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Note

Photochemical cycloaddition of 1,3-diacetoxy-2-propanone to (trimethylsilyloxy)ethylene*

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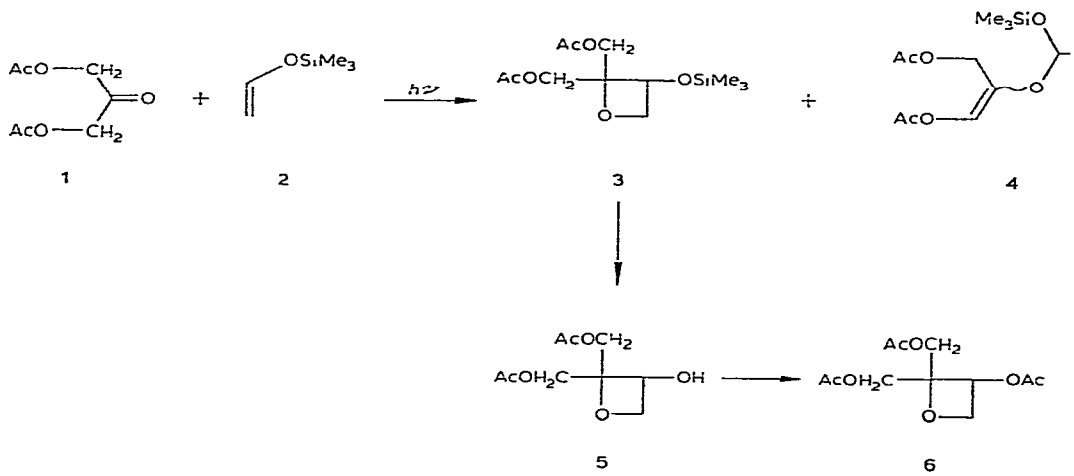
In previous papers[1,2], we have described the photochemical, cycloaddition reactions of 1,3-diacetoxy-2-propanone (**1**) with various ethylenediol and ethylenol derivatives for the synthesis of branched-chain sugars. As the alkenic species for the reactions, such enol acetates as 2-(benzyloxy)vinyl acetate and vinylene diacetate, which were prepared from the corresponding aldehydes, were used, in addition to such commercially available compounds as vinyl acetate, isopropenyl acetate, and ethoxyethylene[1]. However, enolacetylation is known as not necessarily giving a good yield[1,3], but, on the other hand, enolsilylation of aldehydes and ketones is known to proceed effectively[4]. Consequently, judging from the recent, enormous advance in organosilicon chemistry, the utility of the photochemical, cycloaddition reaction in the field of organic chemistry would be increased were the enol silyl ethers widely employed in the reaction. This conclusion prompted us to perform photochemical cycloaddition of **1** to (trimethylsilyloxy)ethylene (**2**), and the results thus obtained are described herein.

Irradiation of a solution of **1** (0.25M) and **2** (0.5M) in benzene with a high-pressure, mercury lamp, followed by chromatographic separation on a column of silica gel†, gave 2,2-bis(acetoxymethyl)-3-(trimethylsilyloxy)oxetane (4,4′-di-*O*-acetyl-1,3-anhydro-2-*O*-(trimethylsilyl)-DL-apiitol) (**3**) (57% yield) and 1,3-diacetoxy-2-[1-(trimethylsilyloxy)ethoxy]propylene (**4**) (4% yield). *O*-Desilylation of **3** with acetic acid in methanol gave a quantitative yield of 2,2-bis(acetoxymethyl)-3-oxetanol (4,4′-di-*O*-acetyl-1,3-anhydro-DL-apiitol) (**5**). Acetylation of **5** in the usual way gave the corresponding acetate (**6**), which was identical (i.r. and ^{1}H-n.m.r. spectra) with an authentic specimen[1] prepared by the photochemical cycloaddition of **1** to vinyl acetate.

*Part 17 of the series: Synthetic Studies of Carbohydrate Derivatives by Photochemical Reactions. For Part 16, see ref. 1.
†The separation was completed within one day, in order to minimize the effect of hydrolysis on the yield of **3**.



Incidentally, an interesting effect of dilution on the ^{1}H-n.m.r. spectrum of **5** (see Fig. 1) was observed, *i.e.*, a solution of **5** in chloroform-*d* at the customary concentration gave its methylene proton signals of the two acetoxymethyl groups as two singlets, but, on dilution, one of the singlets was collapsed to a broad doublet, although first-order analysis of the splitting pattern was impossible. This phenomenon suggests that, in dilute solution, **5** may form an intramolecular hydrogen-bond such as is depicted in **5a**. In the ^{1}H-n.m.r. spectrum of **4**, on the other hand, two sets of three-proton signals appeared at δ 6.94, 5.59, and 4.53, and at δ 7.11, 5.30, and 4.72 (area ratio, 57:43), although it is impossible to assign these to the *cis* and *trans* isomers based on the evidence obtained thus far.

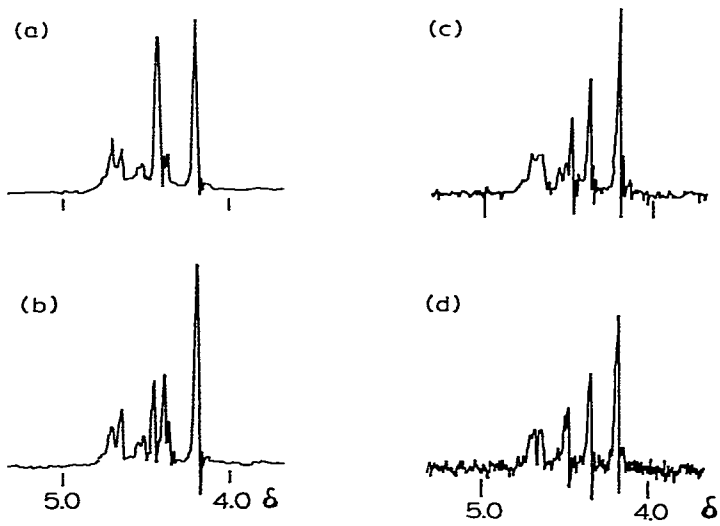
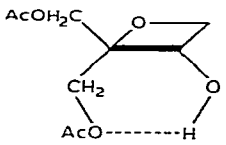


Fig. 1. Part of the n.m.r. spectrum of 2,2-bis(acetoxymethyl)-3-oxetanol (**5**). [Concentration of **5** in $CDCl_3$: (a), 0.6M; (b), 0.3M; (c), 0.15M; and (d), 75mM.]

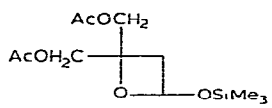
1,3-Diacetoxy-2-(1,2-diacetoxyethoxy)propylene, an analog of **4**, has similarly been obtained as a minor product in the reaction of **1** with (*Z*)-vinylene diacetate[1].



5a

The reversed regioisomer (**7**) of **3** was not isolated in the chromatography described, probably because of its high susceptibility to hydrolysis by water in the silica gel, a typical property of the 2-alkoxyoxetane structure[5]; however, an aldehyde species which would arise from the hydrolysis of **7** was not isolated.

An attempt was then made to isolate the species by treating the mixture (resulting from the photochemical cycloaddition) with acetic acid–methanol and subsequently with (2,4-dinitrophenyl)hydrazine, followed by chromatographic separation on a column of silica gel; the fraction containing part of **5** and **8** could not thus be separated, and so it was acetylated (to make **5** less polar), and the product was chromatographed. In this way, the formation of **7** was confirmed by the isolation of (*E*)-4-acetoxy-3-(acetoxymethyl)-3-hydroxybutanoaldehyde (2,4-dinitrophenyl)hydrazone (**8**) (15% yield), the *O*-acetyl derivative (**9**) of **8** (6%), and the (*Z*)-isomer (**10**) of **8** (1%), in addition to **5** (6%), **6** (40%), acetaldehyde (2,4-dinitrophenyl)hydrazone (**11**) (4%), the (2,4-dinitrophenyl)hydrazone (**12**) of **1** (4%), and **1** (1%). Therefore, the total yields of **5** and **6** (46%), and of **8**, **9**, and **10** (22%), were concluded to have respectively arisen from **3** and **7**.



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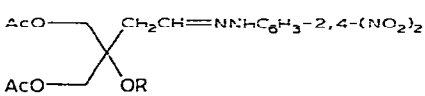
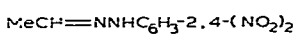


8 (E) R = H
9 (E) R = $COCH_3$
10 (Z) R = H



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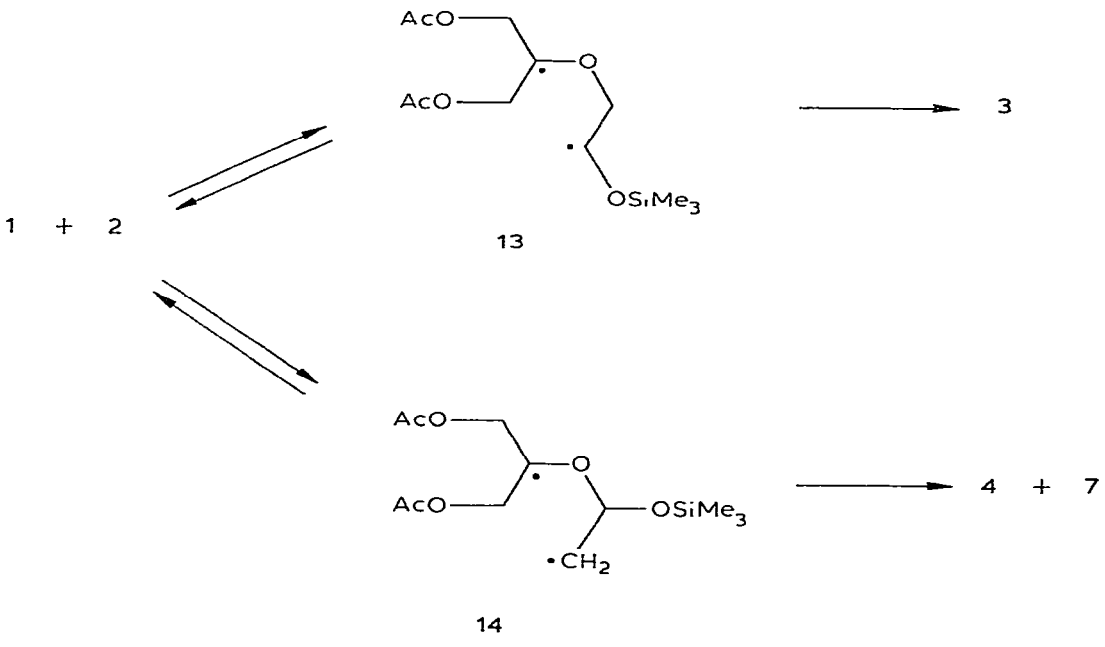
The *cis,trans* isomerism between **8** and **10** was determined by ^{1}H-n.m.r. spectroscopy; the methine proton of **8** appeared at lower field than that of **10** ($\Delta\delta$ = 0.5). Compounds **8** and **10** were respectively assigned the (*E*) and (*Z*) configuration on the basis of a report[6] that demonstrated that the methine proton of a -CH=N- structure in *cis* relationship to *N*-substituents appears at lower magnetic field than that in *trans* relationship. Similarly, **9** was assigned as the (*E*) isomer because the methine proton of **9** appeared at substantially the same chemical shift as that of **8**. Acetaldehyde, identified as its (2,4-dinitrophenyl)hydrazone (**11**), must have been formed by hydrolysis of **4**, as **2** would have evaporated from the resulting mixture prior to hydrolysis.

Mechanistically, it is considered that **4** is produced by intramolecular, hydrogen abstraction of the biradical intermediate **14**, which suggests that **3** and **7** might also be produced by intramolecular cyclization of the biradical intermediates **13** and **14**, respectively. Formation of the two latter can be expected to occur through the photochemical addition of **1** in the n→π^* triplet state to **2**, as in the usual photochemical, cycloaddition reaction[7].



Incidentally, silyl ethers of enols are well known to be susceptible to reaction with carbonyl compounds in the presence of a Lewis acid, to give an aldol type of product[8]. Consequently, a non-photochemical reaction of **1** with **2** in the presence of titanium(IV) chloride was attempted, but no product differing from those from the photochemical reactions was isolated.

EXPERIMENTAL

General. — The following instruments were used: m.p. (uncorrected) Yanagimoto micro melting-point apparatus; i.r., Hitachi 285; ^{1}H-n.m.r., Varian T-60, the spectra being recorded for solutions in deuteriochloroform containing tetramethylsilane as the internal standard; g.l.c., Hitachi K-53 [1-m column of 10% of SE 30 on Chromosorb W (60–80 mesh); carrier gas, nitrogen; detection by use of f.i.d.]. Column chromatographic separations on silica gel were performed by use of Wakogel C-300 (Wako Pure Chemicals, Japan), and t.l.c. was conducted on DC-Alufolien Kieselgel 60 F254 (thickness, 0.2 mm). Photoirradiation of a mixture was performed by use of a Ushio u.v., 450-W, high-pressure mercury lamp in a Pyrex-glass test-tube at room temperature at a distance of ~5 cm, after sufficiently passing argon gas through the mixture. Benzene used for the photoirradiation was purified as usual. The resulting mixtures were evaporated below 30°.

2,2-Bis(acetoxymethyl)-3-(trimethylsilyloxy)oxetane (**3**) *and 1,3-diacetoxy-2-[1-(trimethylsilyloxy)ethoxy]propylene* (**4**). — Two aliquots of a solution of 1,3-diacetoxy-2-propanone[9] (**1**) (871 mg, 5.00 mmol) and (trimethylsilyloxy)ethylene[10] (**2**) (1162 mg, 10.0 mmol) in benzene (20 mL) were irradiated for 40 h. T.l.c. analysis of the resulting mixtures indicated that **1** was almost completely consumed. The aliquots were combined, and the solvent and unchanged **2** were evaporated. The residue was chromatographed on a column of silica gel (60 mL), using cyclohexane–ethyl acetate as the eluant, to give **4** (63 mg, 4% yield; 57:43 mixture of the *cis* and *trans* isomers), **3** (827 mg, 57% yield), and a mixture of several other materials (447 mg). The mixture was re-chromatographed on a column of silica gel (60 mL), using benzene–ethyl acetate as the eluant, to give **1** (32 mg, 4% recovery yield). G.l.c. of **2**: retention time 2.4 min (oven temp. 40°, injection temp. 140°, carrier gas at 0.4 kg/cm^2).

Compound **3**. This was a syrup; ν_{max}^{NaCl} 1745 cm^{-1}; n.m.r.: δ 4.3–4.8 (m, 5 H), 4.22 (bs, 2 H, C*H*$_2$OAc), 2.12 (s, 3 H, C*H*$_3$CO), 2.08 (s, 3 H, C*H*$_3$CO), and 0.10 (s, 9 H, Me$_3$Si).

Anal. Calc. for $C_{12}H_{22}O_6Si$: C, 49.63; H, 7.64. Found: C, 49.54; H, 7.61.

Compound **4**. This was a syrup; n.m.r. (major isomer): δ 6.94 (bs, 1 H, C*H*=C), 5.59 (q, 1 H, *J* 5 Hz, C*H*-Me), 4.53 (bs, 2 H, C*H*$_2$-C=), 2.18 (s, 3 H, C*H*$_3$CO), 2.08 (s, 3 H, C*H*$_3$CO), 1.44 (d, 3 H, C*H*$_3$-C), and 0.17 (s, 9 H, Me$_3$Si); (minor isomer): δ 7.11 (s, 1 H), 5.30 (q, 1 H, *J* 5 Hz), 4.72 (s, 2 H), 2.18 (s, 3 H), 2.08 (s, 3 H), 1.44 (d, 3 H), and 0.17 (s, 9 H).

Anal. Calc. for $C_{12}H_{22}O_6Si$: C, 49.63; H, 7.64. Found: C, 49.67; H, 7.54.

2,2-Bis(acetoxymethyl)-3-oxetanol (**5**). — To a solution of compound **3** (730 mg) in methanol (20 mL) was added acetic acid (1 mL), and the mixture was stirred for 10 h at room temperature, and then evaporated *in vacuo*, to give **5** (541 mg, 99% yield) as a syrup; ν_{max}^{NaCl} 3450 (br) and 1740 cm^{-1}; n.m.r.: δ 4.3–4.8 (m, 3 H, C*H*-C*H*$_2$), 4.43 (2 H, s or d according to the concentration, C*H*$_2$-OAc), 4.20 (s, 2 H, C*H*$_2$-OAc), and 2.11 (s, 6 H, 2 C*H*$_3$CO).

Anal. Calc. for $C_9H_{14}O_6$: C, 49.54; H, 6.47. Found: C, 49.24; H, 6.34.

3-Acetoxy-2,2-bis(acetoxymethyl)oxetane (**6**). — A solution of **5** (199 mg) in a mixture of pyridine (1 mL) and acetic anhydride (1 mL) was stirred for 5 h at room temperature, and evaporated; the residue was chromatographed on a column of silica gel, using cyclohexane–ethyl acetate as the eluant, to give **6** (224 mg, 94% yield), identified with authentic material[1] by n.m.r. and i.r. spectra.

(E)- (**8**) *and* (Z)-*4-Acetoxy-3-(acetoxymethyl)-3-hydroxybutanoaldehyde* (*2,4-dinitrophenyl)hydrazone* (**10**), *and* (E)-*3,4-diacetoxy-3-(acetoxymethyl)butanoaldehyde* (*2,4-dinitrophenyl)hydrazone* (**9**). — A solution of **1** (871 mg, 5.00 mmol) and **2** (1162 mg, 10.0 mmol) in benzene (20 mL) was irradiated for 40 h as already described, and then evaporated; the residue was dissolved in methanol (20 mL), acetic acid (1 mL) was added, and the mixture was stirred for 7 h at room temperature. To the resulting mixture was added a solution of (2,4-dinitrophenyl)hydrazine (495 mg, 2.50 mmol) in *N,N*-dimethylformamide (10 mL), and the mixture was stirred for a further 20 h, evaporated, and the residue chromatographed on silica gel (80 mL), using benzene–ethyl acetate as the eluant. The eluate was collected in five fractions, each of which contained several materials (the first fraction is designated *f*1, and so on). Rechromatography of *f*1 (60 mg) on silica gel, with cyclohexane–ethyl acetate as the eluant, gave acetaldehyde (2,4-dinitrophenyl)hydrazone (**11**) (46 mg, 4% yield based on **1**). Rechromatography of *f*2 (88 mg) on silica gel, using benzene–cyclohexane–ethyl acetate as the eluant, gave the (2,4-dinitrophenyl)hydrazone (**12**) of **1** (65 mg, 4% yield), and **1** (7 mg, 1% recovery yield). Rechromatography of *f*3 (51 mg) on silica gel, using benzene–ethyl acetate as the eluant, gave **10** (29 mg, 1% yield), and **8** (18 mg).

Acetylation of *f*4 (1155 mg) with acetic anhydride (3 mL)–pyridine (3 mL) for 24 h, followed by evaporation *in vacuo*, and chromatographic separation on silica gel (benzene–ethyl acetate), gave a mixture of **6** plus **9** (582 mg), **6** (104 mg), and **8** (290 mg). Rechromatography of the mixture of **6** and **9** on silica gel (cyclohexane–ethyl acetate as the eluant) gave **6** (410 mg), a 3:17 mixture of **6** and **9** (46 mg), and **9** (100 mg). Rechromatography of *f*5 (106 mg) on silica gel (benzene–ethyl acetate) gave **5** (66 mg, 6% yield). These chromatographic separations gave, *in toto*, 521 mg (40% yield) of **6**, 308 mg (15%) of **8**, and 139 mg (6%) of **9**.

Compound **8**. This was obtained as yellow crystals, m.p. 114–114.5° (CH_2Cl_2–hexane); ν_{max}^{KBr} 3500, 3290, 1740, and 1725 cm^{-1}; n.m.r.: δ 10.99 (bs, 1 H, NH), 9.01 (d, 1 H, *J* 2.5 Hz), 8.22 (dd, 1 H, *J* 2.5 and 9.5 Hz), 7.83 (d, 1 H, *J* 9.5 Hz), 7.60 (t, 1 H, *J* 5.5 Hz, CH=N), 4.15 (s, 4 H, 2 CH_2OAc), 2.71 (d, 2 H, CH_2-CH), and 2.13 (s, 6 H, 2 CH_3CO).

Anal. Calc. for $C_{15}H_{18}N_4O_9$: C, 45.23; H, 4.56; N, 14.07. Found: C, 45.03; H, 4.47; N, 13.91.

Compound **9**. This was isolated as yellow crystals, m.p. 142.5–143° (CH_2Cl_2–hexane); ν_{max}^{KBr} 3280, 1750 (sh), and 1735 cm^{-1}; n.m.r.: δ 11.02 (bs, 1 H, NH), 9.00 (d, 1 H, *J* 2.5 Hz), 8.25 (dd, 1 H, *J* 2.5 and 9.5 Hz), 7.85 (d, 1 H, *J* 9.5 Hz), 7.55 (t,

1 H, *J* 5.5 Hz, CH=N), 4.47 (s, 4 H, 2 CH_2OAc), 3.09 (d, 2 H, CH_2-CH), 2.11 (s, 6 H, 2 CH_3CO), and 2.08 (s, 3 H, CH_3CO).

Anal. Calc. for $C_{17}H_{20}N_4O_{10}$: C, 46.37; H, 4.58; N, 12.72. Found: C, 46.33; H, 4.58; N, 12.72.

Compound **10**. This was obtained as yellow crystals, m.p. 116.5–117.5° (CH_2Cl_2–hexane); ν_{max}^{KBr} 3510, 3250, and 1735 cm^{-1}; n.m.r.: δ 11.43 (bs, 1 H, NH), 9.00 (d, 1 H, *J* 2.5 Hz), 8.23 (dd, 1 H, *J* 2.5 and 9.5 Hz), 7.85 (d, 1 H, *J* 9.5 Hz), 7.10 (t, 1 H, *J* 6.0 Hz, CH=N), 4.19 (s, 2 H, CH_2OAc), 4.16 (s, 2 H, CH_2OAc), 2.69 (d, 2 H, CH_2-CH), and 2.14 (s, 6 H, 2 CH_3CO).

Anal. Calc. for $C_{15}H_{18}N_4O_9$: C, 45.23; H, 4.56; N, 14.07. Found: C, 45.26; H, 4.40; N, 14.27.

Compound **11**. This was isolated as yellow plates, m.p. 159–162° (ethanol); lit.[11] m.p. 164°.

Compound **12**. This was obtained as orange needles, m.p. 79.5–80° (ethanol) [lit.[12] m.p. 86–88° (ethanol)]; ν_{max}^{KBr} 3300 and 1740 cm^{-1}; n.m.r.: δ 11.70 (bs, 1 H, NH), 9.00 (d, 1 H, *J* 2.5 Hz), 8.26 (dd, 1 H, *J* 2.5 and 9.5 Hz), 7.88 (d, 1 H, *J* 9.5 Hz), 4.88 (s, 2 H, CH_2OAc), 4.84 (s, 2 H, CH_2OAc), 2.22 (s, 3 H, CH_3CO), and 2.15 (s, 3 H, CH_3CO).

Anal. Calc. for $C_{13}H_{14}N_4O_8$: C, 44.07; H, 3.98; N, 15.81. Found: C, 43.95; H, 3.93; N, 15.86.

Attempted reaction of 1,3-diacetoxy-2-propanone (**1**) *with (trimethylsilyloxy)-ethylene* (**2**) *in the presence of titanium(IV) chloride.* — To a solution of **1** (871 mg, 5.00 mmol) and titanium(IV) chloride (0.60 mL, 5.5 mmol) in dry dichloromethane (20 mL) was added **2** (0.70 mL, 5.5 mmol), and the mixture was stirred for 1 day. T.l.c. of the resulting mixture then demonstrated that almost all of compound **1** remained unchanged, and therefore another portion of titanium(IV) chloride (0.60 mL) was added to the mixture, which was then stirred for 2 days; the mixture, which had become discolored (dark-brown), was treated with water (30 mL), and made neutral by addition of solid $NaHCO_3$ in small portions. A large volume of ethanol was added, and the salts that were precipitated were filtered off. The filtrate was evaporated *in vacuo*, and the residue was dissolved in dimethyl sulfoxide (20 mL); (2,4-dinitrophenyl)hydrazine (1.09 g, 5.5 mmol) and acetic acid (1 mL) were added, and the solution was stirred for 1 day, and evaporated, and the residue was chromatographed on silica gel, to give no hydrazone derivatives; the only compound isolated was 1,3-dinitrobenzene (0.46 g, 50% yield); the mechanism of its formation is not yet known.

ACKNOWLEDGMENT

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