

suspension was filtered while hot to remove insoluble VII, and the filtrate concentrated to small volume by aspirating the solvent. After refrigerating for several hours, the crop of nearly white needles of 2-amino-4-nitrobenzenesulfonic acid (III) was collected and dried. Additional quantities of the acid were obtained by further concentrating and refrigerating the mother liquor. The total yield of the sulfonic acid (practically pure, as obtained), was 2.2 g. (70%). A similar hydrolysis of 2,4-dinitrobenzenesulfonyl chloride yielded the same product, but only in 40% yield; and from 2,4-dinitrobenzenesulfenamide only a 20% yield of III resulted. The analytical sample was prepared by repeated crystallization from water. The product decomposed at 305–310°.

Anal. Calcd. for $C_6H_8O_6N_2S$: neut. equiv. 218; C, 33.03; H, 2.77; N, 12.84. Found: neut. equiv. 213; C, 33.18; H, 2.77; N, 13.04.

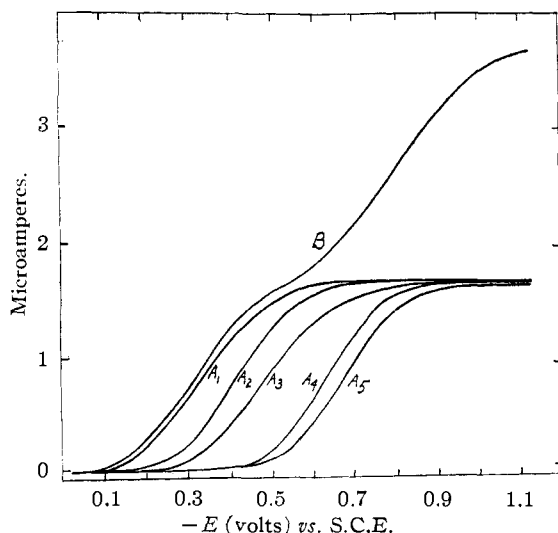


Fig. 1.—Polarographic reduction of 2-amino-4-nitrobenzenesulfonic acid, $10^{-3} M$ (curves A_1 to A_5 , at pH values 1.0, 2.8, 5.0, 8.1 and 9.0, respectively); and of 2,4-dinitrophenol (curve B), $10^{-3} M$, at pH 3.3.

The S-benzylthiuronium salt of the above acid crystallized from alcohol as orange-yellow needles, m.p. 136–137°.

Anal. Calcd. for $C_{14}H_{15}N_4O_6S_2$: C, 43.85; H, 3.94; N, 14.61. Found: C, 44.03; H, 4.24; N, 14.91.

2-Nitro-4-aminobenzenesulfonic acid was prepared from *m*-nitroaniline by the method of Nietzki and Helbach.⁹ The S-benzylthiuronium salt of this acid, rhombic olive crystals, melted at 177–180°.

Anal. Calcd. for $C_{14}H_{15}N_4O_6S_2$: C, 43.85; H, 3.94; N, 14.61. Found: C, 43.69; H, 3.77; N, 14.82.

Both 2-amino-4-nitrobenzenesulfonic acid (our product) as well as 4-amino-2-nitrobenzenesulfonic acid yielded 2,4,6-tribromo-3-nitroaniline, which was identical with the authentic product prepared by bromination of *m*-nitroaniline. The tribromo compound obtained from 2-amino-4-nitrobenzenesulfonic acid melted at 102°, and was analyzed.

Anal. Calcd. for $C_6H_3O_2N_2Br_3$: C, 19.22; H, 0.81. Found: C, 19.54; H, 0.83.

There was no depression in m.p. of a mixture of the above products with a sample of 2,4,6-tribromo-3-nitroaniline, prepared from *m*-nitroaniline.¹⁶ A typical indicator dye (similar to methyl orange) resulted when diazotized III was coupled with dimethylaniline.

Polarographic comparison of III with dinitrophenol (Fig. 1) showed only one nitro group in III. The reductions of 2-amino-4-nitrobenzenesulfonic acid were carried out at several pH values. Plotting the half-wave potentials for A_1 to A_5 (respectively, 0.32, 0.34, 0.42, 0.49 and 0.67 v.) against the corresponding pH gives a linear relation. The determinations were carried out with a manually operated Fisher Eledropode. The concentration of nitro compound in each case was $10^{-3} M$, and drop time was one drop per three seconds at $21 \pm 1^\circ$. Degassing was carried out for 15 minutes with nitrogen flowing at 1.5 ml. per sec. Potassium chloride (1 *N*) was used as the supporting electrolyte, and 0.01% of gelatin was used as maxima suppressor. Buffering between pH 1.2–3.2 was done with 0.2 *M* sodium hydroxide, regulated to the desired pH with hydrochloric acid; for pH 3.9–5.8, 0.2 *M* sodium acetate, regulated with acetic acid, was used; and pH 8.6–10.5 was obtained with 0.2 *M* sodium hydroxide, adjusted to the desired pH with ammonium chloride.

(16) E. Nolting and A. Collin, *Ber.*, **17**, 266 (1884).

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY AND LABORATORY FOR NUCLEAR SCIENCE AND ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

Hydrolysis of Alkyl Halides and Sulfonium Salts by Light and Heavy Water¹

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t-Butyl chloride hydrolyzes 40% faster in light water than in heavy water, whereas *t*-butyldimethylsulfonium ion and methyl halides hydrolyze at the same rate in the two media. The reaction of methyl halides with pyridine also is unaffected by this solvent change. The significance of these results is discussed.

One of the most powerful and subtle methods for studying reaction mechanisms involves measuring the difference in chemical reactivity between two isotopes of the same element, *i.e.*, the so-called "isotope effect." We have measured rates of some especially simple reactions in both light and heavy water (protium and deuterium oxides) to learn more about the role of the medium. The results are shown in Table I.

Methyl halides react at the same rate in the two solvents within experimental error, with either water or pyridine. On the other hand, *t*-butyl chloride hydrolyzes 40% faster in light than in

heavy water. This compound is much more dependent on electrophilic solvation in the rate-determining step and more discriminating between different electrophilic reagents than the methyl halides.² Although light and heavy water have

(2) Relative rates of solvolysis in 100% ethanol, 50% acetone–50% water and water are 1:10:27 for methyl bromide at 50° but 1:1900:340,000 for *t*-butyl chloride at 25°. The entropy of activation of hydrolysis of methyl chloride in water at 33° is –3 e.u. (E. A. Moelwyn-Hughes, *Proc. Roy. Soc. (London)*, **A196**, 540 (1949)) whereas our data give +9 e.u. for *t*-butyl chloride (and +20 e.u. for *t*-butyldimethylsulfonium ion) in 90% water–10% dioxane at 25°. The transition state for *t*-butyl chloride is thus much looser, *i.e.*, there is considerably more disruption of the carbon–halogen bond and of water–water hydrogen bonds at the transition state with *t*-butyl chloride than with methyl chloride.

(1) Supported in part by the programs of research of the Atomic Energy Commission and the National Institutes of Health.

TABLE I
RATES OF REACTION IN LIGHT AND HEAVY WATER^a

Halide	Nucleophilic reagent	Temp., °C.	Rate constant ^b in H ₂ O	Rate constant ^b in D ₂ O	k _{H₂O} /k _{D₂O} ^c
CH ₃ Cl	H ₂ O	99.8	10.5	9.8	1.1
		72.8	0.89	0.89	1.0
		52.5	0.17	0.17	1.0
CH ₃ I	H ₂ O	75.0	3.35	3.30	1.0
		52.5	0.32	0.32	1.0
CH ₃ I	C ₆ H ₅ N	72.8	17.1	16.7	1.0
(CH ₃) ₂ CCl	H ₂ O	25.2	1730	1260	1.4
		5.5	110	75	1.5
(CH ₃) ₂ CS [⊖]	H ₂ O	69.7	10.9	11.2	1.0
		(CH ₃) ₂ I [⊖]	52.5	0.797	0.797
(CH ₃) ₂ CS [⊖]	H ₂ O	69.7	11.2		
		(CH ₃) ₂ Cl [⊖]			

^a Medium is water for methyl halides, 90% water-10% dioxane for *t*-butyl compounds. ^b k_1 for hydrolysis in sec.⁻¹ $\times 10^6$ or k_2 with pyridine in M^{-1} sec.⁻¹ $\times 10^3$. ^c Estimated uncertainty for all ratios is ± 0.1 .

very similar physical properties,³ it appears that light water is a considerably better electrophilic reagent than heavy water.⁴

The hydrolysis of *t*-butyldimethylsulfonium ion involves splitting off uncharged dimethyl sulfide, which is much less in need of electrophilic solvation than the chloride ion from *t*-butyl chloride. Consequently identical rates were observed in light and heavy water.

Since the rate constants for these reactions vary over many powers of ten, it was not convenient to compare the values for each compound at one temperature. However, the difference in heat of activation for a given reaction in the two solvents is experimentally so small that ratios of rates in the two solvents may be compared without correcting for temperature differences.

Olivier found that cyclohexyl bromide hydrolyzed 20% faster in 50% light water-50% acetone than in 50% heavy water-50% acetone at 50° and 60°. The isotope effect with *t*-butyl chloride is not changed by changing the solvent from 90% water-10% dioxane to 20% water-80% dioxane.⁵

Lewis and Boozer⁷ and Shiner⁸ have shown that replacement of β -hydrogen atoms by deuterium in secondary and tertiary halides retards their rate of solvolysis, evidently because hyperconjugation⁷

(3) Boiling point, 100° (H₂O), 101.4° (D₂O); dielectric constant at 25°, 78.54, 78.25; refractive index, n_{20}^D 1.333, 1.328; viscosity at 25°, 8.9, 11.0; density at 25°, 0.9971, 1.1045; solubility of sodium chloride at 25° in g. per g. water, 0.36, 0.31; K_w at 25°, 1.0×10^{-14} , 1.6×10^{-15} ; cf. I. Kirshenbaum, "Heavy Water," McGraw-Hill Book Co., Inc., New York, N. Y., 1951.

(4) We define an "electrophilic" reagent as an electron-pair acceptor which tends to form a bond rapidly. The greater electrophilic reactivity of light water is caused primarily by the difference in zero-point vibrational energy (bending plus stretching) of protium and deuterium. This means that light water is more acidic and more ionized, and that water-water bonds are more easily broken and water-chloride (solvation) bonds more easily formed in light water than in heavy water. Since water-water and water-chloride bonds are mostly electrostatic, the large (up to sevenfold) isotope effects often observed when highly covalent hydrogen-carbon or hydrogen-oxygen bonds are broken are not expected.

(5) S. C. J. Oliveir, *Rec. trav. chim.*, **56**, 247 (1937).

(6) M. Allen, S. B. thesis, M.I.T., May, 1952.

(7) E. S. Lewis and C. E. Boozer, *THIS JOURNAL*, **74**, 6306 (1952); **76**, 791, 794 (1954).

(8) V. J. Shiner, Jr., *ibid.*, **75**, 2925 (1953); **76**, 1603 (1954).

or solvation⁸ of a β -hydrogen contributes more driving force than that of a β -deuterium. This is another example of a "secondary" isotope effect, one in which the isotope does not appear to be breaking its bond in the stoichiometric equation which is written for the rate-determining step, but must be undergoing bond-weakening nevertheless.

Experimental

All deuterium oxide used in these experiments was 99.5% obtained from the Stewart Oxygen Co.

t-Butyl chloride, b.p. 50.5°, was dissolved in peroxide-free dioxane to give an approximately 0.1 *M* stock solution. Runs were followed by the method of intermittent titration.⁹ Nine ml. of carbon dioxide-free water was placed in the cell and three drops of brom thymol blue added. A microburet containing sodium hydroxide was arranged so that the tip was just below the surface of the solution which was then cooled to 23.6°. One ml. of the stock solution of *t*-butyl chloride was then added as rapidly as possible, the heat of mixing raising the temperature to 25.2°, the temperature of the thermostat in which the tube was immersed. Intermittent additions of 0.175 *M* sodium hydroxide equivalent to 5-20% reaction were made with the buret and the time for neutralization noted after each addition. Since less than 1 ml. of titrant was added totally, the decrease in % dioxane in the medium (from 10 to 9.3%) is insignificant; also the half-life of a first-order reaction is independent of volume changes. Infinity points were taken after a period of fifty half-lives had elapsed. A similar procedure was used in carrying out the runs at 5.5°, the tube being immersed in a cyclohexane-bath held at its freezing point. In this reaction, excessive agitation of the solution by stirring or bubbling nitrogen through greatly accentuates errors due to volatility losses; consequently the solution was stirred only when base was added.

t-Butyldimethylsulfonium iodide was prepared by dissolving a mixture of *t*-butyl iodide and dimethyl sulfide in nitromethane and allowing it to stand for three days.¹⁰ The product which had crystallized out was filtered and washed with 95% alcohol until colorless. An approximately 0.01 *M* solution in 90% dioxane-10% water was prepared and kept in a refrigerator until used to prevent any appreciable hydrolysis of the compound.

Runs were carried out in small sealed ampoules each containing 1 ml. of the solution. At intervals ampoules were removed from the thermostat, quenched in ice-water and then broken into an Erlenmeyer flask containing 2 ml. of carbon dioxide-free water and two drops of brom thymol blue. The acid formed was determined using a 0.0012 *M* base solution. Infinity points were taken by letting three ampoules react at 80° for 24 hours.

As it was found difficult to isolate *t*-butyldimethylsulfonium chloride, an attempt was made to prepare the stock solution directly at a suitable concentration. *t*-Butyldimethylsulfonium iodide (0.125 g.) was mixed with 50 ml. of 90% water-10% dioxane mixture. About 5 g. of freshly prepared silver chloride was added to the solution and the mixture shaken for 15 hours in an ice-bath. The mixture was filtered and runs carried out in sealed ampoules as described above.

Methyl chloride was studied using saturated solutions prepared by bubbling the gas from a cylinder through either light or heavy water for several hours. The volatility of methyl chloride and the ease with which the solution is degassed calls for special methods of filling the tubes in which the reaction is carried out in order to ensure that each tube contains the same concentration of methyl chloride. To fill reaction tubes, we used a device consisting of an inverted buret, the tip of which was bent so that it pointed vertically downwards. The other end of the buret was joined through a two-way stopcock to two reservoirs: one holding mercury, the other, reaction solution. The stopcock was first turned so that reaction solution filled the buret; it was then reversed and mercury allowed to displace solution up to the zero mark. The buret stopcock was then closed. Two ml. of solution was expelled into each tube by

(9) P. D. Bartlett and C. G. Swain, *ibid.*, **71**, 1406 (1949); C. G. Swain, R. M. Esteve, Jr., and R. H. Jones, *ibid.*, **71**, 969 (1949).

(10) E. D. Hughes and C. K. Ingold, *J. Chem. Soc.*, 1575 (1933).

opening the stopcock and allowing the mercury level to rise by this amount. The solution was therefore open to the atmosphere only at the instant the tube was filled, then the tube was sealed immediately. Runs were carried out using approximately 0.1 *M* methyl chloride sealed in Pyrex tubes each containing 2 ml. At suitable times tubes were removed from the thermostat, quenched in ice-water, and broken into excess silver nitrate solution, and chloride determined by the Volhard method.

The hydrolysis of methyl iodide was studied in a similar manner except that stock solutions of the compound were prepared by weighing the ice-cold liquid into water.

The reaction of methyl iodide with pyridine was studied in an apparatus consisting of a bulb of about 40-ml. capacity joined at the top through a stopcock to a length of capillary bent so that the tip pointed downwards and at the bottom to a mercury reservoir which could be raised or lowered. The reaction solution was introduced into the bulb by filling both the bulb and capillary with mercury and then lowering the reservoir after the capillary had been inserted in the solution. The bulb could be filled quite rapidly by suction in this way. Pyridine and methyl iodide solutions

were prepared by weighing into 50-ml. volumetric flasks and making up to that mark with light or heavy water. The initial concentration of methyl iodide was assumed to equal the concentration of iodide found after ten or more half-lives had elapsed. The solutions to be used were warmed to the temperature at which the reaction was to be studied, mixed rapidly, and introduced into the reaction vessel, the bulb of which was immersed in a thermostat. The stopcock was closed and the mercury reservoir raised to prevent loss of methyl iodide during the course of the run. About 2.5 ml. was run out at intervals by opening the stopcock and 2 ml. immediately pipetted into 5 ml. of standard silver nitrate solution which was back-titrated with ammonium thiocyanate using ferric alum indicator. Although methyl iodide reacts with silver nitrate,¹¹ we have found that, under the conditions used, it is so slow that after 10 minutes the titration with thiocyanate has not altered to any appreciable extent.

(11) Moelwyn-Hughes, ref. 2.

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[CONTRIBUTION FROM THE B. F. GOODRICH RESEARCH CENTER]

Vinylidene Cyanide. VI. The Aluminum Chloride Catalyzed Reaction with *t*-Alkanes

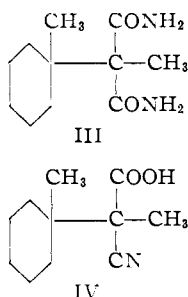
By J. C. WESTFAHL AND T. L. GRESHAM

RECEIVED JULY 19, 1954

Vinylidene cyanide reacts, in the presence of two equivalents of anhydrous aluminum chloride, with methylcyclohexane to give 1-methylcyclohexyl-(methyl)-malononitrile. The structure of this substance was proved by degradation and synthesis of a degradation product. Reaction with isopentane gave a product which has been assigned the structure *t*-amyl-(methyl)-malononitrile.

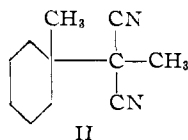
As a continuation of the study of the reactions of vinylidene cyanide (I),¹ the reaction of I with *t*-alkanes was studied. This paper reports the synthesis of two *t*-alkyl(methyl)-malononitriles and their structural study.

Addition of a solution of equimolar amounts of I and methylcyclohexane in *sym*-tetrachloroethane to a stirred suspension of two equivalents of anhydrous aluminum chloride in *sym*-tetrachloroethane gave a flocculent aluminum chloride complex. When the reaction mixture was stirred with an acidified ice and water mixture, hydrolysis of the complex occurred and a *sym*-tetrachloroethane solution of 1-methylcyclohexyl(methyl)-malononitrile (II) resulted. II, isolated in 42.8% yield, was a colorless liquid which was insoluble in aqueous base and which hydrolyzed with great difficulty. The major hydration and hydrolysis products are shown in Chart 1.



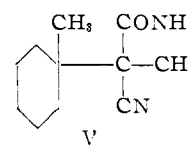
aq. alc. KOH
reflux 263 hr.

CHART 1



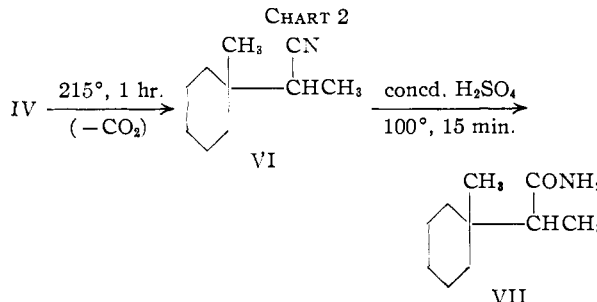
aq. NaOH
reflux 41.5 hr.

concd. H₂SO₄
90°, 10 min.



The solid acid, IV, was degraded further as

(1) Paper V in this series. THIS JOURNAL, 76, 1076 (1954).



shown in Chart 2. The solid amide, VII, was synthesized as shown in Chart 3.

The samples of VII prepared by degradation of II and by the synthesis shown in Chart 3 were shown to be identical by comparison of their infrared absorption spectra and by the melting point of a mixture.

Reaction of I with isopentane gave a 29.7% yield of *t*-amyl-(methyl)-malononitrile (XIV). Pure XIV