acid by the method of Roth and Erlenmeyer.[18] 6-Methylquinoline-2-carboxylic acid[19] was prepared by a method similar to that described by Kaslow and Stayner[20] for the synthesis of 4-methylquinoline-2-carboxylic acid. 4-Methoxyquinoline-2-carboxylic acid[21] was prepared by the methylation of kynurenic acid with diazomethane. 2-Bromoquinoline-4-carboxylic acid[22] and 2-chloroquinoline-4-carboxylic acid[23] were prepared by the action of phosphorus halides on the 2-hydroxy acid.

pK_a Values.—The pK_a values were determined by potentiometric titration. pH Values were measured between 30 and 70% neutralization using a Beckman Expandomatic pH meter. The electrodes were standardized before each determination in aqueous buffers, and the standardization was checked following completion of the titration. A correction was applied to the pH values for the medium effect and the residual liquid-junction error. The value for this correction (0.18 pH unit) was obtained for 44.25% ethanol by interpolation using values given by Bates[5] for other aqueous ethanol solvents. A correction was also made for hydrogen ion activity. The temperature of the solutions was maintained at 25.0 + 0.1° by measuring the pH of the solutions in a jacketed beaker through which was pumped water from a constant-temperature bath. The average of values for six to nine points in one titration constituted one determination.

Registry No.—1, 93-10-7; 2, 879-65-2; 3, 15733-82-1; 4, 15733-83-2; 5, 15733-84-3; 6, 15733-85-4; 7, 6480-68-8; 8, 486-74-8; 9, 15733-87-6; 10, 5467-57-2; 11, 15733-89-8; quinoline, 91-22-5.

Acknowledgments.—We wish to thank Miss Susan Tatelbaum for the preparation of 8-nitroquinoline-2-carboxylic acid. Appreciation is expressed to the University of Pennsylvania and to the National Science Foundation for financial assistance to Charles W. Donaldson.

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The Reactions of β-Dicarbonyl Compounds with Tetrakis(dimethylamino)titanium

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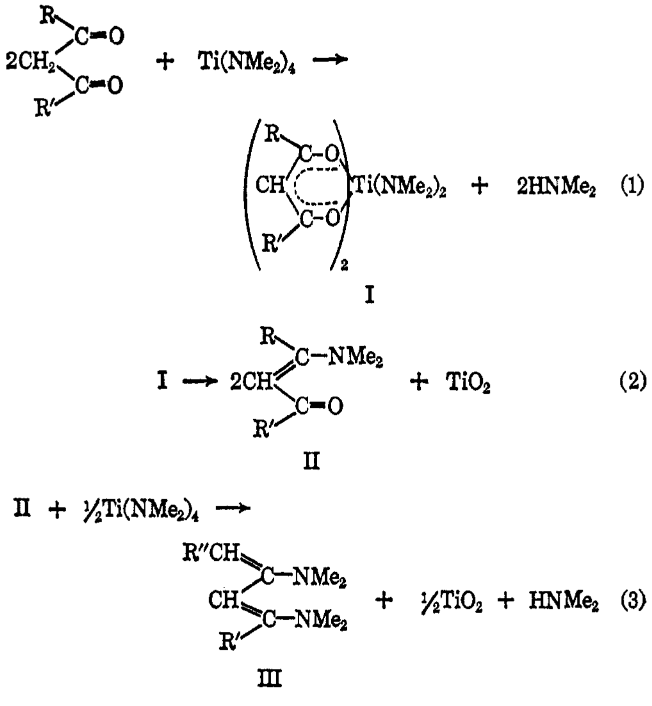
β-Dicarbonyl compounds ($RCOCH_2COR'$) have been found to react with tetrakis(dimethylamino)titanium to give complexes, enamine amides, enamine esters, ketenamines, and the previously unknown dienediamines and dienetriamines depending on the nature of the R and R′ groups.

The amination of carbonyl containing organic compounds by $B(NR_2)_3$, $P(NR_2)_3$, $As(NR_2)_3$, and $Ti(NR_2)_4$ has recently been the subject of several papers.[1-6] In the reactions with aldehydes, ketones, and carboxylic acids, the relative order of reactivity has been found to be $Ti(NR_2)_4 \gg As(NR_2)_3 > P(NR_2)_3$. $B(NR_2)_3$ and $P(NR_2)_3$ react with β-diketones and β-keto esters yielding enamino ketones and β-enamino esters or amides, respectively.[1,6] This paper presents the results of a study of the reactions of the much more reactive $Ti(NR_2)_4$ with some representative β-diamides, β-diesters, β-ketamides, β-keto esters, and β-diketones.

Results and Discussion

Tetrakis(dimethylamino)titanium reacts with β-dicarbonyl compounds according to eq 1, 2, and 3, where the nature of the products obtained depends upon the substituents R and R′ and the ratio of $Ti(NMe_2)_4$ to carbonyl compound. Reactions of all other aminating agents studied with β-dicarbonyl compounds stop at the enamine (II). However, with $Ti(NMe_2)_4$, two new classes of compounds, 1,3-diene-1,3-diamines (III) and 1,3-diene-1,1,3-triamines (III, R′ = NMe_2), can be formed.

N,N,N′,N′-Tetramethylmalonamide and dimethyl malonate both react with $Ti(NMe_2)_4$ to yield deep red complexes (I, R = R′ = NMe_2 and R = R′ = OMe, respectively). These complexes are analogous to the dihalo- and dialkoxybis(β-diketonato)titanium compounds,[7-11] and their structure and properties will presently be the subject of another paper.



Methyl acetoacetate and N,N-dimethylacetoacetamide react with $Ti[N(CH_3)_2]_4$ to yield methyl 3-(dimethylamino)crotonate (II, R = CH_3 and R′ = OCH_3)[12] and 3-(dimethylamino)-N,N-dimethylcroton-

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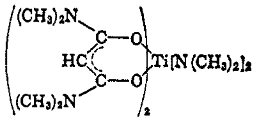
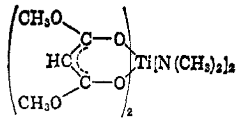
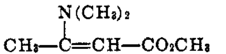
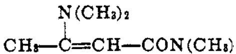
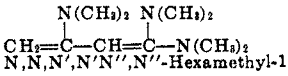
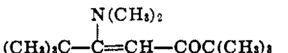
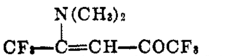
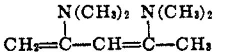
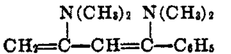
[12] *Cf.* the reactions of $P(NR_2)_3$ and $B(NR_2)_3$ with β-keto esters given in ref 1 and 6.

TABLE I

Compound (no.)	Yield,[a] %	Anal, %								Mol wt[b]	Bp (mm), °C	n^{25}_D	Nmr[c] (τ)	Ir, cm^{-1} [d]	
		Calcd				Found									
		C	H	N	Ti	C	H	N	Ti					$\gamma_{C=O}$	$\gamma_{C=C}$
 Bis(dimethylamino)bis(dimethylmalonato)titanium (1)	75	42.2	6.5	7.0	12.1	42.4	6.8	7.3	12.0	398 ± 1	87–89 (mp)		(s) 5.39, 6.40, 6.61 (bd)[d,e] (1:6:6)	1643	1614
 Bis(dimethylamino)bis(N,N,N',N'-tetramethylmalonamidato)titanium (2)	84	48.0	8.4	18.7	10.7	47.5	8.4	18.7	10.5	458 ± 10[l]	119–120 (mp)		(s) 5.74, 6.30 (bd), 7.30 (1:6:12)	1574	1539
 $CH_3-\overset{\overset{N(CH_3)_2}{\vert}}{C}=CH-CO_2CH_3$ Methyl 3-(dimethylamino)crotonate (3)	50	58.7	9.1	9.8		58.4	9.0	10.0		143	50 (0.15)	1.5250	(s) 5.06 (bd), 6.23, 7.55, 7.70 (1:3:3:6)	1694	1590
 $CH_3-\overset{\overset{N(CH_3)_2}{\vert}}{C}=CH-CON(CH_3)_2$ 3-(Dimethylamino)-N,N-dimethylcrotonamide (4)	51	61.5	10.2	18.4		61.9	9.9	18.1		156	94 (0.4)	1.5451	(s) 5.29, 7.18, 7.54, 7.57 (1:6:3:6)	1617	1577
 $CH_2=\overset{\overset{N(CH_3)_2}{\vert}}{C}-CH=\overset{\overset{N(CH_3)_2}{\vert}}{C}-N(CH_3)_2$ N,N,N',N'N'',N''-Hexamethyl-1,1,3-butadienetriamine (5)	77	65.6	11.5	22.9		65.1	11.8	22.9		183	43 (0.4)	1.5129	(d) 5.88, 6.02; (m) 6.27; (s) 7.37, 7.41, 7.54 (1:1:1:6:6:6)		1620
 $(CH_3)_3C-\overset{\overset{N(CH_3)_2}{\vert}}{C}=CH-COC(CH_3)_3$ 3-(Dimethylamino)-2,2,6,6-tetramethyl-3-hepten-5-one (6)	64	74.0	11.8	6.6		74.3	11.3	6.6		211	49 (0.2)	1.4917	(s) 4.31, 7.33, 8.76, 8.90 (1:6:9:9)	1645	1544
 $CF_3-\overset{\overset{N(CH_3)_2}{\vert}}{C}=CH-COCF_3$ 2-(Dimethylamino)-1,1,1,5,5,5-hexafluoro-2-penten-4-one (7)	75	35.7	3.0	6.0		35.4	3.1	6.4		235	48 (4)	1.4212	^{1}H (q) 4.22, J_{FH} = 0.5 cps, 7.57, J_{FH} = 0.8 cps (1:6) ^{19}F (heptet) 66.1 ppm, J_{FH} = 1.0 cps; (s) 77.6 ppm (1:1)[f]	1674	1588
 $CH_2=\overset{\overset{N(CH_3)_2}{\vert}}{C}-CH=\overset{\overset{N(CH_3)_2}{\vert}}{C}-CH_3$ N,N,N'N'-Tetramethyl-1,3-pentadiene-2,4-diamine (8)	70	70.1	11.7	18.2		69.9	11.4	18.2		154	55 (1.2)	1.5108	(s) 5.46 (bd); 6.28 (bd); (m) 6.42; (s) 7.40, 7.46; (d) 8.90 (1:1:1:6:6:3)[g]		1630
 $CH_2=\overset{\overset{N(CH_3)_2}{\vert}}{C}-CH=\overset{\overset{N(CH_3)_2}{\vert}}{C}-C_6H_5$ N,N,N',N'-Tetramethyl-1-phenyl-1,3-butadiene-1,3-diamine (9)	70	77.8	9.2	13.0		77.4	9.2	13.0		216	82 (0.3)	1.5653	(m) 2.36, 3.00; (m) 4.92, 6.20; (d) 6.23; (s) 7.48, 7.63 (5:1:1:1:6:6) (m) 2.36, 3.00; (d) 4.82; (s,bd) 5.90; (?)[h] 6.17; (s) 7.41, 7.47 (?)[i] (5:1:1:1:6:6)[j,k]		1615

[a] No special effort was made to optimize yields. [b] Molecular weights were determined by mass spectroscopy. [c] Benzene solvent, TMS internal standard except where otherwise stated. [d] PhCN solvent. In benzene solution the OMe and NMe_2 adsorption have approximately the same chemical shifts. [e] bd, unusually broad peak. [f] $CFCl_3$ as external standard. [g] Neat material. [h] Multiplicity uncertain. [i] Position uncertain. [j] Two isomers present in 4:1 ratio. [k] C_6D_6 solvent. [l] Cryoscopy in benzene.

amide (II, R = CH_3 and R' = NMe_2), respectively. Reaction of the crotonamide with excess $Ti[N(CH_3)_2]_4$ gives N,N,N',N',N'',N''-hexamethyl-1,1,3-butadienetriamine (III, R' = NMe_2 and R'' = H). The same product is obtained from methyl 3-(dimethylamino)crotonate, the reaction proceeding stepwise *via* the amide.

β-diketones which have no hydrogens on the α-carbon of the R or R' groups react with $Ti[N(CH_3)_2]_4$ to give enamino ketones. For example, dipivaloylmethane and hexafluoroacetylacetone react to form 3-(dimethylamino)-2,2,6,6-tetramethyl-3-hepten-5-one (II, R = R' = *t*-butyl) and 2-(dimethylamino)-1,1,1,5,5,5-hexafluoro-2-penten-4-one (II, R = R' = CF_3), respectively.

However, β-diketones with hydrogens on the α-carbon atom of either the R or R' groups react vigorously with $Ti[N(CH_3)_2]_4$ to give the previously unknown 1,3-diene-1,3-diamines in good yield. Acetylacetone and benzoylacetone form N,N,N',N'-tetramethyl-1,3-pentadiene-2,4-diamine[13] (II, R'' = H and R' = CH_3) and N,N,-N',N'-tetramethyl-1-phenyl-1,3-butadiene-1,3-diamine (III, R'' = H and R' = C_6H_5), respectively. Similar reactions were found to take place, on the nmr scale, with dimedone and 1-acetylcyclohexanone.

The physical and analytical properties of the compounds prepared are collected in Table I and are all consistent with the assigned structures. The $\gamma_{C=O}$ and $\gamma_{C=C}$ bands for the complexes were assigned after Behnke and Nakamoto.[14]

Addition of $Ti[N(CH_3)_2]_4$ to the β-dicarbonyl compounds always gave an intense red coloration indicating chelate formation which has been proposed as the first step in this type of reaction.[1] This color faded rapidly for the reactions of the titanium amide with methyl

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[13] The reaction of tetrakis(dimethylamino)titanium with ferric acetyl acetonate was also found to give N,N,N',N'-tetramethyl-1,3-pentadiene-2,4-diamine.

[14] G. T. Behnke and K. Nakamoto, *Inorg. Chem.*, **6**, 433 (1967).

acetoacetate, hexafluoroacetylacetone, and the β-diketones with hydrogen on the α-carbon of the R or R′ groups,[15] all of which reacted rapidly at ambient temperatures. However, for the other reactions which required heating under reflux for various lengths of time, the color persisted until the reaction neared its completion. Furthermore, for the slowest reaction, dipivaloylmethane with $Ti[N(CH_3)_2]_4$, the nmr spectrum showed a singlet at τ 4.0 and two multiplets in the t-butyl region, as expected for a β-diketone titanium complex,[7-11] which slowly decreased in intensity as the spectra of the product grew. Thus, the decomposition of the β-dicarbonyl–titanium complex is probably the rate-determining step of the reaction. The mechanism proposed is analogous to that outlined elsewhere[1,4] and will not be discussed further here.

In only one example studied was evidence for the formation of more than one geometric isomer obtained. The nmr spectrum of N,N,N′,N′-tetramethyl-1-phenyl-1,3-butadiene-1,3-diamine, as given in Table I, showed the presence of two isomers in the ratio 4:1. Certain of the peaks for the isomers present in low concentration were partially hidden leading to uncertainties in the multiplicity of one of the peaks and the chemical shift of another. The isomers are apparently present in their thermodynamic equilibrium concentrations since addition of a trace of acetic acid led to coalescence of the separate spectra into one set of broadened peaks and addition of strong base, $Ti[N(CH_3)_2]_4$, regenerated the original spectra with no change in relative concentration.

Experimental Section

Synthesis.—All the compounds were synthesized in an atmosphere of dry nitrogen. Analyses for C, H, N, and Ti were performed in the Physical Sciences Center, Central Research Department, Monsanto Co.

Bis(dimethylamino)bis(dimethylmalonato)titanium.—A solution of tetrakis(dimethylamino)titanium (2.24 g, 0.01 mol) in 20 ml of ether was added slowly, with stirring, to a solution of dimethyl malonate (2.64 g, 0.02 mol) in 20 ml of ether. After removal of the solvent deep red crystals were obtained which were recrystallized from pentane.

Bis(dimethylamino)bis(N,N,N′,N′-tetramethylmalonamidato)titanium.—A solution of tetrakis(dimethylamino)titanium (2.24 g, 0.01 mol) in 20 ml of ether was slowly added, with stirring, to a mixture of N,N,N′,N′-tetramethylmalonamide (3.16 g, 0.02 mol) in 20 ml of ether. After removal of the solvent, deep red crystals were obtained which were recrystallized from pentane.

Methyl 3-(Dimethylamino)crotonate.—A solution of tetrakis(dimethylamino)titanium (1.12 g, 0.005 mol) in 10 ml of ether was added dropwise, with vigorous stirring, to a solution of methyl acetoacetate (1.16 g, 0.01 mol) in 10 ml of ether. On addition of the titanium compound a deep red coloration was obtained which rapidly disappeared on stirring to leave an orange solution. After the addition was complete, stirring was continued for 2 hr and the reaction mixture was then left standing overnight. The titanium dioxide, which slowly separated out, was filtered off and the solvent was removed. Distillation of the remaining oil gave the colorless product.

3-(Dimethylamino)-N,N-dimethylcrotonamide.—A solution of tetrakis(dimethylamino)titanium (1.57 g, 0.007 mol) in 10 ml of ether was slowly added, with stirring, to a solution of N,N-dimethylacetoacetamide (1.61 g, 0.0125 mol) in 10 ml of ether and the resulting deep red solution was heated under reflux for 48 hr. The solvent was then removed and distillation of the remaining oil gave the pale yellow product. A small amount (10%) of N,N,N′,N′,N″,N″-hexamethyl-1,1,3-butadienetriamine was also isolated as a distillation forerun.

N,N,N′,N′,N″,N″-Hexamethyl-1,1,3-butadienetriamine.—A solution of tetrakis(dimethylamino)titanium (0.9 g, 0.004 mol) in 10 ml of ether was slowly added to a solution of 3-(dimethylamino)-N,N-dimethylcrotonamide (1.17 g, 0.0075 mol) in 10 ml of ether and the resulting deep red solution was heated under reflux for 96 hr. The solvent was then removed and distillation of the residue gave the colorless product.

3-(Dimethylamino)-2,2,6,6-tetramethyl-3-hepten-5-one.—A solution of tetrakis(dimethylamino)titanium (1.34 g, 0.006 mol) in 10 ml of ether was slowly added, with stirring, to a solution of dipivaloylmethane (1.84 g, 0.01 mol) in 10 ml of ether and the resulting deep red solution was heated under reflux for 5 days. The solvent was removed and distillation of the residue gave the pale yellow product.

2-(Dimethylamino)-1,1,1,5,5,5-hexafluoro-2-penten-4-one.—A solution of tetrakis(dimethylamino)titanium (1.2 g, 0.0054 mol) in 10 ml of ether was slowly added, with stirring, to a solution of hexafluoroacetylacetone (2.08 g, 0.01 mol) in 10 ml of ether and the resulting orange-red solution was left standing overnight. The white precipitate which formed was filtered off, the solvent was removed, and the residual oil was distilled to give the pale yellow product.

N,N,N′,N′-Tetramethyl-1,3-pentadiene-2,4-diamine.—A solution of tetrakis(dimethylamino)titanium (1.5 g, 0.0067 mol) in 10 ml of ether was slowly added, with stirring, to a solution of acetylacetone (0.6 g, 0.006 mol) in 10 ml of ether and the resulting deep red solution[15] was left standing for 12 hr. The precipitate of titanium dioxide, which slowly formed, was filtered off and the solvent was removed. Distillation of the remaining oil gave the colorless product.

N,N,N′,N′-Tetramethyl-1-phenyl-1,3-butadiene-1,3-diamine.—A solution of tetrakis(dimethylamino)titanium (1.2 g, 0.0053 mol) in 10 ml of ether was slowly added, with stirring, to a solution of 1-benzoylacetone (0.81 g, 0.005 mol) in 10 ml of ether and the resulting deep red solution[15] was left standing for 12 hr. The precipitate of titanium oxide, which slowly formed, was filtered off and the solvent was removed. Distillation of the remaining oil gave the colorless product.

Infrared Spectra.—A Beckman IR-4 was used and the spectra of the liquids were obtained using thin films and sodium chloride windows. The spectra of the complexes were obtained from Nujol mulls.

Nuclear Magnetic Resonance Spectra.—A Varian A-60 spectrometer was used for the nmr measurements. Chemical shifts are believed to be accurate to ±0.02 ppm and the coupling constants to ±0.2 cps. The ^{19}F magnetic resonance measurements were performed on a Varian A-56/60. Chemical shifts are believed to be accurate to ±0.1 ppm and coupling constants to ±0.2 cps.

Registry No.—1, 12239-98-4; 2, 12239-99-5; 3, 15895-69-9; 4, 15895-70-2; 5, 15895-71-3; 6, 15895-75-7; 7, 15895-72-4; 8, 15895-73-5; 9, 15895-74-6.

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[15] Although the initial deep red color was rapidly lost after the initial addition of β-diketone, the solution slowly darkened as the addition was continued, presumably owing to the formation of side products containing large chromophores.