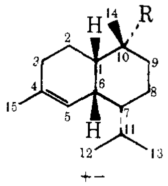


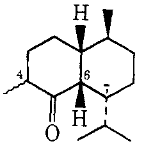
2, R = $\overset{+-}{\mathrm{NC}}$
3, R = NCS
4, R = NHCHO
5, R = H
6, R = NHMe

finic isomers about C-10 (5% of mixture), which we did not rigorously separate. Isocyanide **2** (42%) (mp 40-42°; $[\alpha]_D$ −75° (*c* 5.0, CCl_4); $C_{16}H_{25}N$; ν_{max} 2130 cm^{-1}) was purified by repeated tlc. Isothiocyanate **3** (10%) (oil; $[\alpha]_D$ −63° (*c* 7.4, CCl_4); $C_{16}H_{25}NS$; λ_{max} 214 (1800), 243 (940) nm; ν_{max} 2250, 2100 cm^{-1}) could be separated from its diterpenoid counterpart by tlc (silica gel, hexane) only after allowing the mixture to react with aniline at room temperature, which left **3** unreacted, presumably because of the hindered nature of the isothiocyanate. Formamide **4** (43%) ($C_{16}H_{27}NO$; $[\alpha]_D$ −50° (*c* 5.1, CCl_4); ν_{max} 1680 cm^{-1}) was always contaminated with an equal amount of aliphatic material from which it could be completely freed by LAH reduction of **4** to **6.** Mass and nmr spectra made it at once apparent that these compounds differed only by their functionality at C-10. This was proven by converting **4** to **2** (py and $C_6H_5SO_2Cl$), **2** to **4** (glacial HOAc), and **2** to **3** (S, 120°, 16 hr).

The cadalene (1,6-dimethyl-4-isopropylnaphthalene, **7**) skeleton for the *Halichondria* terpenoids was proven by direct Pd–C conversion of **4** to **7**, or better by Li-$EtNH_2$ treatment of **2**, followed by Pd–C, resulting in **7**, which had expected spectral properties and formed orange picrate, mp 113-115° (lit.[5] 115°).

Principal evidence for the tertiary nature of the functional group rests on the absence of pmr signals in **2** between δ 2.5 and 5.5 and on a cmr triplet at δ 57.6 assigned to C-10, which is coupled to ^{14}N (J = 4 ± 1 Hz)[6] and becomes a broad singlet in the off-resonance spectrum. C-7 was eliminated as a possible locus of the functionality, since a low-field methyl singlet (δ 1.42) in **2** had to be on the carbon bearing the isocyanide while the isopropyl signals (δ 0.91, 0.97, d, J = 6.5 Hz) showed no isocyanide influence.

To distinguish between structure **2** for the isocyanide and an equally plausible alternate with functionality at C-4 and a 9,10-double bond, the isocyanide function was removed with Li-$EtNH_2$, yielding hydrocarbon **5**, $[\alpha]_D$ +11° (*c* 9, CCl_4), the pmr spectrum of which had lost the methyl signal at δ 1.42 but had retained a broad methyl singlet at δ 1.61 for the C-4 methyl. Treatment of **5** with *m*-chloroperbenzoic acid furnished the 4,5-epoxide (C-4 methyl, s, δ 1.25, H-5, s, δ 2.52), which on treatment with BF_3-etherate yielded **8** (mp 50-52°, $[\alpha]_D$ +85° (*c* 2, CCl_4), ν_{max} 1710 cm^{-1}, C-4 methyl, δ 1.18, d (J = 7 Hz), H-6, t, δ 2.95 (J = 4 Hz)). Reaction of **8** with methyllithium, followed by treatment with formic acid and dehydrogenation with Pd–C, led without isolation of intermediates to 5-methylcadalene (1,5,6-trimethyl-4-isopropylnaphthalene), picrate mp 100-102° (lit.[7] 102.5-103.5°).



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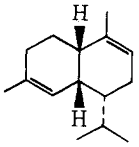

9

Ketone **8** not only served to place the functionality unambiguously at C-10 but also provided key evidence for the assigned stereochemistry. The small equal coupling (J = 4 Hz) of H-6 (δ 2.95, t) with H-1 and H-7 is consistent only with axial-equatorial protons in a *cis*-decalone system,[8] as trans diaxial coupling should be 10 Hz. On the reasonable assumption of an equatorial C-7 isopropyl because of its bulk, the *Halichondria* sesquiterpenes possess amorphane (**5**) stereochemistry at C-1, 6, and 7. Both amorphane enantiomers are known natural products.[9,10] They may be distinguished by CD as the octant rule predicts a positive Cotton effect for **8.**[10] We confirmed the stereochemical assignment by a positive Cotton effect of **8** (Φ_{302} +4173, θ_{302} +9264), and by partial epimerization of C-6 of **8** in base to the trans ketone (oil; $[\alpha]_D$ +55° (*c* 2, CCl_4)) exhibiting a weak positive (Φ_{320} +191) and a somewhat stronger negative (Φ_{290} −407) Cotton effect.[10]

Finally, stereochemistry at C-10 was inferred from LAH reduction of **4** to **6** followed by MeI quaternization and Hofmann degradation with Ag_2O. The resulting hydrocarbon mixture, $[\alpha]_D$ +101° (*c* 0.74, CCl_4), has only weak ir absorption and no nmr signals for an exocyclic double bond and must therefore be a mixture of Δ^1 and Δ^9 olefins. These olefins can only have arisen from an axial amine by diaxial elimination, thereby proving stereochemical assignments as shown in **2–6.** The olefinic mixture was subjected to glc (6 ft × ⅛ in., 3% OV-17 on Gas-Chrom Q, column t 95°). When an authentic sample[11] of (+)-α-amorphene (zizanene, **9**) was coinjected, its glc peak coincided with the major component of the Hofmann mixture.

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References and Notes

(1) F. Cafieri, E. Fattorusso, S. Magno, C. Santacroce, and D. Sica, *Tetrahedron* **29**, 4259 (1973).
(2) L. Minale, R. Riccio, and G. Sodano, *Tetrahedron*, **30**, 1341 (1974).
(3) I. Hagedorn and H. Tönjes, *Pharmazie*, **12**, 567 (1957); *Chem. Abstr.*, **52**, 6362c (1958).
(4) H. Achenbach and H. Grisebach, *Z. Naturforsch. B*, **20**, 137 (1965).
(5) J. R. A. Pollock and R. Stevens, ed., "Dictionary of Organic Compounds," Vol. 1, Oxford University Press, New York, N.Y., 1965, p 532.
(6) W. McFarlane, *J. Chem. Soc. A*, 1660 (1967).
(7) S. Dev, *J. Indian Chem. Soc.*, **25**, 69 (1948).
(8) H. O. House and H. W. Thompson, *J. Org. Chem.*, **28**, 360 (1963).
(9) N. H. Andersen, *Tetrahedron Lett.*, 4651 (1970).
(10) O. Motl, M. Romanuk, and V. Herout, *Collect. Czech. Chem. Commun.*, **31**, 2025 (1966).
(11) Kindly furnished by Dr. N. H. Andersen.
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Oscillations in Chemical Systems. VII.[1] Effects of Light and of Oxygen on the Bray–Liebhafsky Reaction

Sir:

The first established oscillating chemical reaction in a homogeneous system was the iodate catalyzed decomposition of hydrogen peroxide reported by Bray[2] over 50 years ago. It has recently been studied extensively by Liebhafsky

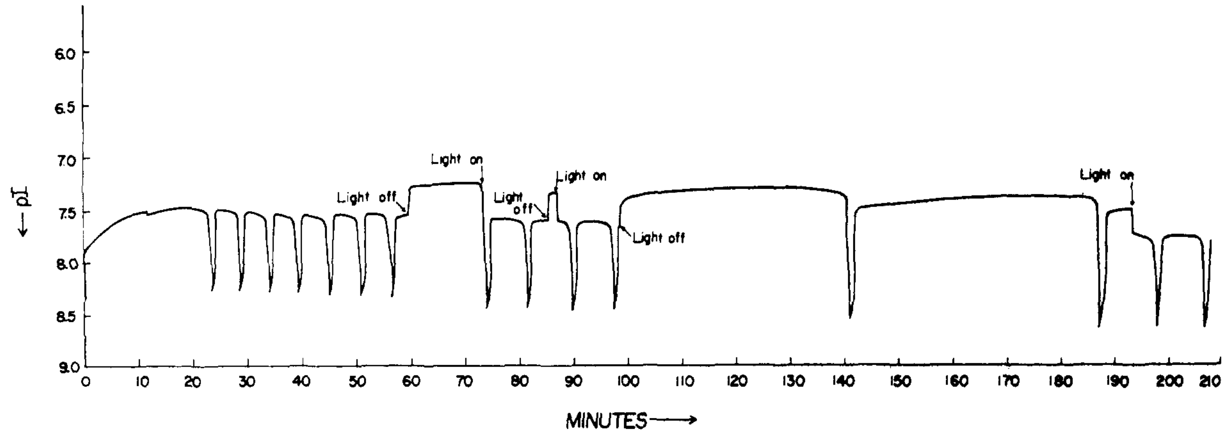

Figure 1. Potentiometric traces of pI *vs.* time at 50° for reactants with low hydrogen peroxide and low acidity. Initial concentrations were $[H_2O_2]_0 = 0.098$ *M*, $[KIO_3]_0 = 0.105$ *M*, and $[HClO_4]_0 = 0.0472$ *M*. Light was initially on and corresponded to a 150-W lamp at about 6 in. In the absence of light, the induction period would be very long at these concentrations.

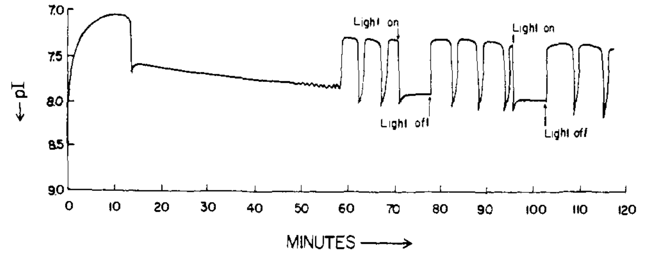

Figure 2. Potentiometric traces of pI *vs.* time at 50° for reactants with high hydrogen peroxide and high acidity. Initial concentrations were $[H_2O_2]_0 = 0.490$ *M*, $[KIO_3]_0 = 0.105$ *M*, and $[HClO_4]_0 = 0.059$ *M*. Light was a 150-W lamp about 6 in. away; it was off initially.

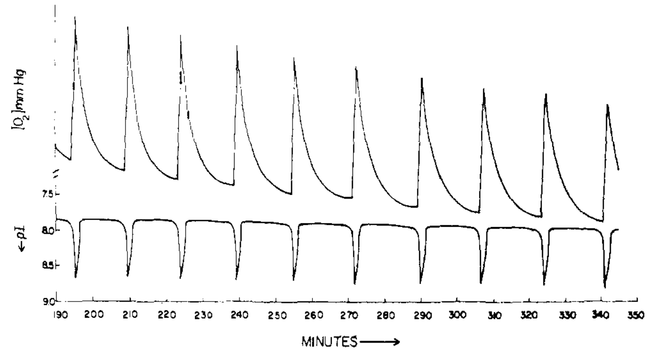

Figure 3. Potentiometric traces of pI and of $[O_2]$ (without absolute calibration) *vs.* time at 50°. Initial concentrations were $[H_2O_2]_0 = 0.098$ *M*, $[KIO_3]_0 = 0.105$ *M*, $[HClO_4]_0 = 0.059$ *M*. Amplitude of O_2 oscillations corresponds to about 300 mm of Hg. Solution was not specifically illuminated.

and coworkers,[3] and tentative mechanisms involving entirely nonradical processes have been proposed.[4,5] Another suggested mechanism[6] has included radical processes, but all proposals have regarded elementary oxygen to be the inert product of hydrogen peroxide decomposition.

The very existence of the oscillatory phenomenon was questioned by Shaw and Pritchard[7] who claimed that oscillations were suppressed by excluding light, while Degn and Higgins[8] maintained they observed oscillations with no light except that necessary for occasional spectrophotometric monitoring. Bray[2] noted in his first paper that light affected the reaction but also commented that oscillations could take place in total darkness.

We now report that the situation is still more complicated and that light can either promote or inhibit oscillations depending upon the concentrations of reactants. We also report that the solution becomes grossly supersaturated with oxygen during part of each cycle and that dissolved oxygen can affect the kinetic behavior of the system.

Figure 1 shows a trace of the potential from an iodide ion specific electrode in a solution of low acidity and low hydrogen peroxide concentration. This reaction and those for the other figures shown here took place in a 150-ml round-bottomed flask that was stirred magnetically at a constant rate throughout the experiment. Oscillations in Figure 1 occur frequently when the solution is illuminated with an ordinary tungsten lamp, but the iodide concentration increases and oscillations occur much less frequently when the system is darkened. The effect is reversible.

Figure 2 shows a trace for a similar solution at higher acidity and high concentration of hydrogen peroxide. Oscillations occur in the dark, but exposure to light can reversibly change the system to a nonoscillating state of low iodide concentration.

The reacting solution for Figures 1 and 2 was contained in a Pyrex flask that would have transmitted little of the small amount of ultraviolet light from the lamp, and separate experiments demonstrated the small temperature change due to the light was not responsible for the observed effect. It is hard to suggest any species except molecular iodine that absorbed significantly under these conditions. We have also observed oscillations potentiometrically in solutions receiving no visible or ultraviolet light whatsoever, thereby substantiating the original claim of Bray.[2]

Figure 3 shows the simultaneous recordings from an iodide ion specific electrode and from a Beckman Oxygen Macro Electrode which measured dissolved oxygen diffusing through a polypropylene membrane. The latter electrode was not calibrated absolutely, but the amplitude in Figure 3 corresponds to a change of about 300 mm of Hg in the equilibrium pressure of dissolved oxygen.

Figure 3 demonstrates only that the solution becomes supersaturated with dissolved oxygen when hydrogen peroxide is decomposing most rapidly. We have also observed that in certain concentration ranges we can affect kinetic behavior by changing the pressure of an oxygen atmosphere in static contact with the solution or by changing a flushing gas between oxygen and nitrogen. These effects are not easy to characterize quantitatively. At low acidity, increasing oxygen pressure can behave like light and promote oscillations in a system that would otherwise remain with high iodide concentration. However, at higher acidity, increasing oxygen pressure facilitates oscillation by driving the system from low to high iodide concentration!

These light effects indicate that oscillations involve transition between a condition of nonradical reactions characterized by high iodide concentration and a condition of radical reactions characterized by low iodide concentration. Such a mechanism resembles that of the oscillatory Belousov-Zhabotinskii reaction.[9,10] Illumination can promote oscillations in a system that would otherwise remain mostly in the nonradical condition, and it can eliminate oscillations by forcing a susceptible system entirely into the radical condition.

Although elementary oxygen is a thermodynamically stable product of hydrogen peroxide decomposition in this system, our observations indicate it is not inert to interactions with some of the reaction intermediates. Depending upon the conditions, oxygen can apparently function either to promote radical formation or to reduce the reactivity of radicals already present.

We are now developing and testing a detailed chemical mechanism for the processes in this remarkable system.

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References and Notes

(1) Paper No. VI is R. M. Noyes and R. J. Field, *Ann. Rev. Phys. Chem.*, **25**, 95 (1974).

(2) W. C. Bray, *J. Amer. Chem. Soc.*, **43**, 1262 (1921).

(3) I. Matsuzaki, R. Simic, and H. A. Liebhafsky, *Bull. Chem. Soc. Jap.*, **45**, 3367 (1972).

(4) H. A. Liebhafsky and L. S. Wu, *J. Amer. Chem. Soc.*, in press.

(5) I. Matsuzaki, T. Nakajima, and H. A. Liebhafsky, *Faraday Sym. Chem. Soc.*, No. 9 (1975), in press.

(6) R. M. Noyes and R. J. Field, 167th National Meeting of the American Chemical Society, Los Angeles, Calif., April 2, 1974.

(7) D. H. Shaw and H. O. Pritchard, *J. Phys. Chem.*, **72**, 1403, 2693 (1968).

(8) H. Degn and J. Higgins, *J. Phys. Chem.*, **72**, 2692 (1968).

(9) R. J. Field, E. Körös, and R. M. Noyes, *J. Amer. Chem. Soc.*, **94**, 8649 (1972).

(10) D. Edelson, R. J. Field, and R. M. Noyes, *Int. J. Chem. Kinet.*, in press.

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Asymmetric Synthesis in a Cholesteric Liquid Crystal Solvent

Sir:

The simple introduction of a center of chirality into achiral compounds is extremely relevant to the prebiological origin of optical activity.[1-3] Asymmetric syntheses of this type have been the subject of considerable research[4] and recently were observed to occur in a lattice-controlled reaction within a single crystal.[5,6] In this communication we describe a "lattice-controlled" reaction utilizing the *anisotropic* ordering of solutes in liquid crystalline mesophases to direct the course of a chemical reaction in a manner not normally achieved in *isotropic* media. Several authors have reported their attempts to utilize the anisotropic ordering of reactants to produce unusual reaction products or rate variations.[7-15] However, to date there is a lack of sufficient evidence to demonstrate clearly the effect of anisotropic ordering on chemical reaction sequences.[15]

In the cholesteric mesophase there exists a macroscopic helical structure formed by the chiral organization of "nematic-like" layers with uniaxial molecular arrangement within the layers. This mesophase can be considered to be a super chiral environment where rod-shaped solute molecules are readily organized within the nematic layers. It is expected that this special type of ordering within the cholesteric mesophase will effect chemical reactivity unlike that of asymmetric solvation in an isotropic media.

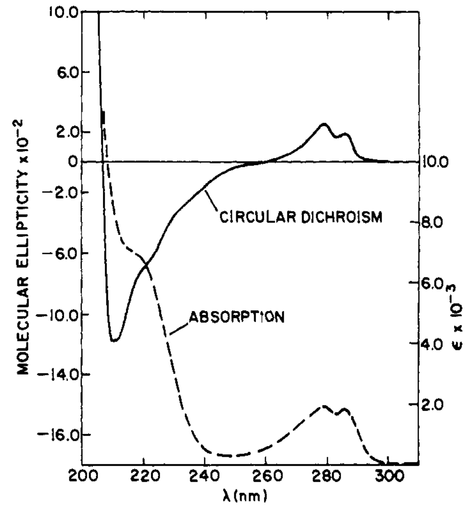
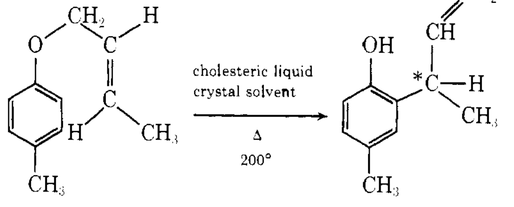


Figure 1. Circular dichroism and absorption spectra of 2-(α-methylallyl)-4-methylphenol (**2**) in methylcyclohexane.

We report a novel asymmetric synthesis using a cholesteric liquid crystalline solvent as an asymmetric catalyst. γ-Methylallyl-*p*-tolyl ether (**1**) undergoes an ortho Claisen rearrangement in a stereospecific manner to produce chiral 2-(α-methylallyl)-4-methylphenol (**2**) in a cholesteric liquid crystalline solvent as shown below.



1 2

The rearrangement of **1** was carried out in the cholesteric mesophase formed by cholesteryl-*p*-nitrobenzoate (**3**) at 200°, using 5 wt % of **1** in **3**. The reaction was run for 6 hr and the product (~60% yield) of the rearrangement isolated from the acidic phenolic fraction by means of glc on a $\frac{1}{2}$ in. × 6 ft Carbowax 20M column.

The optical activity of compound **2** was demonstrated by the presence of circular dichroism (CD) within its electronic transitions between 205 and 290 nm (see Figure 1). Compound **2** shows positive CD throughout the 280-nm $^1L_b \leftarrow {}^1A$ ($\Delta\epsilon/\epsilon = 3.7 \times 10^{-5}$) transition and negative CD within the $^1L_a \leftarrow {}^1A$ transition. CD measurements were made on a Cary 61 spectropolarimeter at 22° in methylcyclohexane solvent, and compounds **1** and **2** were characterized by nmr, uv, as well as by their physical constants.

Rearrangement of **1** (200°) in an anisotropic cholesteric composition containing 30% of **1** and in an isotropic solution containing 50% of the Claisen ether in **3** yielded **2** which exhibited no observable CD between 205 and 290 nm. The existence of the mesophase in the 5 and 30% mixtures was determined by optical microscopy and was readily apparent by visual inspection. From the above experimental observations it is concluded that the diastereomeric interaction that exists in the isotropic chiral cholesteryl-*p*-nitrobenzoate is not sufficient to produce an observably chiral **2**. The same is true for high concentration of **1**, *i.e.*, 30 wt % **1** in **3**, where the ability of the liquid crystal matrix to order solute molecules falls off with increasing solute concentration.[16]