Table III. Solubility Corrections for Syn/Anti Dimer Ratios

p-XC$_6$H$_4$Br, X	Registry no.	0.1 mol % ArBr Uncorrected	0.1 mol % ArBr Corrected	10 mol % ArBr Uncorrected	10 mol % ArBr Corrected
H	108-86-1	4.96	4.96	1.10	1.06
CH$_3$	106-38-7	4.46	4.53	0.86	0.91
OCH$_3$	104-92-7	3.69	3.71	0.53	0.58
CHO	1122-91-4	2.98	3.00	0.11	0.14
CF$_3$	402-43-7	3.38	3.40		

Table IV[a]

p-XC$_6$H$_4$Br	p-XC$_6$H$_4$Br in CH$_3$OH, mol %								
	0.1	0.4	0.7	1	2	4	6	8	10
X = CH$_3$									
Yield, g	0.30	0.33	0.35	0.38	0.80	0.96	1.17	1.24	1.25
	0.34	0.34	0.38	0.28	0.95	0.91		1.20	1.21
Av yield, %	32	34	37	33	58	62	78	81	82
X = OCH$_3$									
Yield, g	0.21	0.31	0.38	0.38	0.88	1.00	1.13	1.09	1.08
	0.30	0.37	0.38	0.40	0.85	0.94	0.98	1.08	1.07
Av yield, %	25	34	38	39	58	65	70	72	72
X = H									
Yield, g	0.28	0.31	0.37	0.43	0.67	0.91	1.12	1.09	1.26
	0.36	0.36	0.38	0.41	0.77	0.94	1.06	1.15	1.25
Av yield, %	32	34	38	42	48	62	73	75	84
X = CF$_3$									
Yield, g	0.34	0.41	0.41	0.42	0.80	1.17	1.21	1.29	1.27
	0.28	0.38	0.40	0.46	0.77		1.11	1.26	1.26
Av yield, %	31	40	41	44	52	78	77	85	84
X = CHO									
Yield, g	0.33	0.35	0.35	0.39	0.79	0.89	1.25	1.16	1.30
	0.35	0.38	0.41	0.44	0.63	1.19		1.34	1.22
Av yield, %	34	37	38	42	47	69	83	83	84

[a] Eight blank samples were also photolyzed, four of which contained 1.0 g of 1 in methanol (total volume 10 mL) and four of which contained 1.5 g of 1 in methanol (total volume 15 mL). See Table I and the Experimental Section. The observed yields were 0.20 (20%), 0.18 (18%), 0.19 (19%), 0.21 (20%), 0.23 (15%), 0.35 (23%), 0.32 (21%), and 0.18 g (12%). These may be compared to a literature value of 42.5% reported by Cowan and Drisko for their standardized conditions.[1]

on the heavy atom. However, while it seems likely that solvent dielectric constants will differ significantly at ArBr concentration levels near 10 mol %, they will differ very little at ArBr concentration levels near 1 mol %. For example, the dielectric constants of methanol and bromobenzene are 32.63 and 5.40, respectively, at 25 °C.[11] On the assumption that the dielectric constant for a binary liquid can be approximated by (mol fraction of A)(dielectric constant of A) + (mol fraction of B)(dielectric constant of B), dielectric constants of 29.91, 32.35, and 32.60 can be computed for bromobenzene in methanol at the 10, 1, and 0.1 mol % concentration levels. For p-bromoanisole (D = 7.06 at 30 °C),[12] the corresponding computed D values are 30.07, 32.37, and 32.60. The fact that the relative syn/anti ratios in this study follow the same substituent trend at 10 mol % ArBr in methanol as at 0.1 mol % ArBr in methanol (where dielectric constants are nearly identical) indicates that solvent dielectric is not a serious controlling factor here.

We have, at this time, no information concerning possible light absorption by the heavy-atom solvents and subsequent energy transfer from them to acenaphthylene, nor have we assessed the possibility of direct reactions between acenaphthylene and the aryl bromides.

Experimental Section

General. Acenaphthylene and all of the substituted bromobenzenes used in this investigation were purchased from the Aldrich Chemical Co. and were designated as 99% pure. Acenaphthylene was recrystallized twice from 95% ethanol (mp 90–91 °C), and p-bromobenzaldehyde was recrystallized twice from 95% ethanol (mp 57–58 °C). Bromobenzene (bp 154–156 °C), p-bromotoluene (bp 183–185 °C), p-bromoanisole (bp 215–216 °C), and p-bromobenzotrifluoride (bp 154–155 °C) were distilled prior to use. Ultraviolet spectra were recorded on a Cary-17 UV–vis–near-IR spectrophotometer. All melting points and boiling points recorded herein are uncorrected.

Reaction Mixtures. Acenaphthylene (2.50 g) was dissolved in each binary solvent and diluted volumetrically with that solvent to 25 mL. A 10-mL aliquot (for solvents 0.1–1 mol % in ArBr) or a 15-mL aliquot (for solvents 2–10 mol % in ArBr) was subsequently removed and transferred to a Pyrex tube (25 cm long × 12 mm wide × 1 mm thick). Each reaction mixture was then degassed by two freeze (liquid N$_2$)–pump–thaw cycles, and each reaction vessel was sealed under vacuum.

Irradiation Procedure. Irradiations were conducted with a 450-W, Ace-Hanovia 6515-34 quartz mercury-vapor lamp fitted with a uranium glass sleeve and immersed in a Vycor cooling well. The reaction vessels were placed in a merry-go-round apparatus and situated 7.5 cm from the light source. For each set of data, 45 reaction mixtures were irradiated, but they could not be irradiated all at once. They were divided into batches of 20 (0.1–1.0 mol % in ArBr; all substituents), 15 (2–10 mol % in ArBr; H, CH$_3$, and OCH$_3$ substituents), and 10 (2–10 mol % in ArBr; CHO and CF$_3$ substituents). The first batch was accompanied with two "blanks" (1 in pure methanol), and the remaining batches were accompanied with one blank sample each. Thus, for both sets of data, eight blank samples were irradiated. The irradiations were continued for 15 h at room temperature, during which time the acenaphthylene photodimers precipitated from solution. The temperature of the reaction mixtures was ~30 °C during photolysis.

Product Analysis. The photodimers were isolated by filtration and washed with methanol (10 mL) to remove any 1 that may have coprecipitated during the reaction. The weights of dimer and percent conversions to dimer are summarized in Table IV for two sets of reactions. The dimer mixtures were then thoroughly powdered and subjected to UV analysis.

Solubility Measurements. The syn or anti photodimer (0.50 g) was added to 25 mL of a given solvent, and the mixture was allowed to stand with shaking for 20 h at ~22–24 °C. The insoluble material was subsequently removed by filtration, and the filtrate was con-

Table I.[a] UV Irradiation of 1 in p-XC_6H_4Br/Methanol

p-XC_6H_4Br	Syn/anti ratio									
	H		CH_3		OCH_3		CHO		CF_3	
mol %	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
0.1	4.85	4.97	4.60	4.48	3.68	3.66	3.00	2.97	3.52	3.36
Av	4.91		4.54		3.67		2.99		3.44	
0.4	3.53	3.63	3.17	3.17	2.76	2.72	1.72	1.68	1.75	1.88
Av	3.58		3.17		2.74		1.70		1.82	
0.7	2.39	2.35	2.21	2.16	2.07	1.94	1.23	1.14	1.08	1.16
Av	2.37		2.19		2.01		1.19		1.12	
1.0	2.30	2.28	2.04	2.06	1.60	1.67	1.04	0.83	1.00	0.96
Av	2.29		2.05		1.64		0.94		0.98	
2.0	1.91	1.83	1.55	1.62	1.32	1.34	0.83	0.78	1.03	0.99
Av	1.87		1.59		1.33		0.81		1.02	
4.0	1.23	1.30	1.19	1.16	1.24	1.03	0.51	0.51	0.82	0.84
Av	1.27		1.18		1.14		0.51		0.83	
6.0	1.08	1.14	1.20	1.17	0.70	0.65	0.45	0.44	0.74	0.65
Av	1.11		1.19		0.68		0.44		0.70	
8.0	0.95	1.06	0.92	1.02	0.58	0.58	0.35	0.32	0.33	0.24
Av	1.01		0.97		0.58		0.34		0.29	
10.0	0.79	1.01	0.57	0.68	0.55	0.53	0.16	0.11	0.21	0.23
Av	0.90		0.63		0.54		0.14		0.22	

[a] Eight blank samples were also photolyzed, four of which contained 1.0 g of 1 in methanol (total volume 10 mL) and four of which contained 1.5 g of 1 in methanol (total volume 15 mL). See the Experimental Section for more details. The observed syn/anti ratios were 6.29, 6.59, 6.32, 6.70, 6.27, 6.43, 6.56, and 6.23 (av 6.42). These values may be compared to a literature value of 5.74.[1]

Table II[a]

Authentic dimer mixtures			UV analysis of mixtures	
Wt of syn dimer, mg	Wt of anti dimer, mg	Syn/anti ratio	Syn/anti ratio	Error, %
11.42	1.71	6.68	6.50	2.7
11.13	1.63	6.83	6.68	2.2
10.90	2.14	5.09	5.15	1.1
10.84	2.11	5.14	5.03	2.1
9.71	3.29	2.95	2.86	3.1
9.66	3.27	2.95	2.87	2.7
8.76	4.41	1.99	2.06	3.5
8.62	4.18	2.06	1.99	3.4
6.61	6.73	0.98	1.02	4.1
6.48	6.23	1.04	1.01	2.9
5.38	7.91	0.68	0.71	4.2
4.34	8.34	0.52	0.55	5.8
3.25	9.85	0.33	0.36	9.1
3.19	10.29	0.31	0.34	9.7

[a] It can be seen that the average error in the determination of syn/anti ratios by the UV method is about 4% and is somewhat lower for high ratios than it is for low ratios. The error is sufficiently low, however, so that *relative* ratios are pretty much maintained as one proceeds from one perturber to the next at the various concentration levels.

Irradiations of 1 were conducted with a 450-W, Ace-Hanovia 6515-34 quartz mercury-vapor lamp fitted with a uranium glass sleeve and a merry-go-round apparatus such that the sample tubes were placed 7.5 cm from the light source. Each reaction solution, containing acenaphthylene and solvent (10%, w/v), was degassed, and each Pyrex reaction vessel was sealed prior to irradiation. The irradiations were continued for 15 h at room temperature, during which time the photodimers precipitated from solution. The crude dimer mixtures were subsequently isolated, washed with methanol to remove any unreacted 1, and subjected to UV analysis. A determination of absorbances for each mixture at *two* wavelengths coupled with a knowledge of extinction coefficients for the pure dimers at those wavelengths allowed the computation of syn/anti ratios. An assessment of the accuracy of this analytical method, first utilized by Cowan and Drisko,[4] is presented in Table II. Authentic dimer mixtures were prepared from the pure dimers, and the known ratios were compared to those determined by UV analysis.

The syn and anti photodimers of 1 exhibit measurable solubilities in p-X-C_6H_4-Br/CH_3OH. Thus, the ratios presented in Table I require correction because they were determined by analysis of dimers which had precipitated and do not account for the quantity of dimers which remained in solution. If the dimers exhibited *identical* solubilities corrections would be unnecessary, but they do not. Fortunately, in those instances where solubilities were determined, the corrections did not lead to serious changes, and most of the discussion herein pertains to uncorrected ratios. Dimer solubilities in XC_6H_4Br/CH_3OH at the 0.1 and 10 mol % extremes of aryl bromide concentration were measured. Corrected and uncorrected syn/anti ratios are compared in Table III.

Inspection of Table I indicates clearly that *most* of the heavy-atom perturbation is achieved by the time concentration levels of ArBr in methanol have reached 1–2 mol %. Although the various aryl bromides do not appear to differ greatly in their ability to reduce syn/anti ratios (i.e., to promote S $\rightsquigarrow$ T), they do differ, and the difference seems to be real. There also seems to be a clear indication that electrophilic substituents enhance the heavy-atom effect. For example, at the 1 mol % ArBr level, syn/anti ratios of 2.05 (CH_3), 1.64 (OCH_3), 0.94 (CHO), and 0.98 (CF_3) were observed. However, those ratios do not correlate with Hammett's σ constants. For example, p-CH_3 (σ −0.170) is more electrophilic than p-OCH_3 (σ −0.268). Yet, the latter substituent induces a lower syn/anti ratio. Similarly, p-CF_3 (σ +0.54) is more electrophilic than p-CHO (σ +0.51) but less effective in lowering the syn/anti ratio. Finally all the substituted bromobenzenes studied by us were better perturbers than bromobenzene itself *when methanol was the solvent*, a curious fact for which we have no explanation.

It has been demonstrated by Hartmann, Hartmann, and Schenck that acenaphthylene photodimer ratios depend on the dielectric constant of the reaction medium.[10] A plot of log ([anti]/[syn]) vs. $(D - 1/2D + 1)(\rho/M)(10^2)$ for *eleven* solvents gave a straight line with a negative slope.[10] It seems possible, then, that the trends reported herein may manifest differences in dielectric for the binary "solvents" p-X-C_6H_4-Br/CH_3OH and have little or nothing to do with substituent perturbations

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Heavy-Atom Effect on the Photodimerization of Acenaphthylene: Substituent Analysis on the Efficiency of External Aromatic Perturbers

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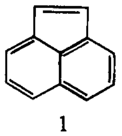
The photodimerization of acenaphthylene in the presence of various para-substituted bromobenzenes in methanol was studied in order to determine if the photochemical heavy-atom effect responds to a substituent change. A substituent effect was indeed observed, but the photodimer ratios do not vary linearly with Hammett's σ constants.

The photodimerization of acenaphthylene (1) in the presence of organic halides provides an excellent illustration of the photochemical heavy-atom effect. This reaction has been studied thoroughly by Cowan, Drisko, and Koziar, who employed standardized irradiation conditions so that syn/anti dimer ratios associated with various solvent systems could be compared.[1–7] For example, when 1 was irradiated in cyclohexane, the syn/anti photodimer ratio was determined to be 4.17, but, when *n*-propyl bromide was the solvent, the ratio dropped to 0.41.[1] These results can be explained if it is assumed that the syn dimer is derived primarily from an excited singlet state (or excimer) of 1 and that the anti dimer is derived from an excited triplet state. The heavy-atom solvent, *n*-propyl bromide, promotes singlet → triplet intersystem crossing, a perturbation that eventuates in a higher relative yield of anti dimer and a lower syn/anti ratio. The dimer ratio is also sensitive to the nature of the heavy atom, RI being a more effective "perturber" than RBr, while RCl is relatively ineffective.[3] In binary solvents of the type cyclohexane/RX, the syn/anti ratio varies inversely with the mol % of RX.[2,4]



1

An analysis of the influence of substituents on the efficiency of external aromatic heavy-atom perturbers has not yet been reported for a photochemical process. However, an interesting structure–efficiency relationship has been noted for a photophysical process. McGlynn and his co-workers observed that the T←S absorption band in the electronic spectrum of 1-chloronaphthalene was enhanced when that compound was codissolved with various alkyl iodides, the degree of enhancement conforming to the following trend: $CH_3I > CH_3CH_2I > CH_3CH_2CH_2I > (CH_3)_2CHCH_2CH_2I$.[7] Thus, the heavy-atom perturbation *decreased* as the electron-donating capacity of the alkyl group *increased.* Consistent with this trend is the observation that *p*-fluorobromobenzene caused more T←S enhancement in 1-chloronaphthalene than did bromobenzene.[7]

Results and Discussion

In this paper, we report an investigation of the photodimerization of acenaphthylene in the presence of various para-substituted bromobenzenes dissolved in methanol. Dimer ratios were determined at aryl bromide concentration levels of 0.1, 0.4, 0.7, 1, 2, 4, 6, 8, and 10 mol %, and the substituents that were studied include H, CH_3, OCH_3, CHO, and CF_3. The substituents NH_2, COOH, and CN were not studied because the corresponding aryl bromides are not sufficiently soluble in methanol over the concentration range of interest to us. Methanol was chosen as the cosolvent instead of cyclohexane because a broader range of syn/anti ratios is accessible with methanol.[1] We report two complete sets of data; i.e., for each aryl bromide at each concentration level, two reactions were conducted, but they were not run at the same time. One set of data was first collected for *all* aryl bromides, and then another data set was collected. The results are presented in Table I.

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Table V

	Syn/anti ratio	Yield, g
Not degassed	2.65	0.513
	2.62	0.481
Degassed (2 cycles)	2.43	0.533
	2.46	0.524
Degassed (5 cycles)	2.44	0.534
	2.38	0.535

centrated to the residual solid which had dissolved. The *residue* was then weighed.

Isolation of the Anti Dimer. Acenaphthylene (10 g) was dissolved in 50 mL of p-OHC-C_6H_4-Br (20 mol %)/benzene and irradiated (*without* prior degassing) for 25 h. The crude product which had precipitated was isolated, washed with three portions (500 mL total) of hot cyclohexane, and recrystallized from benzene as white needles: mp 301–302 °C (lit. mp 306–307 °C);[9] UV (cyclohexane) 219 (ϵ 6.56 $\times 10^4$), 225 nm (ϵ 1.11 $\times 10^5$).

Isolation of the Syn Dimer. A solution of acenaphthylene (10 g) in methanol (50 mL) was degassed and irradiated for 25 h. The crude product which precipitated was recrystallized from cyclohexane as white prisms: mp 232–234 °C (lit. mp 232–234 °C);[9] UV (cyclohexane) 219 (ϵ 1.10 $\times 10^5$), 225 nm (ϵ 4.99 $\times 10^4$).

Control. Photostability of Acenaphthylene Photodimers. The pure anti dimer (1.0 g, see above) was added to a sufficient quantity of methanol so that the final volume was 10 mL, and the resulting solid/liquid mixture was degassed and irradiated for 15 h in the usual fashion. Ultraviolet analysis of the insoluble "product" gave a syn/anti dimer ratio of 0.18.

The pure syn dimer was treated analogously and gave a syn/anti ratio of 4.37.

Control. Syn/Anti Ratios as a Function of Sample Degassing. In all of the reactions previously described, the reaction mixtures were degassed by *two* freeze–pump cycles. That two cycles are sufficient is indicated by the following study. Six reaction mixtures were prepared, each containing 1.0 g of acenaphthylene in 1.0 mol % of bromobenzene in methanol (total volume 10 mL). Two reaction mixtures were *not* degassed, two were degassed with *two* freeze (liquid N_2)–pump–thaw cycles, and two were degassed with *five* freeze–pump–thaw cycles. After irradiation and product analysis in standard fashion, the syn/anti ratios and dimer yields were obtained (Table V).

Registry No.—**1**, 208-96-8; *syn*-**1** photodimer, 15065-28-8; *anti*-**1** photodimer, 14620-98-5.

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Nucleosides. 108. Ribo–Xylo Interconversions of 6,5′-Cyclopyrimidine Nucleosides via Autoxidation and Retro-Aldol Reactions[1,2]

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The 5′*S* and 5′*R* epimers of 6,5′-cyclouridine undergo autoxidation to 5′-oxo-6,5′-cyclouridine when treated with oxygen and 1 N NaOH. 5′-Oxo-6,5′-cyclouridine is stable in 1 N NaOH, but under less strongly alkaline conditions, e.g., ethanolic ammonia, it undergoes 3′ epimerization to give 6,5′-cyclo-5′-oxo-1-(β-D-xylofuranosyl)uracil, probably via formation and recyclization of a pyrimido[1,6-*c*][1,3]oxazine intermediate generated by retro-aldol cleavage. The 5′-carbonyl group of 5′-oxo-6,5′-cyclouridine is predominately hydrated in aqueous systems, whereas the 5′-oxo-xylo isomer exists as the keto form under the same conditions. These ribo–xylo epimers consequently show large differences in ultraviolet spectral properties in water that are useful in monitoring the retro-aldol equilibrium reaction. Similar differences in the UV spectra of hydrated orotaldehyde (261 nm) and anhydrous orotaldehyde (300 nm) were noted. Reduction of 5′-oxo-6,5′-cyclouridine with sodium cyanoborohydride in acetic acid affords only 6,5′(*S*)-cyclouridine. Similar reduction of the 5′-oxo-xylo nucleoside affords both 5′*S* and 5′*R* epimers of 6,5′-cyclo-1-(β-D-xylofuranosyl)uracil in a ratio of 5:1, possibly indicating that the 5′*R*-xylo isomer is formed via participation of the 3′-hydroxyl group. The identity of each xylo 5′ epimer was established from NMR spectra and by the ready formation of a 3′,5′-*O*-isopropylidene derivative of the 5′*S* epimer.

Nucleosides and nucleotides restricted to one type of conformation, but retaining a full complement of hydrogen-bonding sites, are useful for probing the conformational factors that affect the specificities of the enzymes of nucleic acid metabolism.[3] In this regard, we have previously reported[4] the synthesis of the 5′*R* and 5′*S* epimers of 6,5′-cyclouridine (**1** and **2**, Scheme I). These nucleosides are fixed in the anti conformational range, and the orientations of the 5′-hydroxyl groups correspond approximately to the gauche–trans and trans–gauche $C_{4',5'}$ rotamers, respectively, of unrestricted nucleosides.

In addition to their potential as biochemical tools, 6,5′-cyclonucleosides are interesting from a chemical viewpoint because the allylic character of C-5′ enhances the reactivity of that position relative to ordinary nucleosides. For example, derivatives of **1** and **2** in which the 5′-hydroxyl groups are protected undergo base-catalyzed epimerization at C-5′ via a mechanism involving 5′-carbanion intermediates.[4] We now wish to report that 6,5′-cyclopyrimidine nucleosides with unsubstituted 5′-hydroxyl groups readily undergo base-catalyzed autoxidation and that the resulting 5′-oxo nucleosides can rearrange to give their D-xylo epimers.

The first example of autoxidation of a 6,5′-cyclopyrimidine nucleoside was encountered during the synthesis of inter-

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