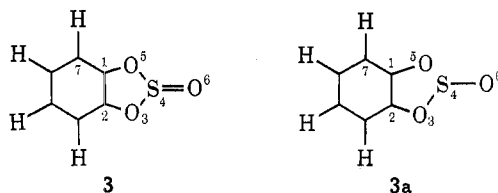


energies of the +1 charged species of **4** and **2** are used, the sum of the energies of SO and **4** (charged) is 4 kcal lower than the sum of the energies of SO₂ and **2** (charged). The preferred loss upon electron impact is SO. Geometries of **2** and **4** are given in Table III.

In Table IV are listed the overlap populations ob-

TABLE IV
OVERLAP POPULATIONS FROM CALCULATIONS MADE ON **3**



Structure	Charge	Overlap population for bond ^a			
		1-5, 2-3	3-4, 4-5	2-3	3-4
3	0	0.822	0.620		
3	+1	0.799	0.638		
3a	0			0.813	0.646
3a	+1			0.804	0.642

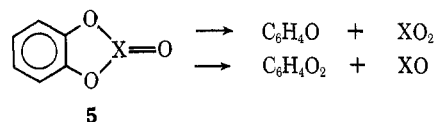
^a The program modified to exclude d orbitals was used.

tained from **3** and **3a** using the geometries given in Table III. The program which was modified to exclude contributions from d orbitals was used. The weakest bond in **3** is the S-O bond of the ring, rather than the C-O bond. For intermediate **3a**, which would form from cleavage of this S-O bond, the calculations show that cleavage of the bond with the lowest overlap population would lead to expulsion of SO from both the charged and the uncharged species. This is the be-

havior observed experimentally, as described in eq 2. If contributions from d orbitals are included, the overlap populations of the bonds between S and O increase, since the net overlap of all the orbitals on S and O is greater if d orbitals are included.

Thus, relating overlap populations to relative bond strengths for bonds involving two different sets of atoms, *i.e.*, C-O and S-O in **3**, might not be so meaningful as in the case of **1** where only C-O bonds are compared. However, the comparison of the sums of the energies of the species produced by the competing losses of SO and SO₂ gives the same qualitative results.

In summary, there are two competing pathways experimentally observed for fragmentation of system **5**



upon pyrolysis and electron impact. When X = C, the loss of XO₂ is preferred and when X = S, the loss of XO is preferred. The molecular orbital approach described here rationalizes this behavior both in terms of relative bond strengths and energies of the species produced by the competing paths.

Registry No.—**1**, 2171-74-6; **3**, 6255-58-9.

Acknowledgment.—We wish to thank Drs. P. A. Scheer and A. Tannin for helpful discussions. We also wish to acknowledge the service of the Wayne State University Computing and Data Processing Center.

A Free Electron Molecular Orbital Model of Aromaticity

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Breslow's criterion for aromaticity applied to the simplest FEMO model yields results for single ring molecules in conformity with the literature. In particular, it is shown that incompletely filled shells may produce antiaromaticity in small ring molecules, but underlying closed shells dominate in larger rings so that all annulene and polymethine series eventually become aromatic.

Although the free electron molecular orbital (FEMO) model has shown a degree of success in the interpretation of electronic spectra of conjugated systems,¹ the extension of the approach to chemical properties has given rather limited agreement. In particular, an attempt to use FEMO (in its more refined network model) to calculate resonance energies gave "surprisingly poor" results.² However, it is the purpose of this paper to show that FEMO can be used to analyze aromaticity, provided Breslow's recent reformulation of the criterion for aromaticity³ is employed; *i.e.*, the π energy of a cyclic compound is compared to that of the corresponding iso- π -electronic linear compound,

a decrease in π energy upon cyclization indicating aromaticity, an increase indicating antiaromaticity.

The Model.—We shall use in this paper FEMO in its simplest form. The behavior of the π electronic wave functions perpendicular to the carbon skeleton is assumed to be separable from the behavior along the bonds, and to be constant for all π systems considered. Consequently, this component is ignored in all subsequent considerations. For the component along the carbon skeleton the actual periodic potential energy function is replaced by a constant, taken to be zero for convenience; *i.e.*, straight-chain systems are treated as electrons in a linear box while cyclic systems are treated as electrons on circular rings.

The one remaining assumption for each type of molecule is the effective length of the π system. To avoid prejudicing our results, we adopt two assumptions found in the literature. Throughout this paper we will assume all C-C bonds, whether in a straight

(1) A review of the method is given by N. S. Bayliss, *Quart. Rev., Chem. Soc.*, **6**, 319 (1952). A collection of papers has been reprinted: J. R. Platt, *et al.*, "Free-Electron Theory of Conjugated Molecules," Wiley, New York, N. Y., 1964.

(2) C. W. Scherr, *J. Chem. Phys.*, **21**, 1413 (1953).

(3) R. Breslow, *Chem. Eng. News*, **43** (26), 90 (1965); *Chem. Brit.*, **4**, 100 (1968); *Angew. Chem., Int. Ed. Engl.*, **7**, 565 (1968).

chain or a cyclic compound, to have an average length, d . For the linear system, the variable component of the orbital energy is

$$\epsilon_s = \frac{p^2 h^2}{8ma^2} \quad (1)$$

$$p = 1, 2, 3, \dots$$

where h is Planck's constant, m is the mass of the electron, and a is the length of the box. Kuhn⁴ has obtained quantitative fits to the electronic spectra of cyanine dyes by assuming that the path of π electrons extends one bond length beyond each end of the carbon skeleton, *i.e.*

$$a = (n + 1)d \quad (2)$$

where n is the number of carbon atoms. The corresponding energy contribution for a cyclic system is

$$\epsilon_c = \frac{q^2 h^2}{2mL^2} \quad (3)$$

$$q = 0, \pm 1, \pm 2, \dots$$

where L is the circumference of the ring. We adopt here Platt's perimeter model⁵ in which the circumference is taken to be equal to the total bond length of the π system.

$$L = nd \quad (4)$$

Incidentally, Pilar⁶ has given a theoretical justification for these assumptions regarding total lengths.

In this paper we will be interested in the signs and relative magnitudes of energy changes. It is thus convenient to express our energies in units of $h^2/8md^2$. In these units (indicated by primes), eq 1-4 become

$$\epsilon_s' = \frac{p^2}{(n + 1)^2} \quad (5)$$

$$\epsilon_c' = \frac{4q^2}{n^2} \quad (6)$$

These two expressions emphasize the two factors that lead to different molecular orbital energy level diagrams for straight chain and for cyclic conjugated systems: (1) the differing structures of the allowed set of quantum numbers (*cf.* eq 1 and 3 for p and q) and (2) the slightly different dependencies of the orbital energies on chain length (through n).

The total π electron energy is a sum over the occupied orbitals.

$$E' = \sum_{\text{occ}} \epsilon' \quad (7)$$

In the present model these sums are easily evaluated through a standard formula since they involve a finite sum over squares of integers. Following Breslow³ we define a " π stabilization energy" as the difference in total π energy of the cyclic and the corresponding straight chain conjugated molecules.

$$\Delta E' \equiv E_c' - E_s' \quad (8)$$

If this π stabilization energy is less than zero the cyclic compound has the lower π energy and is aromatic; if the stabilization energy is greater than zero the straight chain molecule has the lower energy and the

TABLE I

π STABILIZATION ENERGIES		
n	Species	$\Delta E'$
$4r$	Molecule	$\frac{-2r^2 + 4r + 1}{6r(4r + 1)}$
$4r + 1$	Cation	$\frac{r(-16r^2 + 20r + 15)}{6(4r + 1)^2(2r + 1)}$
	Radical	$-\frac{32r^3 + 8r^2 + 3}{12(4r + 1)^2(2r + 1)}$
	Anion	$-\frac{16r^3 + 28r^2 + 15r + 3}{6(4r + 1)^2(2r + 1)}$
$4r + 2$	Molecule	$-\frac{2(r + 1)^2}{3(2r + 1)(4r + 3)}$
$4r + 3$	Cation	$-\frac{(2r + 1)(16r^2 + 44r + 27)}{24(4r + 3)^2(r + 1)}$
	Radical	$-\frac{32r^3 - 56r^2 - 8r + 15}{24(4r + 3)^2(r + 1)}$
	Anion	$-\frac{-32r^3 - 8r^2 + 82r + 57}{24(4r + 3)^2(r + 1)}$

cyclic compound is antiaromatic; and if the difference is zero then the ring compound is termed nonaromatic. Also, paralleling the use of resonance energies, we shall take the magnitude of the π stabilization energy as a measure of the "degree" of aromaticity or antiaromaticity. General expressions for the π stabilization energy of several series of single ring species are given in Table I. An obvious advantage of the simple model developed in this paper is the ability to write and analyze such general formulae.

Results

The specific results can be presented in terms of four series: the $[4r + 2]$ annulenes, the $[4r]$ annulenes, the cyclic $[4r + 1]$ polymethines, and the cyclic $[4r + 3]$ polymethines.

$n = 4r + 2$.—The π stabilization energy of these molecules is always negative, so that the compounds are predicted to be always aromatic, in complete conformity to the Hückel rule. The magnitude of $\Delta E'$ is largest for benzene (0.12698) and slowly decreases (0.10909 for cyclodecapentaene, 0.10159 for cyclotetradecaheptaene) to a value of $1/12 = 0.08333$ for large r .

$n = 4r$.—Here the trend is more involved, the first members of the series being predicted as antiaromatic, but the later members as aromatic. Cyclobutadiene ($\Delta E' = +0.10000$) would be expected to be significantly antiaromatic, cyclooctatetraene ($\Delta E' = +0.00926$) weakly antiaromatic, while cyclododecahexaene ($\Delta E' = -0.02137$) is foreseen to be slightly aromatic. The π stabilization energy decreases steadily for further increases in ring size, approaching the same limit ($-1/12$) as the $4r + 2$ series for large r .

Qualitatively, this trend agrees with some results of Breslow and Mohacsi.⁷ These authors calculated from the Hückel molecular orbital method the change in delocalization energy upon cyclization for a number of hydrocarbon molecules and ions. There is quantitative disagreement, however, in that Breslow and Mohacsi indicate that cyclooctatetraene should be slightly aromatic. A similar result could be obtained with the FEMO model by use of slightly different assumptions regarding the total length of the π systems. On

(7) R. Breslow and E. Mohacsi, *J. Amer. Chem. Soc.*, **85**, 431 (1963).

(4) H. Kuhn, *J. Chem. Phys.*, **16**, 840 (1948); *Helv. Chim. Acta*, **31**, 1411 (1948).

(5) J. R. Platt, *J. Chem. Phys.*, **17**, 484 (1949).

(6) F. L. Pilar, "Elementary Quantum Chemistry," McGraw-Hill, New York, N. Y., 1968, p 654.

the other hand, our prediction of antiaromaticity for cyclooctatetraene is consistent with the same conclusion reached by Figeys⁸ through use of his LCAO-BETA method.

$n = 4r + 1$.—The cation series here exhibits a trend similar to the $n = 4r$ molecules. Cyclopentadienyl cation ($\Delta E' = +0.04222$) is expected to be antiaromatic, cyclononatetraenyl cation ($\Delta E' = -0.00741$) weakly aromatic, with the remaining cations increasing in degree of aromaticity. The π stabilization energy is negative for all members of the radical and the anion series, the anions being especially aromatic, *e.g.*, $\Delta E' = -0.13778$ for cyclopentadienyl anion and $\Delta E' = -0.11235$ for cyclononatetraenyl anion. The limit of the π stabilization energy for large r for all three series is again $-1/12$.

$n = 4r + 3$.—In this case the cations are always aromatic with relatively large π stabilization energies ($\Delta E' = -0.12500$ for cyclopropenyl cation, $\Delta E' = -0.11097$ for cycloheptatrienyl cation, $\Delta E' = -0.10273$ for cycloundecahexaenyl cation). Cyclopropenyl radical is antiaromatic ($\Delta E' = +0.06944$) while the remaining radicals are aromatic ($\Delta E' = -0.03444$ for cycloheptatrienyl radical, $\Delta E' = -0.05521$ for cycloundecahexaenyl radical). The first two anions are antiaromatic ($\Delta E' = +0.26389$, a quite high value, for cyclopropenyl anion, and $\Delta E' = +0.04209$ for cycloheptatrienyl anion), the series then becoming aromatic, although the π stabilization energy for cycloundecahexaenyl anion (-0.00769) is quite small. Again, all three series converge to $\Delta E' = -1/12$ for large r .

The conclusions for the cyclopropenyl ions (cation aromatic, anion highly antiaromatic) are, of course, in agreement with the extensive discussions of Breslow.³ The order of the three cycloheptatrienyl species follows that plotted by Breslow and Mohacsy,⁷ although these authors show the anion to be very slightly aromatic while we have predicted it to be slightly antiaromatic.

Dependence of Aromatic Character on Ring Size.—It is obvious from the above cases that ring size is a determinant of aromaticity. We now systematically investigate this dependence. For a fixed number of electrons the π stabilization energy has the form

$$\Delta E' = \frac{A}{n^2} - \frac{B}{(n+1)^2} \quad (9)$$

where A and B are positive quantities depending only on the number of electrons. Let us treat for the moment n as a continuous variable and differentiate the π stabilization energy expression to give, after collecting terms,

$$\frac{d\Delta E'}{dn} = -\frac{2}{n} \Delta E' - \frac{2}{n} \frac{B}{(n+1)^2} \quad (10)$$

The last term in eq 10 is of the same order as the preceding one times a factor $1/(n+1)$. Hence for large n we get the asymptotic expression

$$\frac{d\Delta E'}{dn} \approx -\frac{2}{n} \Delta E' \quad (11)$$

Thus, in this limit, if n is increased the change in $\Delta E'$ is opposite in sign to $\Delta E'$ itself; *i.e.*, an aromatic compound will get less aromatic and an antiaromatic compound will move towards aromaticity.

(8) H. P. Figeys, *Tetrahedron*, **26**, 5225 (1970).

TABLE II
THE SIZE RULE

Species	n	$\Delta E'$	Character
Four-Electron Systems ($A = 8, B = 10$)			
$C_3H_3^-$	3	+0.26389	Antiaromatic
C_4H_4	4	+0.10000	Antiaromatic
$C_5H_5^+$	5	+0.04222	Antiaromatic
$C_6H_6^{2+}$	6	+0.01814	Antiaromatic
Six-Electron Systems ($A = 16, B = 28$)			
$C_4H_4^{2-}$	4	-0.12000	Aromatic
$C_5H_5^-$	5	-0.13778	Aromatic
C_6H_6	6	-0.12698	Aromatic
$C_7H_7^+$	7	-0.11097	Aromatic
$C_8H_8^{2+}$	8	-0.09568	Aromatic
Eight-Electron Systems ($A = 48, B = 60$)			
$C_6H_6^{2-}$	6	+0.10884	Antiaromatic
$C_7H_7^-$	7	+0.04209	Antiaromatic
C_8H_8	8	+0.00926	Antiaromatic
$C_9H_9^+$	9	-0.00741	Aromatic
$C_{10}H_{10}^{2+}$	10	-0.01587	Aromatic

To explore behavior away from the asymptotic limit, we note that the last term in eq 10 is always negative. Thus if $\Delta E' > 0$ (the cyclic compound is antiaromatic) the behavior is the same as the asymptotic limit. If $\Delta E' < 0$ (the cyclic compound is aromatic) deviation from the asymptotic behavior may occur if the π energy of the straight chain molecule is sufficiently large relative to the π stabilization energy, and n is relatively small.

The above considerations are summarized as the tentative rule: the aromatic or antiaromatic character of a cyclic compound with specified number of electrons will decrease when the ring size is increased (the number of electrons remaining the same), possible exceptions occurring for aromatic compounds of small size or weak aromaticity.

Calculations of the π stabilization energy for three iso- π -electronic series are presented in Table II. The four-electron antiaromatic series with a 20-fold change in $\Delta E'$ obeys the rule perfectly. There is one exception in the six-electron aromatic series, the smallest ring cyclobutadienyl dianion having a π stabilization energy that is too low, although still strongly aromatic. In the more complicated eight-electron sequence, the change in $\Delta E'$ between the cyclononatetraenyl cation and the cyclodecapentaenyl dication is in the wrong direction, presumably because of the very weak aromatic character of the cyclononatetraenyl cation.

Discussion

Of the several questions that could be raised concerning the theory of the present paper, the first might be why such a simple model should be successful. The computation of the orbital energies depended on assuming the effective potential energy function for the π electrons to be constant so that the FEMO energies are entirely kinetic. As Lichten⁹ has shown, FEMO in this form does not satisfy the virial theorem relating average kinetic and potential energies. In addition, the detailed analysis of the bond in the hydrogen molecule-ion by Feinberg, *et al.*,¹⁰ revealed that

(9) W. Lichten, *J. Chem. Phys.*, **22**, 1278 (1954).

(10) M. J. Feinberg, K. Ruedenberg, and E. L. Mehler, *Advan. Quantum Chem.*, **5**, 27 (1970).

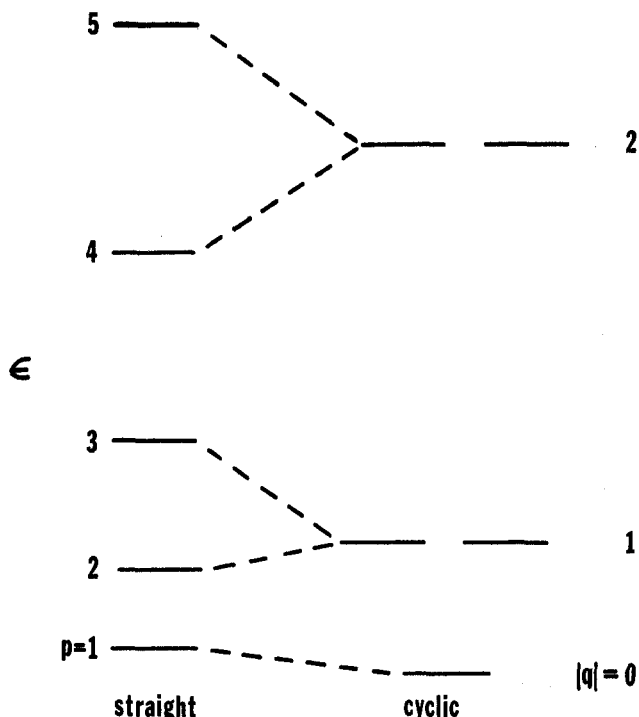


Figure 1.—Correlation of orbital energies (relative values are approximately those for $n = 8$.)

the bond energy was the resultant of a number of competing kinetic and potential energy contributions, chief among them being the lowering of the component of kinetic energy along the bond direction because of the interference density (delocalization of the electron from its atomic density) permitting contraction of the orbitals toward the nuclei with a consequent substantial lowering of potential energy and a concomitant increase in total kinetic energy. However, if we recognize that the energy changes in the FEMO model can be correlated with the kinetic energy contribution of delocalization, and if we are allowed to extrapolate the work of Feinberg, *et al.*, to the present case and thus assume that a contraction of orbitals and lowering of potential energy would occur with the total energy change paralleling the change in kinetic energy of delocalization, then our results should be qualitatively correct. This point is emphasized by the fact that we have dealt in this paper with *changes* in π energy, not with total energies.

Within this context it is interesting to explore why stabilization or destabilization may occur upon cyclization. It is *not* because of further delocalization; in fact in our model the total length of the π system in the cyclic molecule (nd) is less than that in the linear molecule [$(n + 1)d$]. Rather, the effect lies in the pattern of orbital energies. Using the pattern of nodes in the real form of the wave functions, the following correlation can be made between the orbitals of the linear system and those of the cyclic system upon ring closure.

$$p = \begin{cases} 2|q| \\ 2|q| + 1 \end{cases} \longrightarrow |q| \quad (12)$$

These correlations are illustrated schematically in Figure 1.

The lowest orbital of the ring compound ($q = 0$) correlates with the lowest orbital of the linear compound ($p = 1$) and the change in orbital energy

$$\Delta\epsilon' \equiv \epsilon_0' - \epsilon_1' \quad (13)$$

is always negative, giving a stabilizing contribution to $\Delta E'$. For $|q| > 0$, the ring orbitals are doubly degenerate and correlate with a pair of nondegenerate linear system orbitals. The contribution to the π stabilization energy of an electron in the lower of these two is

$$\Delta\epsilon' = \frac{4q^2(2n + 1)}{n^2(n + 1)^2} \quad (14)$$

a quantity that is always greater than zero representing a destabilizing contribution. An electron in the upper orbital of the straight chain pair contributes the amount

$$\Delta\epsilon' = \frac{4q^2(2n + 1) - (4|q| + 1)n^2}{n^2(n + 1)^2} \quad (15)$$

which is less than zero (stabilizing) for $|q| < n/2$. The total contribution for two electrons in each of these orbitals of the linear molecule can be shown for sufficiently large n to be negative for $|q| < n/4$. Thus completely filled levels of the ring compound give stabilizing contributions to $\Delta E'$, so that closed shell cyclic molecules should be aromatic.

Antiaromaticity may arise if the uppermost pair of ring orbitals is incompletely filled, the determining factor being ring size. Thus for the $[4r + 3]$ polymethine series the model predicts that both the cyclopropenyl radical with one electron in the unfilled level and the anion with two electrons in this level are antiaromatic, while only the anion of the cycloheptatrienyl series is expected to be antiaromatic, and all cycloundecahexaenyl species are forecast as aromatic. Obviously a single electron may determine the character of a small ring compound, but in the larger rings the closed shells exert a dominant influence. For very large rings, the contribution of any given orbital to the π stabilization energy is negligibly small, but since the number of orbitals in the linear molecule goes approximately as $n/2$, the total effect is nonzero. In fact, if we neglect the contributions of the $p = 1$ orbital and any electrons in an unfilled shell, *i.e.*, if we consider only filled pairs of orbitals, the limit for large n of $\Delta E'$ is $-1/12$, precisely the value found in all series discussed in this paper.

The theory and results presented above differ in several aspects from a treatment of the same problem conducted by Dewar using his perturbational molecular orbital (PMO) method.¹¹ In the present context the PMO theory determines energy changes when the ring is formed by treating the additional π bond formed as a first-order perturbation on the π molecular orbitals of the linear molecule. In practice he uses only the nonbonding molecular orbital of the appropriate odd alternant hydrocarbon. As a consequence he obtains singular predictions for each series, *e.g.*, the $[4r]$ annulenes are always antiaromatic tending toward nonaromaticity for large size, the $[4r + 1]$ polymethine cations and the $[4r + 3]$ polymethine anions are always antiaromatic, while the polymethine radicals are predicted to be nonaromatic. It is clear that the deviation of Dewar's PMO predictions from the results of the present paper is caused by his use of only the

(11) M. J. S. Dewar in "Aromaticity," The Chemical Society Special Publication No. 21, London, 1967, pp 198-210; M. J. S. Dewar, "The Molecular Orbital Theory of Organic Chemistry," McGraw-Hill, New York, N. Y., 1969, Chapter 6, and references cited therein.

uppermost occupied orbital in calculating the energy changes. As our discussion of the various polymethine species has indicated, this uppermost orbital may dominate in small rings, but becomes a minor factor for larger sizes. By putting sole emphasis on the small ring determinant, Dewar misses the crossover from antiaromatic to aromatic character and the limiting degree of aromaticity for all large rings.

On the other hand, our conclusions parallel resonance energies, calculated by the Pople method (including bond alternation),¹² for the first ten annulenes that show negative resonance energies (antiaromaticity) for cyclobutadiene and cyclooctatetraene, but positive values for all the others (including, incidentally, the

(12) M. J. S. Dewar, "The Molecular Orbital Theory of Organic Chemistry," McGraw-Hill, New York, N. Y., 1969, p 179.

smallest value for cyclododecahexaene) which seem to quickly converge to a constant value (2.8 kcal/mol) as the ring dimension increases.

In addition to the qualifications on the FEMO model mentioned at the beginning of this section, it should be pointed out that our simple model also neglects any effects arising from the noncircular shape of the cyclic molecules, and perhaps more importantly bond alternation, although it is hoped in the latter case that the effects on the linear and the corresponding ring compounds are approximately the same and cancel in the calculation of the π stabilization energy.

Acknowledgment.—The idea of this paper was stimulated by several conversations with Professor Stephen J. Weininger of Worcester Polytechnic Institute.

A New Synthesis of Substituted 2(1H)-Pyridones. Synthesis of a Potential Camptothecin Intermediate

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The acylation of 3-carbalkoxycitraconic esters **1** with amide acetals provides a good method for the synthesis of dimethylaminoalkylidene malonates **3**; these compounds upon treatment with a primary amine cyclize to 2,3-dicarbalkoxy 6-substituted 2(1H)-pyridones **4**. Application of this reaction to the acetal or imminium salt from *o*-cyanoarylamides **9a,b** similarly affords the corresponding enamines **3d,e**; hydrogenation of **3** leads directly to the fused pyridones **11** and **13**, a potential camptothecin intermediate.

The acylation of active methylene compounds with acetals of dimethylformamide to give the corresponding dimethylaminomethylene compounds has been reported.^{2,3} The analogous condensation between an acetal derived from an alkyl- or arylamide and an alkylidene malonic ester would afford a vinylogous amide which, upon treatment with a primary amine, might undergo enamine exchange and cyclization to a 6-substituted 2(1H)-pyridone. Because of the nucleophilic reactivity reported⁴ for amide acetals possessing an α hydrogen [arising *via* elimination of alcohol to give the enamine C=C(OEt)NR₂], we chose to restrict our investigation to the hydrogen- and aryl-substituted systems (2, R = H or aryl). We describe below the successful completion of this sequence and its application *via* an intramolecular cyclization to the facile synthesis of **13**, a potential intermediate in the synthesis of the antitumor alkaloid camptothecin (**14**).⁵

Initial studies were carried out using ester **1a**, readily prepared from diethyl malonate and ethyl pyruvate.⁶ When equimolar quantities of **1a** and the diethyl acetal of dimethylformamide (**2a**) were heated in DMF at 80° for 5 hr, the yellow enamine **3a** was obtained in

87% yield. The enamine double bond in **3a** was assigned as *trans* on the basis of the vinyl hydrogen coupling constant of 13 Hz in the nmr spectrum. Subsequent reaction of **3a** with benzylamine afforded the *N*-benzylpyridone **4a** in 90% yield.

The feasibility of this approach as a route to camptothecin required the selective transformation of the 3-carbomethoxy group into a hydroxymethyl group; the carboxyl group remaining at C₄ would provide the basis for assembly of the α -hydroxy acid moiety. Differentiation of the carbomethoxy groups was readily accomplished *via* hydrolysis with 1 equiv of potassium hydroxide to give the acid ester **5a** in 78% yield. Assignment of **5a** as the saponification product was based on the fact that reaction of **5a** with trichloroethanol and *N,N*-dicyclohexylcarbodiimide afforded an ethyl trichloroethyl ester whose nmr spectrum was clearly different from that of the pyridone ester prepared from di(trichloroethyl) malonate and ethyl pyruvate. Extensive efforts to carry out selective reduction of the carbomethoxy group proved fruitless. Thus our approach was modified to permit the specific synthesis of the "alternate" acid ester **5b** (Scheme I).

The triester **1b**, prepared from dimethyl malonate,⁶ condensed smoothly with **2a** to give the corresponding enamine **3b** in 83% yield; reaction with benzylamine as above led to the crystalline pyridone diester **4b**. When pyridone **4b** was refluxed with anhydrous lithium iodide in pyridine⁷ for 1 hr, a single acid ester **5b** was isolated in 86% yield. The nmr spectrum demonstrated unequivocally that the methyl ester had been

(1) Alfred P. Sloan Foundation Fellow.

(2) H. Meervein, W. Florian, N. Schön, and G. Stopp, *Justus Liebigs Ann. Chem.*, **641**, 1 (1961).

(3) An acylation of this general type has been utilized in the synthesis of the pyrone ring in fulvoplumierin; see G. Büchi and J. A. Carlson, *J. Amer. Chem. Soc.*, **90**, 5336 (1968).

(4) (a) T. Oishi, M. Ochiai, T. Nakayama, and Y. Ban, *Chem. Pharm. Bull.*, **17**, 2314 (1969); (b) for a recent review of amide acetals, see J. Gloede, L. Haase, and H. Gross, *Z. Chem.*, **9**, 201 (1969).

(5) M. E. Wall, M. C. Wani, C. E. Cook, K. H. Palmer, A. T. McPhail, and G. A. Sim, *J. Amer. Chem. Soc.*, **88**, 3888 (1966); A. T. McPhail and G. A. Sim, *J. Chem. Soc. B*, 923 (1968).

(6) R. Malachowski and W. Czornodola, *Chem. Ber.*, **68B**, 363 (1935).

(7) F. Elsinger, J. Schreiber, and A. Eschenmoser, *Helv. Chim. Acta*, **43**, 113 (1961).