Complex Metal–Nicotine Compounds

By Claude R. Smith

Received July 30, 1952

This work is a continuation of the efforts of this Laboratory to prepare a large number of derivatives and compounds of nicotine.[1,2] In one previous publication[3] 25 complex salts of nicotine, some involving acid dyes, were listed but not described. In another[4] the author described the preparation of 11 double sulfates. The present paper covers the preparation of 76 complex metal–nicotine compounds of two types—double salts and nicotinammino compounds.

Table I

Thiocyanates

No.	Compound[a]	Nicotine, % Calcd.	Nicotine, % Found	–CNS, % Calcd.	–CNS, % Found	Crystals
1	$ZnA_2 \cdot RN_2 \cdot HA$	40.2	40.2	43.2	42.9	Dimorphic, irregular or prisms
2	$CdA_2 \cdot 2(RN_2 \cdot HA)$	48.3	48.3	34.6	34.6	Irregular leaves
3	$CdA_2 \cdot 2RN_2$	58.6	59.7	21.0	21.3	Prisms (tricl.), often in rosettes
4	$CoA_2 \cdot 2(RN_2 \cdot HA)$	52.5	52.5	37.6	37.7	Red prisms (tricl.)
5	$NiA_2 \cdot 2(RN_2 \cdot HA)$	52.5	52.4	37.6	37.1	Blue-green prisms (tricl.)
6	$NiA_2 \cdot 3RN_2$	73.5	72.3	17.6	17.2	Brown, irregular
7	$MnA_2 \cdot 2(RN_2 \cdot HA)$	52.8	52.1	37.9	36.9	Prisms
8	$FeA_2 \cdot 2(RN_2 \cdot HA)$	52.8	52.4	37.8	37.7	Yellow prisms (tricl.)
9	$3AgA \cdot RN_2 \cdot HA$	22.5	22.6	(8.0)[b]	(8.0)[b]	Pink prismatic needles, m.p. 130–131°
10[c]	$CuA_2 \cdot 2(RN_2 \cdot HA)$	52.1	50.0	..	..	Irregular green
11[c]	$CuA \cdot RN_2 \cdot HA$	47.3	47.2	..	..	Irregular yellow
12[c]	$CuA \cdot RN_2$	57.1	55.6	..	..	Rod-like prisms
13[d]	$CrA_3 \cdot 1.3(RN_2) \cdot 4H_2O$	41.4	40.8	34.2	34.0	Purple, irregular
				Piperidine, %		
14	$CoA_2 \cdot 2(C_5H_{11}N \cdot HA)$	36.7	37.2	50.1	50.0	Deep-blue prisms

[a] A = –CNS; $RN_2 = C_{10}H_{14}N_2$. [b] Refers to –CNS combined with nicotine, determined by warming the compound in water acidified with nitric acid, cooling, and titrating. [c] No. 10, 11 and 12: calcd., Cu 10.2, 18.5 and 22.9, respectively; found, Cu, 10.9, 18.4 and 22.5, respectively. [d] Calcd., Cr, 10.2; found, Cr, 9.9.

Table II

Salicylates

No.	Compound[a]	Nicotine, % Calcd.	Nicotine, % Found	Salicylic acid, % Calcd.	Salicylic acid, % Found	Crystals
1	$CuA_2 \cdot 2(RN_2 \cdot HA)$	34.6	34.6	..	..	Purple prisms
2	$CuA_2 \cdot 2(RN_2 \cdot HA) \cdot H_2O$	34.3	34.3	56.7	57.1	Blue prisms
3	$CoA_2 \cdot 2(RN_2 \cdot HA) \cdot 2H_2O$	33.5	33.6	56.8	56.2	Pink plates, irregular
4	$MnA_2 \cdot 2(RN_2 \cdot HA) \cdot 2H_2O$	33.6	33.6	57.2	56.8	Irregular
5	$CdA_2 \cdot 2(RN_2 \cdot HA) \cdot 2H_2O$	31.7	31.5	54.4	54.4	Irregular
6	$ZnA_2 \cdot 2(RN_2 \cdot HA) \cdot 2H_2O$	33.3	33.4	56.7	56.4	Irregular
7	$NiA_2 \cdot 2(RN_2 \cdot HA) \cdot 2H_2O$	33.4	33.1	56.8	56.4	Irregular

[a] A = $–OOC(C_6H_4)OH$-*o*; $RN_2 = C_{10}H_{14}N_2$.

Table III

Picrates

No.	Compound[a]	Nicotine, % Calcd.	Nicotine, % Found	Picric acid, % Calcd.	Picric acid, % Found	H_2O, % Calcd.	Loss at 110°, % 15 min.	Loss at 110°, % 30 min.
1	$CoA_2 \cdot 2RN_2 \cdot 5H_2O$	34.9	34.9	48.9	48.3	9.7	9.8	9.8
2	$NiA_2 \cdot 2RN_2 \cdot 6H_2O$	34.3	34.1	48.4	48.9	11.4	11.4	11.4
3	$CdA_2 \cdot 2RN_2 \cdot 6H_2O$	32.4	32.4	45.8	46.1	10.8	7.6	7.9
4	$MgA_2 \cdot 2RN_2 \cdot 6H_2O$	35.5	35.4	50.2	51.1	11.8	11.5	12.7
5	$MnA_2 \cdot 2RN_2 \cdot 4H_2O$	35.7	35.7	50.5	51.1	7.3	7.3	7.9
6	$ZnA_2 \cdot 2RN_2$	38.3	38.3	54.2	54.7	..	..	..
7	$AlA_3 \cdot 3RN_2$	40.6	40.5	57.4	57.8	..	..	..
8	$FeA_3 \cdot 3RN_2$	39.7	39.7	56.0	56.2	..	..	..
9	$AgA \cdot RN_2$	32.6	33.3	46.0	45.8	..	..	..
10[b]	$CuA_2 \cdot 2(RN_2 \cdot HA)$	24.9	25.2	..	..	..	..	..
11	$ZnA_2 \cdot 2(RN_2 \cdot HA)$	24.8	24.3			..	..	..
12[c]	$AgA \cdot 2(RN_2 \cdot HA)$	29.0	29.1			..	..	..

[a] A = $–OC_6H_2(NO_2)_3$; $RN_2 = C_{10}H_{14}N_2$. [b] Calcd., Cu, 4.9; found, Cu, 5.1. [c] Calcd., Ag, 9.6; found, Ag, 9.0.

Double salts result from the combination of the metal and the nicotine salts of the same selected acid. Ammino compounds result when nicotine

---

[1] C. F. Woodward, A. Eisner and P. G. Haines, This Journal, **66**, 911 (1944); P. G. Haines, A. Eisner and C. F. Woodward, *ibid.*, **67**, 1258 (1945); P. G. Haines and A. Eisner, *ibid.*, **72**, 4618, 1719 (1950).

[2] C. P. Woodward, C. O. Badgett and J. J. Willaman, *Ind. Eng. Chem.*, **36**, 540, 544 (1944); U. S. Dept. Agric. E-725 (processed) (1947); *Arch. Biochem.*, **29**, 241 (1950).

[3] C. R. Smith, U. S. Dept. Agric. E-646 (processed) (1945).

[4] C. R. Smith, This Journal, **71**, 2844 (1949).

TABLE IV

o-BENZOYLBENZOATES

No.	Compound[a]	Nicotine, % Calcd.	Nicotine, % Found	HA, % Calcd.	HA, % Found	H_2O, % Calcd.	Loss at 110°, % 15 min.	Loss at 110°, % 30 min.
1	$CoA_2\cdot 2RN_2\cdot 6H_2O$	34.5	34.4	48.0	48.5	11.4	9.9	10.6
2	$NiA_2\cdot 2RN_2\cdot 6H_2O$	34.5	34.3	48.1	47.8	11.4	10.1	10.1
3	$MnA_2\cdot 2RN_2\cdot 6H_2O$	34.6	34.5	48.2	48.6	11.5	9.7	11.0
4	$CdA_2\cdot 2RN_2\cdot 6H_2O$	32.5	32.6	45.4	45.2	10.8	10.0	10.6
5	$ZnA_2\cdot 2RN_2\cdot 6H_2O$	34.2	34.0	47.7	48.3	11.4	8.8	9.9
6	$MgA_2\cdot 2RN_2\cdot 6H_2O$	35.8	35.9	49.9	49.8	11.9	11.8	13.6
7	$FeA_2\cdot 2RN_2\cdot 6H_2O$	34.6	34.4	48.2	48.4	11.5	9.4	9.9
8[b]	$CuA_2\cdot 2RN_2\cdot 5H_2O$	35.0	35.0	..	..	9.7	9.3	9.4
9[b]	$CuA_2\cdot 2RN_2\cdot 2C_2H_5OH$	34.8	34.8	..	..	(9.9)[c]	9.6	10.5
10[d]	$(AgA)_2\cdot RN_2$	19.6	20.6	..	..	..	..	..
11[b]	$CuA_2\cdot 2(RN_2\cdot HA)$	25.0	24.2	..	..	..	..	..

[a] $A = OOC\cdot C_6H_4(OC\cdot C_6H_5)$-*o*; $RN_2 = C_{10}H_{14}N_2$. [b] No. 8, 9 and 12: calcd., Cu, 6.8, 6.8 and 4.8, respectively; found, Cu, 6.8, 6.8 and 4.6, respectively. [c] Ethanol. [d] Calcd., Ag, 26.1; found, Ag, 26.0.

TABLE V

p-NITROBENZOATES

No.	Compound[a]	Nicotine, % Calcd.	Nicotine, % Found	HA, % Calcd.	HA, % Found	H_2O, % Calcd.	Loss at 110°, % 15 min.	Loss at 110°, % 30 min.
1	$CoA_2\cdot 2RN_2\cdot 4H_2O$	41.1	40.7	42.4	42.6	9.1	8.2	8.2
2	$CdA_2\cdot 2RN_2\cdot 4H_2O$	38.5	38.3	39.7	39.7	8.6	9.1	9.3
3	$MnA_2\cdot 2RN_2\cdot 4H_2O$	41.4	40.9	42.6	42.9	9.2	9.1	10.9
4	$CuA_2\cdot 2RN_2\cdot 2H_2O$	42.8	42.9	44.2	44.5	4.8	4.8	4.8
5	$NiA_2\cdot 2RN_2\cdot 2H_2O$	43.1	42.0	44.5	44.8	4.7	4.1	4.1
6[b]	$CuA_2\cdot 2RN_2\cdot 4HA$	23.4	23.3	..	..	...	...	

[a] $A = -OCC\cdot C_6H_4\cdot NO$-*p*; $RN_2 = C_{10}H_{14}N_2$. [b] No. 7: calcd., Cu, 4.6; found, Cu, 4.6.

TABLE VI

DIBASIC ACIDS

No.	Compound[a]	Base, % Calcd.	Base, % Found	Copper, % Calcd.	Copper, % Found	Crystals
1[b]	$CuC_2O_4\cdot Na_2C_2O_4\cdot 2H_2O$	..	..	19.8	19.6	Blue prismatic needles
2	$CuC_2O_4\cdot RN_2\cdot H_2C_2O_4$	40.1	39.3	15.7	15.7	Blue prisms (moncl.)
3	$CuC_2O_4\cdot RN_2\cdot H_2C_2O_4\cdot H_2O$	38.4	38.7	14.9	14.8	Prisms, round ends
4[c]	$2CoC_2O_4\cdot RN_2\cdot H_2C_2O_4\cdot 5H_2O$	25.5	24.7	..	..	......
5[d]	$2ZnC_2O_4\cdot RN_2\cdot H_2C_2O_4\cdot 5H_2O$	25.5	25.0	..	..	......
6	$CuPhth\cdot RN_2\cdot H_2Phth\cdot H_2O$	28.3	28.2	11.1	11.1	Green, irreg.
7	$CuPhth\cdot 2HN_3$	13.0	12.9	24.3	24.2	Blue prisms (tetrag.)
8	$CuCr_2O_7\cdot 2RN_2\cdot H_2Cr_2O_7$	39.5	39.3	7.7	7.6	Brown to orange, irreg.
9	$CdCr_2O_7\cdot 2RN_2\cdot H_2Cr_2O_7$	37.2	36.0	..	..	Salmon to brown
10	$Cu(OOC\cdot CH_2)_2\cdot RN_2$	47.4	42.9	19.6	18.0	Green cubes
11	$Cu(OOC\cdot CH_2)_2\cdot 2NH_3\cdot 2H_2O$	13.6	13.9	25.4	25.3	Purple prisms (tricl.)
12	$Cu(OOC\cdot CH_2)_2\cdot 2NH_3$	15.9	15.5	29.7	29.3	Blue prisms (tetrag.)
13	$Cu(OOC{=}CH)_2\cdot 2RN_2\cdot 10H_2O$	47.5	47.3	9.3	9.3	Blue prisms (tricl.)
14[e]	$ZnC_2O_4\cdot NH_3\cdot 3H_2O$	7.6	7.2	..	..	White prisms

[a] $RN_2 = C_{10}H_{14}N_2$; Phth = $-(OOC)_2C_6H_4$-*o*. [b] Calcd.: $H_2C_2O_4$, 78.4; H_2O, 24.0. Found: $H_2C_2O_4$, 79.0; H_2O loss at 110°, 22.6. [c] Calcd.: $H_2C_2O_4$, 42.5; H_2O, 14.1. Found: $H_2C_2O_4$, 42.8; H_2O loss at 110°, 13.7. [d] Calcd.: $H_2C_2O_4$, 42.5; H_2O, 14.1. Found: $H_2C_2O_4$, 42.5; H_2O loss at 110°, 14.0. [e] Calcd.: $H_2C_2O_4$, 39.2; H_2O, 24.0. Found: $H_2C_2O_4$, 39.0; H_2O loss at 110°, 22.6.

alkaloid reacts with a metal salt of the selected acid. The metals which made double salts were Ag, Cd, Co, Cu (-ous and -ic), Fe (-ous and -ic), Mn (-ous) and Ni (-ous). All of these, plus Al, Cr and Mg, formed ammino compounds. The acids successfully incorporated into double salts were benzoic, *o*-benzoylbenzoic, *p*-nitrobenzoic, chromic, hydrocyanic, oxalic, phthalic, picric, salicylic and thiocyanic. Those in ammino compounds were benzoic, *o*-benzoylbenzoic, *p*-nitrobenzoic, ferrocyanic, fumaric (but not maleic), hydrobromic, hydriodic, α-naphthoic, phthalic, picric, succinic and thiocyanic.

Univalent cations combined with univalent anions added only 1 mole of base, forming a mononicotinammino product. Bivalent cations combined with univalent anions formed dinicotinammines, and trivalent cations combined with univalent

TABLE VII

BENZOATES AND NAPHTHOATE

No.	Compound[a]	Nicotine, % Calcd.	Nicotine, % Found	Metal, % Calcd.	Metal, % Found	Crystals
1	$CuA_2\cdot 2(RN_2\cdot HA)$	37.1	35.9	7.3	7.5	Blue prisms
2	$CuA_2\cdot 2RN_2\cdot 2H_2O$	48.7	48.6	9.6	9.8	Blue prisms
3	$CuA_2\cdot RN_2$	34.4	34.0	13.6	13.4	Green hex. plates
4	$CoA_2\cdot 2(RN_2\cdot HA)$[b]	37.3	35.6	..	..	
5	$NiA_2 2(RN_2\cdot HA)$[c]	37.3	33.4	..	..	
6	$ZnA_2\cdot RN_2\cdot HA$	27.3	27.4	..	..	
7	$CdA_2\cdot 2RN_2$	47.7	46.2	..	..	Plates
8	$CuN_2\cdot 2RN_2$[d]	44.4	44.4	8.7	8.8	

[a] $A = -OOC\cdot C_6H_5$; $RN_2 = C_{10}H_{14}N_2$. [b] Calcd., $C_6H_5CO_2H$, 56.1; found, $C_6H_5CO_2H$, 53.4. [c] Calcd., $C_6H_5CO_2H$, 56.2; found, $C_6H_5CO_2H$, 54.3. [d] $N = -OOCC_{10}H_7$-α.

TABLE VIII

HALIDES, CYANIDES AND FERROCYANIDES

No.	Compound[a]	Nicotine, %		Copper, %		Crystals
		Calcd.	Found	Calcd.	Found	
1	$2CuCN \cdot RN_2 \cdot HCN$	44.0	43.0	34.5	34.2	Prisms (tricl.)
2	$CuI \cdot RN_2$	46.0	43.2	..	..	Hydrous, irregular
3[b]	$Ag_2 \cdot RN_2 \cdot H_2FeCy_62H_2O$	25.9	25.9			

[a] $RN_2 = C_{10}H_{14}N_2$. [b] Calcd., Ag, 34.2; found, Ag, 34.8.

anions formed trinicotinammines; nickelous trinicotinammino thiocyanate was an exception. Bivalent cations (principally limited to copper) combined with bivalent anions usually added 2 moles of ammonia or 1 mole of nicotine; the nicotine double salts usually contained only 1 mole of nicotine, but cupric dinicotine dichromate was an exception. The author prepared only two trinicotinammines of trivalent cations—the trinicotinammino picrates of aluminum and iron. Bivalent cations were often associated with 2 moles of nicotine and up to 6 moles of water.

In general, both types of salts were well crystallized, highly water-insoluble compounds of definite and repeatable composition. Many of them contained definite amounts of water of crystallization; in others this was indefinite or fluctuating. Usually they could be prepared by mixing normal solutions of the required salts in water or in water–ethanol, using the acetates of the desired metals and the sodium or ammonium salts of the desired anions. Manipulations had to be juggled in some cases to avoid the formation of metal hydroxides, or to produce the latter in finely dispersed and reactive form. Sometimes one listed compound was prepared from another, as in Table VI, no. 3 from no. 2; and in Table VII, 3 from 2. Usually the crystals formed immediately, sometimes after a few days at room temperature.

Many of the compounds fluoresced. Some of these were cuprous nicotine thiocyanate (Table I), the cadmium salts of nicotine salicylate (Table II) and thiocyanate, and the zinc salts of nicotine thiocyanate, salicylate and benzoate (Table VII).

In the tables, RN_2 is used as an abbreviation for nicotine, $C_{10}H_{14}N_2$, where R represents $C_{10}H_{14}$, obviously not a definite radical, and N_2 indicates possible chelation of two nitrogens.

EASTERN REGIONAL RESEARCH LABORATORY[5]
PHILADELPHIA 18, PENNA.

---

[5] One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture. Article not copyrighted.

Theory of the Variation of Bond Length with Bond Environment

BY RICHARD P. SMITH[1]

RECEIVED NOVEMBER 5, 1952

Recently a theory of the distribution of electronic charge in aliphatic organic molecules has been published.[2] This theory is particularly useful for calculating the variation of the moment of a C–X (X = halogen or hydrogen) bond with the environment of the bond. Concurrently with the development of this theory and its successful application to several problems, a number of C–X internuclear distances ("bond lengths") in substituted methanes have been accurately determined with the use of microwave spectroscopy. In this paper we propose to show that most of the bond length variations with environment which are observed may be related quantitatively to the bond moment variations calculated with inductive effect theory.

Our theory of bond length variation in saturated molecules is based on the model used in discussing charge distributions.[2] This model has a molecule consisting of touching spheres, each sphere representing an atom and having a radius equal to the covalent bond radius. Spread out over the surface of the sphere representing atom a is an amount of electronic charge equal to the "net charge," ϵ_a, which atom a carries. This net charge "sees" charge Z_a, the effective nuclear charge of atom a, given by

$$Z_a = Z_a^\circ + s_a(\epsilon_a/e) \qquad (1)$$

where e is the negative of the charge of an electron, Z_a° is the effective nuclear charge of atom a when it carries zero net charge, and s_a is 0.30 or 0.35 accordingly as a is or is not hydrogen. Equation (1) is an interpolation of one of Slater's screening rules.[2,3]

Let us now consider an equation holding for Slater approximate atomic orbitals,[3] namely

$$R_a = ((n_a^*)^2/Z_a)a_0 \qquad (2)$$

where a_0 = Bohr radius = 0.53 Å., n_a^* is the "effective quantum number" for atom a, and R_a is the distance from the nucleus for which the electronic density for the shell under consideration is a maximum, and may be considered to be the radius of the atom. From equation (2) we see that, for a given effective quantum number (electron shell), an increase in effective nuclear charge goes along with a decrease in effective radius, and *vice versa*. This may be pictured as a "pulling in" of the electron shell by the increased positive effective nuclear charge.

If we consider molecules from the atomic orbital point of view, which is essentially what we are doing when we use the charged sphere model under discussion, we may expect that equation (2) may have a degree of applicability to molecules; just what this degree is cannot be given a clear-cut theoretical answer, but it must be determined empirically. Let us make the following supposition, to be tested empirically. We suppose that equation (2), when coupled with equation (1), may satisfactorily be used for discussing the *variation* of the *effective radius* of an atom *in a*

---

[1] Junior Fellow, Harvard Society of Fellows, 1951–.

[2] R. P. Smith, T. Ree, J. L. Magee and H. Eyring, THIS JOURNAL, **73**, 2263 (1951).

[3] H. Eyring, J. Walter and G. E. Kimball, "Quantum Chemistry," John Wiley and Sons, Inc., New York, N. Y., 1944, pp. 162–163.