors are indebted to Dr. Harriet L. Frush of the National Bureau of Standards for constructive criticism and assistance in the preparation of the manuscript.

REFERENCES

1 A. J. Fatiadi and H. S. Isbell, *J. Res. Natl. Bur. Std.*, 68A (1964) 287.
2 H. S. Isbell and A. J. Fatiadi, *Carbohyd. Res.*, 2 (1966) 204.
3 B. Pecherer, L. M. Jampolskey, and H. M. Wuest, *J. Am. Chem. Soc.*, 70 (1948) 2587.
4 T. Reichstein and R. Oppenauer, *Helv. Chim. Acta*, 16 (1933) 988; 17 (1934) 390.
5 W. Mayer, R. Bachmann, and F. Kraus, *Ber.*, 88 (1955) 316.
6 S. Ruhemann, *J. Chem. Soc.*, 97 (1910) 1438.
7 H. von Pechmann and K. Jenisch, *Ber.*, 24 (1891) 3255.
8 F. Henle and G. Schupp, *Ber.*, 38 (1905) 1372.
9 W. Hahn, R. Bartnik, and J. Epsztajn, *Roczniki Chem.*, 36 (1962) 1645.
10 E. Bamberger, *Ber.*, 24 (1891) 3260.
11 F. Sachs and A. Röhmer, *Ber.*, 35 (1902) 3307; F. Sachs and H. Barschall, *ibid.*, 34 (1901) 3047.
12 C. Harries and H. Türk, *Ber.*, 38 (1905) 1630; C. Harries, *Ann.*, 374 (1910) 351.
13 C. Shoppee, *J. Chem. Soc.*, (1936) 269.
14 W. Mayer and M. B. Neymeyer, *Ann.*, 572 (1951) 212.
15 H. von Euler and H. Hasselquist, *Arkiv Kemi*, 8 (1955) 67.
16 H. Dahn and H. Hauth, *Helv. Chim. Acta*, 40 (1957) 2249, 2261.
17 G. Hesse and F. Urbanek, *Ann.*, 604 (1957) 47.
18 B. Eistert, H. Elias, E. Kosch, and R. Wollheim, *Ber.*, 92 (1959) 130.
19 H. von Euler and B. Eistert, *Chemie und Biochemie der Reduktone und Reduktonate*, Ferdinand Enke Verlag, Stuttgart, 1957, p. 115.
20 H. Zollinger, *Azo and Diazo Chemistry of Aliphatic and Aromatic Compounds*, Interscience Publishers, Inc., New York, 1961, pp. 314–318; R. J. W. Cremlyn, *J. Chem. Soc.*, (1964) 6235.
21 (a) L. Mester, *Advan. Carbohydrate Chem.*, 13 (1958) 105; (b) L. Mester and A. Major, *J. Am. Chem. Soc.*, 78 (1956) 1403.
22 G. Merling, *Ann.*, 278 (1893) 41.
23 G. J. Karabatsos and R. A. Taller, *J. Am. Chem. Soc.*, 85 (1963) 2327, 3624.
24 A. J. Bellamy and R. D. Guthrie, *J. Chem. Soc.*, (1965) 2788, 3528.
25 H. C. Yao, *J. Org. Chem.*, 29 (1964) 2959; H. C. Yao and P. Resnick, *J. Am. Chem. Soc.*, 84 (1962) 3514.
26 R. P. Bell, *The Proton in Chemistry*, Cornell University Press, Ithaca, New York, 1959, Chapter 4.
27 D. E. McGreer, W. Wai, and G. Carmichael, *Can. J. Chem.*, 38 (1960) 2400; T. V. van Auken and K. L. Rinehart, Jr., *J. Am. Chem. Soc.*, 84 (1962) 3736.
28 C. G. Overberger, N. Weinshenker, and J. P. Anselme, *J. Am. Chem. Soc.*, 86 (1964) 5364; 87 (1965) 657.
29 P. Bassignana and C. Cogrossi, *Tetrahedron*, 20 (1964) 2361.
30 R. F. R. Church, A. S. Kende, and M. J. Weiss, *J. Am. Chem. Soc.*, 87 (1965) 2665.
31 R. N. Jones and C. Sandorfy, in *Technique of Organic Chemistry*, Vol. 9, W. West (Ed.), Interscience Publishers, Inc., New York, N. Y. 1956, p. 520.
32 K. Wallenfels and W. Draber, *Tetrahedron*, 20 (1964) 1889.
33 V. C. Barry, J. E. McCormick, and P. W. D. Mitchell, *J. Chem. Soc.*, (1955) 222.
34 G. Henseke and M. Winter, *Ber.*, 92 (1959) 3156.
35 T. W. Milligan and B. C. Minor, *J. Org. Chem.*, 27 (1962) 4663.
36 H. El Khadem and Z. M. El Shafei, *J. Chem. Soc.*, (1958) 3117.
37 H. H. Jaffé and M. Orchin, *Theory and Applications of Ultraviolet Spectroscopy*, Wiley, New York, N. Y., 1962, p. 185.
38 C. N. R. Rao, *Ultraviolet and Visible Spectroscopy: Chemical Applications*, Butterworth, Bethesda, Md., 1961, p. 25.

39 M. L. WOLFROM, A. THOMPSON, AND D. R. LINEBACK, *J. Org. Chem.*, 27 (1962) 2563.
40 O. L. CHAPMAN, R. W. KING, W. J. WELSTEAD, JR., AND T. J. MURPHY, *J. Am. Chem. Soc.*, 86 (1964) 4968.
41 L. MESTER, E. MOCZAR, AND J. PARELLO, *Tetrahedron Letters*, (1964) 3223; *J. Am. Chem. Soc.*, 87 (1965) 596; L. MESTER, *Angew. Chem.*, 4 (1965) 574.
42 M. L. WOLFROM, G. FRAENKEL, D. R. LINEBACK, AND F. KOMITSKY, *J. Org. Chem.*, 29 (1964) 457; H. EL KHADEM, M. L. WOLFROM, AND D. HORTON, *ibid.*, 30 (1965) 838.
43 E. CHARGAFF AND B. MAGASANIK, *J. Am. Chem. Soc.*, 69 (1947) 1459.
44 H. EL KHADEM AND M. M. A. ABDEL RAHMAN, *Carbohyd. Res.*, 3 (1967) 25.
45 J. W. CLARK-LEWIS AND J. A. EDGAR, *J. Chem. Soc.*, (1962) 3887; (1965) 5551; F. WÖHLER AND J. LIEBIG, *Ann.*, 26 (1838) 308.
46 H. HASSELQUIST, *Arkiv Kemi*, 4 (1952) 369.
47 A. J. FATIADI, *J. Res. Natl. Bur. Std.*, 71A (1967) 277.
48 T. A. SPENCER, K. K. SCHMIEGEL, AND K. L. WILLIAMSON, *J. Am. Chem. Soc.*, 85 (1963) 3785.
49 R. ADAMS, *Org. Syn.*, Coll. Vol. 1 (1948) 70.
50 T. POSTERNAK, *Biochem. Prepn.*, 2 (1952) 57.
51 M. FRANKEL, S. PATAI, R. FARKAS-KADMON, AND A. ZILKHE, *Table for Identification of Organic Compounds*, Chemical Rubber Publishing Co., Cleveland, Ohio, 1960, p. 68.
52 G. G. POST AND L. ANDERSON, *J. Am. Chem. Soc.*, 84 (1962) 471.
53 H. E. CARTER, C. BELINSKEY, R. CLARK, E. FLYNN, B. LYTLE, G. MCCASLAND, AND M. ROBBINS, *J. Biol. Chem.*, 174 (1948) 415.
54 B. MAGASANIK AND E. CHARGAFF, *J. Biol. Chem.*, 174 (1948) 173.
55 H. VON PECHMANN, *Ber.*, 21 (1888) 2751; R. STOLLE, *ibid.*, 59 (1926) 1742.