tion of the residue from hexane or methanol afforded 0.97 g (93%) of the diepoxide **3**, mp 80–81°. The same product could be obtained directly from **1** using an excess (two to threefold) of oxidant. Mixtures of **2** and **3** are difficult to resolve by column chromatography, though they can be separated by gas chromatography (10 ft × 0.25 in. column, 20% DEGS on 60/80 Chromosorb W, 150°): ir (CCl_4) 1685 (s), 1660 (w), 1630 (w), 1475 (m), 1455 (w), 1415 (m), 1380 (m), 1375 (w), 1340 (w), 1290 (w), 1255 (s), 1220 (w), 1165 (w), 1155 (w), 1120 (s), 1070 (m), 1030 (m), 940 (w), 875 (s), 700 cm^{-1} (m); uv (cyclohexane) 240 nm (ϵ 607), 217 (1960); mass spectrum (70 eV) *m/e* (rel intensity) 210 (2), 195 (3), 194 (0.5), 178 (4), 167 (20), 153 (32), 139 (100), 125 (37), 121 (33), 97 (43), 81 (49), 69 (40), 57 (46), 55 (91), 53 (64); nmr, see structure.

Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.54; H, 8.63. Found: C, 68.39; H, 8.59.

Irradiation of 2.—A solution of 0.6 g of **2** in 30 ml of anhydrous ether was irradiated through Vycor with a 450-W Hanovia lamp. The photolysis was followed by vpc using a 5 ft × 0.25 in. column, 20% SE-30 on 60/80 Chromosorb W, 144°, He carrier gas flow 150 ml/min. As the reaction proceeded, the peak with a retention time of 9.5 min (starting material) decreased in area and a product peak appeared at 7.5 min. After 10 hr the reaction was complete and the product, **5-acetyl-2,3,4,4,5-pentamethyl-2-cyclopentenone** (**4**) was collected by preparative vpc: ir (CCl_4) 1690 and 1700 (broad, s) 1647 (m), 1385 (m), 1355 (m), 1325 (m), 1020 cm^{-1} (m); uv (cyclohexane) 233 nm (ϵ 14,750); mass spectrum (70 eV) *m/e* (rel intensity) 194 (20), 179 (3), 152 (100), 137 (90), 123 (19), 109 (33), 81 (24); nmr, see structure.

Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.23; H, 9.33.

Irradiation of ether or acetone solutions of **2** as above but through Pyrex gave only unchanged starting material.

Irradiation of 3.—Irradiation of a 1% solution of **3** in ether through quartz, or in acetone through Pyrex for 9–16 hr with a 450-W Hanovia lamp, gave only unchanged starting material.

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Registry No.—**1**, 14790-04-6; **2**, 40940-60-1; **3**, 40940-61-2; **4**, 40940-46-3.

Photochemical Reactions of Nucleic Acid Constituents. Peroxide-Initiated Reactions of Purines with Alcohols

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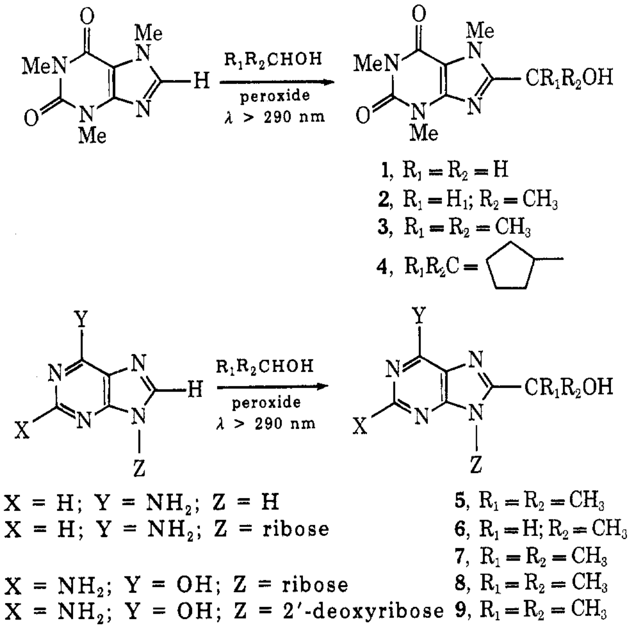
The photoalkylation of purines with alcohols has been described in recent years.[2] Most of these reactions led to the substitution of a hydroxyalkyl group for the C-8 hydrogen atom in the purine nucleus. The reactions were initiated either directly by ultraviolet light (λ > 260 nm), or through photosensitization with acetone (λ > 290 nm). We now report the light-induced reactions of purines with alcohols initiated with peroxides which lead to nearly quantitative yields of the appropriate C-8 hydroxyalkyl purines (with quantum yields of up to 0.05). A variety of peroxides, such as di-*tert*-butyl peroxide (DBP) and dicumyl peroxide (DCP), were employed in these reactions, all leading to high yields of the purine alcohol photoproduct. Light of λ > 290 nm or sunlight was used for the initiation of these reactions, which can be summarized as shown in Scheme I.

SCHEME I



The photoproducts were generally isolated by column chromatography and characterized through their physical properties, as well as by comparison with authentic samples.[2c,e] In some cases (*e.g.*, adenosine and 2-propanol), chromatography could be omitted in the work-up procedure, and the photoproduct was obtained by direct crystallization from the bulk of the reaction mixture. The reactions studied and the photoproducts isolated are summarized in Table I.

Traces (≤1%) of 8-alkylpurines, the alkyl side chain of which depended on the alcohol employed, were sometimes found as by-products of the reactions. For example, 8-isopropyladenine was detected in the reaction of adenine with 2-propanol. A product (**10**)[2e] resulting from the alkylation both at the C-8 position and at the N-7 methyl group of caffeine could be isolated in minute amounts (≤1%) from the caffeine–2-propanol reaction (see Experimental Section).

Spectral measurements indicated that most of the incident light is absorbed by the peroxide (*ca.* 90% with DBP). It is, therefore, suggested that the initiation of the reaction results from the light-induced fragmentation of the peroxide into free radicals, which abstract a hydrogen atom from the solvent, thus generating alcohol free radicals. The latter are scavenged by a purine molecule to yield, subsequently, the appropriate photoproduct.[2e]

To conclude, the reported reactions present a simple method for the synthesis of 8-hydroxyalkyl purines in high yields. The broad choice of alcohols in these reactions makes our method very versatile

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[1] In partial fulfillment of the requirements for a Ph.D. thesis to be submitted to the Feinberg Graduate School.

[2] (a) H. Linschitz and J. S. Connolly, *J. Amer. Chem. Soc.*, **90**, 297 (1968); (b) D. Elad, I. Rosenthal, and H. Steinmaus, *Chem. Commun.*, 305 (1969); (c) H. Steinmaus, I. Rosenthal, and D. Elad, *J. Amer. Chem. Soc.*, **91**, 4921 (1969); (d) B. Evans and R. Wolfenden, *ibid.*, **92**, 4751 (1970); (e) H. Steinmaus, I. Rosenthal, and D. Elad, *J. Org. Chem.*, **36**, 3594 (1971); (f) Y. Yawazoa, M. Maeda, and K. Nushi, *Chem. Pharm. Bull.*, **20**, 1341 (1972).

TABLE I

PHOTOCHEMICAL REACTIONS OF PURINES WITH ALCOHOLS[a]

Purine	Registry no.	Alcohol	Registry no.	Photoinitiator	Product (yield, %)[b]
Caffeine	58-08-2	Methanol	67-56-1	DBP[c]	**1** (90)
				DCP[d]	**1** (97)
		Ethanol	64-17-5	DBP	**2** (90)
				DCP	**2** (86)
				DBP	**2** (80)[e]
		2-Propanol	67-63-0	DBP	**3** (87)
				DCP	**3** (92)
				BHP[f]	**3** (76)
				CHP[g]	**3** (80)
				DBP	**3** (90)[e]
				DCP	**3** (85)[e]
		Cyclopentanol	96-41-3	DBP	**4** (83)
Adenine	73-24-5	2-Propanol		DBP	**5** (96)
				DCP	**5** (100)
				BHP	**5** (82)
				DBP	**5** (85)[e]
				DCP	**5** (82)[e]
Adenosine	58-61-7	Ethanol		DBP	**6** (91)
				DCP	**6** (100)
		2-Propanol		DBP	**7** (100)
				DCP	**7** (100)
				CHP	**7** (86)
				DBP	**7** (81)[e]
				DCP	**7** (76)[e]
Guanosine	118-00-3	2-Propanol		DBP	**8** (90)
				DCP	**8** (90)
2′-Deoxyguanosine	961-07-9	2-Propanol		DBP	**9** (90)
				DCP	**9** (91)

[a] Hanovia 450-W high-pressure mercury vapor lamps (Pyrex filters) were used as the light source. [b] Yields are based on reacted purines. Conversions ranged from 80 to 100%. Irradiation time 22 hr. [c] Di-*tert*-butyl peroxide. [d] Dicumyl peroxide. [e] In sunlight (15–21 days). [f] *tert*-Butyl hydroproxide. [g] Cumyl hydroperoxide.

for the production of new purine derivatives, which may be of pharmacological significance.

Experimental Section

Caffeine (Schuchardt, Muenchen) was freshly crystallized from water prior to use. Other purines (Fluka, CHR grade) were used without purification. Alcohols were freshly distilled before irradiation. Petroleum ether refers to the fraction of bp 60–80°. Kieselgel, 0.063–0.20 mm (Merck, Darmstadt), was used for column chromatography (1 kg packed into a glass column 4.7 cm diameter × 1.20 m). Progress of the reactions was followed by ascending tlc on aluminum plates (Kieselgel SI F, Riedel-de-Haan), using acetone–petroleum ether mixtures for the caffeine derivatives and methanol–chloroform for other purines. Spots were detected by a Mineralight lamp. Chromatography was performed by using the "dry-column" technique[3] with properly deactivated silica gel, followed by elution with the appropriate solvent mixture. Irradiations were carried out in a Pyrex immersion apparatus, using Hanovia 450 W high pressure mercury vapor lamps, which were cooled internally with running water. The irradiation vessel was flushed for 15 min by oxygen-free nitrogen prior to irradiation, and nitrogen bubbling, as well as mechanical stirring, were sustained throughout the irradiation. Quantum yields were measured by ferrioxalate actinometry.[4] Nmr spectra were measured with a Varian A-60 instrument, using TMS as an internal standard. Absorptions are reported in τ values. Mass spectra were recorded on a MAT Atlas CH_4 instrument. Typical experiments are described. All other experiments were conducted under similar conditions.

Reaction of Caffeine and 2-Propanol (with DBP).—A mixture of caffeine (5 g), DBP (10 ml), 2-propanol (140 ml), and water (35 ml) was irradiated for 22 hr. Excess reagents were removed under reduced pressure, and the solid residue was chromatographed on silica gel (1 kg). Elution with acetone–petroleum ether (1:8) afforded pure **10**[2e] (0.03 g). Further elution with the same solvent mixture (1:6) gave **3** (5.1 g), followed by unreacted caffeine (0.54 g), which was eluted with a 1:4 mixture.

Reaction of Adenine and 2-Propanol (with DBP).—A mixture of adenine (2 g), DBP (8 ml), 2-propanol (135 ml), and water (40 ml) was irradiated for 22 hr. Excess reagents were removed under reduced pressure, and the solid residue was chromatographed on silica gel (500 g). Methanol–chloroform (1:10) eluted **5** (2.66 g), followed by unreacted adenine (0.1 g), which was eluted with a 1:8 mixture.

The reaction of caffeine and cyclopentanol yielded **4**, which exhibited mp 178–179° (from acetone–petroleum ether); nmr ($CDCl_3$) τ 5.88 (s, 3 H, $-N-7-CH_3$), 6.26 (broad s, 1 H, OH), 6.60 (s, 3 H, $-N-3-CH_3$), 6.68 (s, 3 H, $-N-1-CH_3$), and 7.95 [broad m, 8 H, $(CH_2)_4$].

Anal. Calcd for $C_{13}H_{18}N_4O_3$: C, 56.1; H, 6.5; N, 20.1; mol wt, 279. Found: C, 56.2; H, 6.7; N, 19.6; mol wt, 279 (mass spectrum).

Reaction of Caffeine and 2-Propanol (with Sunlight).—A mixture of caffeine (0.5 g), 2-propanol (140 ml), DBP (6 ml), and water (35 ml) was exposed to sunlight for 15 days (December). The usual work-up and chromatography led to **3** (0.53 g) and to recovered caffeine (0.05 g).

Reaction of Caffeine and 2-Propanol (with Visible Light).—A mixture of caffeine (0.05 g), 2-propanol (30 ml), DCP (2 g), and water (3 ml) was irradiated with 4 × 20 W fluorescent lamps (G. E.) for 285 hr, using a GWV filter (transmitting light of $\lambda > 370$ nm). The usual work-up and chromatography led to **3** (0.011 g) and to recovered caffeine (0.041 g). Other experiments using visible light led to the same photoproducts as those obtained with uv light. Conversions ranged from 20 to 45%. Irradiation time ranged from 150 to 300 hr.

Registry No.—4, 40919-45-7.

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[4] C. A. Parker, *Proc. Roy. Soc., Ser. A*, **220**, 104 (1953).