TOXIC ACTION OF ELECTROLYTES UPON FISHES

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Several investigations on the toxic action of various aqueous solutions upon plants have been made in this laboratory. It was thought desirable to carry out similar researches with animals; and, after a few preliminary experiments, fishes were found to be subjects upon which experiments of the kind contemplated could readily be performed.

The chief aim of this investigation is to compare various dilute aqueous solutions that conduct electricity by observing how long fishes can live in them. The following is an outline of the method of experimentation. A fish of small size—see definite data in the tables below—was placed in 500 cc of the solution to be tested, which was contained in a porcelain casserole of about 1 liter capacity, and the time required to produce death was carefully noted. Control experiments were conducted in each case, using distilled water, for of course a fish will die in so small an amount of water when the limited amount of dissolved oxygen that it contains has been largely consumed. In noting the time necessary for the fish to succumb, it was at first thought best to pronounce the animal dead when all motion had ceased. This was found to be impracticable, however, for owing to slight muscular contraction that in some cases continued for an appreciable time, the time at which death occurred would not be sufficiently sharply defined. When a fish is placed in a toxic solution, the phenomena observed vary somewhat with the nature of the solution; generally, however, the fish moves about in a lively manner, which movements may in some cases culminate in attempts to jump out of the dish.¹ After a time the

¹ To prevent the fish from getting out of the dish, a glass plate was placed over the casserole in such cases. This plate did not fit the dish closely, however, and so did not entirely prevent the circulation of air beneath it.

movements of the fish become less pronounced; it finally loses control of its motions, and turns over on its back. The latter phenomena occurs suddenly, and though the fish generally continues to move somewhat after its ventral side has turned up, it never again regains control of its motions and the latter soon cease entirely. Because the time at which the fish turns over on its back is so well defined, it was taken in each case as the time at which death occurred. In the tables given below, then, the figures in the column headed "time required to produce death" really indicate the time that elapsed from the instant that the fish was placed in the solution to the moment when its ventral side turned upwards. The post-mortem appearances of the specimens killed in various solutions are of interest and will consequently be given below in each case. After death had occurred, the length and also the weight of each fish was ascertained, the former to about 1 mm and the latter to within 0.01 gram. These data are included in the tables that follow. The experiments were conducted at room temperature, between 18° and 20° C.

Three different species of fish were used in the experiments, viz.: —rock-bass (*ambloplites rupestris*), the common shiner, also called dace or redbfin (*n. megalop. refinesque*), and brook-trout (*salvelinus fontinalis*). A few tests were also made with the ordinary yellow perch (*perca flavescens*). All the specimens except the brook-trout were caught in Lake Mendota¹ near the shore. The investigations were made during the months of October and November, and when in the latter month cold weather came and the fishes sought deeper water, it seemed at first that no further tests could be made at that time. However, through the kindness of Mr. James Nevin, to whom we feel especially indebted, some very fine specimens of brook-trout were obtained from the Wisconsin State Fish Hatcheries, located near Madison. The fishes were of as nearly the same weight and length as could very well be obtained in any quantity, the extreme variations (leaving the perch out of consideration) being 0.5 to

¹ At Madison, Wisconsin.

5 grams, and 25 to 102 mm. They were all of the spring's hatch and were from four to six months old. During the night they were kept in a large perforated pail suspended in the lake, and during the day when they were wanted for experimentation, they were kept near at hand in an aquarium through which coursed a continuous stream of fresh lake water. The vitality of the fishes was thus impaired as little as possible during the time they were held in captivity. Moreover, the experiments were conducted as soon as possible after the fish were caught, usually on the same day. As the fishes are all of well known species, a detailed description of them may here be omitted.

The experimental results are given in Tables I. to IV., which are self-explanatory. The strengths of the solutions are indicated in each case in terms of equivalent normal solutions.

Dilute solutions of hydrochloric, nitric, and sulphuric acids, were tested with rock-bass. The results obtained are presented in Table I.

TABLE I
Rock-bass (*amblo-plites rupestris*)

Length	Weight	Solutions	Time required to produce death
32 mm	0.55 gram	n/100 HCl	6 min
51 "	3.00 "	" "	7 " 30 sec
25 "	0.85 "	" "	6 "
Aver. 36 "	1.46 "		6 " 30 "
32 "	1.30 "	n/100 HNO ₃	6 " 30 "
45 "	2.30 "	" "	7 "
51 "	2.30 "	" "	7 "
Aver. 43 "	1.96 "		6 " 50 "
32 "	0.55 "	n/100 H ₂ SO ₄	7 "
32 "	0.52 "	" "	6 "
45 "	1.94 "	" "	9 "
Aver. 36 "	1.00 "		7 " 20 "

Length	Weight	Solutions	Time required to produce death
Aver. 32 mm	1.47 gram	$n/250$ HCl	9 min
32 "	1.32 "	" "	8 " 30 sec
32 "	1.24 "	" "	9 "
Aver. 32 "	1.34 "		8 " 50 "
32 "	1.64 "	$n/250$ HNO ₃	9 " 30 "
32 "	1.60 "	" "	9 "
32 "	1.34 "	" "	8 " 30 "
Aver. 32 "	1.53 "		9 "
32 "	1.14 "	$n/250$ H ₂ SO ₄	9 " 30 "
32 "	1.24 "	" "	9 " 30 "
32 "	1.40 "	" "	10 " 30 "
Aver. 32 "	1.26 "		9 " 50 "
38 "	1.17 "	$n/500$ HCl	12 "
38 "	1.55 "	" "	11 "
38 "	1.20 "	" "	11 "
Aver. 38 "	1.27 "		11 " 20 "
32 "	1.15 "	$n/500$ HNO ₃	12 "
38 "	1.45 "	" "	12 "
32 "	1.25 "	" "	13 "
Aver. 34 "	1.28 "		12 " 20 "
38 "	1.32 "	$n/500$ H ₂ SO ₄	14 " 30 "
38 "	1.27 "	" "	13 "
38 "	0.85 "	" "	14 "
Aver. 38 "	1.14 "		13 " 50 "
32 "	1.45 "	$n/1000$ HCl	18 " 30 "
45 "	2.10 "	" "	20 "
32 "	1.55 "	" "	21 "
Aver. 36 "	1.70 "		19 " 50 "

Length	Weight	Solutions	Time required to produce death
38 mm	1.87 gram	$n/1000$ HNO_3	23 min 30 sec
45 "	1.50 "	" "	20 "
38 "	1.85 "	" "	21 "
Aver. 40 "	1.77 "		21 " 30 "
38 "	1.70 "	$n/1000$ H_2SO_4	22 " 30 "
51 "	2.65 "	" "	25 "
51 "	2.30 "	" "	27 "
Aver. 47 "	2.22 "		24 " 50 "
38 "	2.20 "	$n/1500$ HCl	47 " 30 "
38 "	2.15 "	" HNO_3	47 "
38 "	2.30 "	" H_2SO_4	49 "
38 "	1.87 "	distilled water	6 hrs 40 min

It will be observed that $n/100$ is the strongest solution of the mineral acids given in the table. In a normal solution of any of these acids or of caustic potash a fish does not survive longer than five to ten seconds, while even in a $n/10$ solution, death occurs in less than a minute, so that these relatively strong solutions could not be used to obtain accurate measurements. Hydrochloric, nitric, and sulphuric acid solutions stronger than $n/500$ cause blood to ooze from the gills of the fish. The more concentrated the solution, the more pronounced the hemorrhage. The acid evidently destroys the delicate protective tissues and lays the blood vessels bare. It is interesting to notice that solutions that cause no hemorrhage also have but a very faint sour taste, the limit at which the sense of taste can still experience sourness being at about $n/800$. The gills change from their beautiful maroon to a dark brown, and finally to a dirty gray color, owing to coagulation of blood. There can be little doubt that death occurs because of the destruction of the breathing apparatus of the animal. The general appearance of the fish after death is changed but little. Some of the mucus

has been removed from the scales; the mouth is open; the color remains about the same.

An inspection of the results shows that a slight difference in the weight of a fish makes but little difference in the time that it is able to survive in the solution; this is also shown by the results of the other tables given below. It is, of course, not to be expected that two fishes of the same species will have exactly the same vitality or resisting power simply because they happen to be of the same length and weight; individuality does come in as a factor in nearly all biological specimens to a certain extent.

The results in Table I. indicate that HCl and HNO₃ have nearly the same destructive effect, the toxic action apparently being a little stronger in the case of the former acid. Sulphuric acid is a little less virulent in its action than the other two acids. This appears even in the $n/1500$ solution, the weakest one tested. It is well to bear in mind that the toxic action of these acids upon rock-bass is in about the same order as it is upon bacteria and higher plants. The nature of the action of these three acids was, furthermore, alike as far as was ascertained from the behavior of the fishes in the solutions and from the post-mortem examinations. The action of the acids must therefore be ascribed to that which they have in common, namely their replaceable hydrogen. As far as the results in Table I. are concerned, it may of course be held with propriety that they harmonize with the theory of electrolytic dissociation, namely, that it is the hydrogen ions that kill the fish. The character of these particular results would hardly warrant an attempt to make a sharp quantitative comparison between the toxic effect of these acids and their degree of hydrogen dissociation. Unfortunately, a number of solutions of acid sodium salts have not yet been tested with fishes, as they have with plants¹ and by means of the sense of taste.² It is contemplated to make such tests when it is again possible to obtain the fishes necessary for the work. It is extremely likely that such tests will show (as they have done in the case of plants and taste) that the assumption that the observed toxic effect is caused by so-called hydrogen ions is not tenable.

¹ Kahlenberg and Austin. *Jour. Phys. Chem.* **4**, 553 (1900).

² Kahlenberg. *Ibid.* **4**, 33, 533 (1900).

Table II. gives the results obtained with shiners. It will be observed that hydrochloric, nitric and sulphuric acids were tested with this species, and that in addition, caustic potash, common salt, and the nitrate and sulphate of silver were used.

TABLE II
Shiner (*n. megalop rafinesque*)

Length	Weight	Solution	Time required to produce death	
51 mm	1.52 gram	<i>n</i> /100 HCl	20 sec	
38 "	1.10 "	<i>n</i> /100 HNO ₃	15 "	
32 "	0.50 "	<i>n</i> /100 H ₂ SO ₄	20 "	
51 "	1.95 "	<i>n</i> /250 HCl	45 "	
51 "	1.95 "	" "	45 "	
64 "	2.35 "	" "	1 min 15 sec	
Aver. 55 "	2.08 "		55 "	
38 "	1.55 "	<i>n</i> /250 HNO ₃	1 "	30 "
51 "	1.55 "	" "	1 "	20 "
45 "	1.15 "	" "	1 "	20 "
Aver. 33 "	1.38 "		1 "	23 "
38 "	0.85 "	<i>n</i> /250 H ₂ SO ₄	2 "	
38 "	1.00 "	" "	2 "	15 "
51 "	0.95 "	" "	2 "	10 "
Aver. 42 "	0.93 "		2 "	8 "
38 "	0.75 "	<i>n</i> /500 HCl	3 "	
38 "	0.70 "	" "	2 "	
38 "	0.70 "	" "	2 "	
Aver. 38 "	0.72 "		2 "	20 "
38 "	0.75 "	<i>n</i> /500 HNO ₃	2 "	
38 "	0.85 "	" "	2 "	15 "
38 "	1.05 "	" "	3 "	5 "
Aver. 38 "	0.88 "		2 "	26 "

Length	Weight	Solution	Time required to produce death
45 mm	0.65 gram	$n/500 \text{ H}_2\text{SO}_4$	3 min
38 "	0.95 "	" "	4 " 30 sec
38 "	1.15 "	" "	4 " 45 "
Aver. 40 "	0.92 "		4 " 5 "
38 "	0.95 "	$n/1000 \text{ HCl}$	5 "
38 "	0.95 "	" "	4 "
64 "	2.65 "	" "	4 "
Aver. 47 "	1.30 "		4 " 40 "
51 "	1.45 "	$n/1000 \text{ HNO}_3$	5 "
51 "	1.25 "	" "	4 "
51 "	1.35 "	" "	4 "
Aver. 51 "	1.35 "		4 " 20 "
38 "	0.90 "	$n/1000 \text{ H}_2\text{SO}_4$	6 "
38 "	1.05 "	" "	6 "
45 "	1.15 "	" "	6 " 30 "
Aver. 40 "	1.03 "		6 " 10 "
76 "	3.25 "	$n/2000 \text{ HNO}_3$	27 "
38 "	1.05 "	distilled water	6 hrs 10 min
38 "	1.75 "	$n/10 \text{ KOH}$	25 sec
51 "	2.10 "	" "	35 "
51 "	2.05 "	" "	30 "
Aver. 47 "	1.96 "		30 "
51 "	2.15 "	$n/100 \text{ KOH}$	1 min 10 sec
76 "	2.95 "	" "	1 " 25 "
38 "	1.75 "	" "	1 " 16 "
Aver. 55 "	2.28 "		1 " 16 "
38 "	1.65 "	$n/500 \text{ KOH}$	1 " 40 "
51 "	2.15 "	" "	1 " 45 "
76 "	3.25 "	" "	1 " 42 "
Aver. 55 "	2.31 "		1 " 42 "

Length	Weight	Solution	Time required to produce death	
51 mm	2.05 gram	$n/1000$ KOH	2 min	10 sec
64 "	2.55 "	" "	2 "	30 "
51 "	1.95 "	" "	2 "	15 "
Aver. 55 "	2.18 "		2 "	18 "
38 "	1.45 "	$n/2000$ KOH	4 "	30 "
51 "	1.85 "	$n/1$ NaCl	1 "	10 "
38 "	1.35 "	" "	1 "	25 "
38 "	1.45 "	" "	1 "	25 "
Aver. 42 "	1.55 "		1 "	20 "
38 "	1.65 "	$n/2$ NaCl	3 "	40 "
51 "	2.10 "	" "	4 "	
38 "	1.55 "	" "	3 "	45 "
Aver. 42 "	1.76 "		3 "	50 "
76 "	3.05 "	$n/4$ NaCl	40 "	
64 "	2.45 "	" "	35 "	
Aver. 70 "	2.75 "		37 "	30 "
25 "	0.60 "	$n/10000$ AgNO ₃	2 "	50 "
38 "	1.45 "	" "	2 "	45 "
25 "	0.70 "	" "	2 "	50 "
Aver. 29 "	0.92 "		2 "	47 "
64 "	2.55 "	$n/10000$ Ag ₂ SO ₄	2 "	55 "
32 "	1.25 "	" "	2 "	45 "
32 "	1.15 "	" "	2 "	50 "
Aver. 53 "	1.65 "		2 "	50 "
76 "	2.95 "	$n/20000$ AgNO ₃	4 "	50 "
38 "	1.45 "	" "	4 "	25 "
38 "	1.75 "	" "	4 "	50 "
Aver. 51 "	2.05 "		4 "	41 "

Length	Weight	Solution	Time required to produce death
38 mm	1.55 gram	$n/20000 \text{ Ag}_2\text{SO}_4$	4 min 50 sec
38 "	1.60 "	" "	4 " 25 "
38 "	1.45 "	" "	5 " 25 "
Aver. 38 "	1.53 "		4 " 53 "
38 "	1.70 "	$n/50000 \text{ AgNO}_3$	5 " 20 "
38 "	1.75 "	" "	5 " 20 "
38 "	1.65 "	" "	6 " 30 "
Aver. 38 "	1.70 "		5 " 43 "
32 "	1.15 "	$n/50000 \text{ Ag}_2\text{SO}_4$	5 " 15 "
51 "	2.10 "	" "	5 " 45 "
51 "	2.20 "	" "	5 " 45 "
Aver. 44 "	1.81 "		5 " 35 "
38 "	1.65 "	$n/100000 \text{ AgNO}_3$	8 " 30 "
51 "	2.05 "	" "	9 " 20 "
51 "	2.10 "	" "	9 " 5 "
Aver. 47 "	1.93 "		8 " 58 "
51 "	1.95 "	$n/100000 \text{ Ag}_2\text{SO}_4$	9 " 25 "
38 "	1.55 "	" "	8 " 45 "
64 "	2.85 "	" "	9 " 25 "
Aver. 51 "	2.11 "		9 " 11 "

A comparison of the results of Table II. with the corresponding ones of Table I. shows that shiners succumb much more readily to the action of acid solutions than do rock-bass. It is well to note in this connection that both species live about the same length of time in distilled water—see Tables I. and II.—as do also brook-trout and perch—see Tables II. and IV. The shiner is a much softer fish than the bass. The membranes of the former are much more delicate and more readily attacked by acids, which is evident from the more profuse hemorrhage from the gills in corresponding solutions.

Table II. shows that in $n/100$ solutions, death occurred five seconds sooner in HNO_3 than in HCl and H_2SO_4 , the time being twenty seconds for each of the latter acids. It will be observed, however, that the specimen placed in HNO_3 was only one-third as heavy as that introduced into HCl . More tests with $n/100$ acids were not made because the number of fishes at hand was limited, and because death occurred so quickly as to make errors in estimating the time relatively great. The results in the case of the solutions weaker than $n/100$ are much more reliable. It will be noted that in $n/250$ solution of HNO_3 , shiner survives for 83 seconds, while in $n/250$ HCl death occurs after 55 seconds, and this in spite of the fact that the specimens in HNO_3 were not so large as those placed in the HCl . Again, in $n/250$ H_2SO_4 shiner survives for 128 seconds; to be sure the specimens used in this acid were somewhat lighter and consequently probably somewhat less resistant than those used in HCl and HNO_3 . In $n/500$ solutions HCl and HNO_3 show about the same toxic power, the time being 140 and 146 seconds respectively; $n/500$ H_2SO_4 , however, permits the fish to live for 245 seconds. In the $n/1000$ solutions HCl and HNO_3 again show the same toxic action, while H_2SO_4 still lags behind, the time for the latter being 370 seconds, while for the former two acids it is 280 and 260 seconds, respectively. Here again, then, as in the case of rock-bass, HCl and HNO_3 exert approximately the same toxic effect; but H_2SO_4 is relatively much weaker in its action than in the previous case. Indeed the action of H_2SO_4 is so weak as compared with that of HCl and HNO_3 , that the assumption that the effect is due to hydrogen ions cannot be held here, for in dilute solutions like $n/1000$ HCl and HNO_3 are practically completely dissociated (if the theory of electrolytic dissociation be assumed) and the same is almost true of H_2SO_4 — compare the results of Kohlrausch's conductivity measurements.¹

It will be observed that a $n/100$ KOH solution is less destructive than a $n/100$ of the strong mineral acids, but a $n/500$ KOH solution is much more toxic than $n/500$ acid, the fish sur-

¹ See Ostwald. Lehrbuch d. Allgem. Chemie, II., 2^{te} Auflage.

viving only 76 seconds in the former, but 140 seconds in the latter. In the $n/1000$ KOH again, the specimens survived but 138 seconds, while in the equivalent solution of HCl they live double that length of time. On the basis of the dissociation theory the action of KOH must be ascribed to the OH ions. The effect that the K ions would have at these dilutions is exceedingly slight, as any one may easily assure himself by placing a fish in a KCl solution of equivalent strength. Again, KOH solutions must be assumed to be fully as highly dissociated as HCl solutions of equivalent strength. It is, therefore, difficult to explain, on the basis of the dissociation theory, why KOH solutions change their toxicity so slightly on dilution as compared with equivalent HCl solutions. Death is no doubt caused by the caustic action of the potash on the membranes of the fish, especially on the membranes of the gills. Hemorrhages occurred in the $n/10$ and $n/100$ solutions, the blood being rapidly coagulated in thick clots. The fish acquired a glossy appearance, simulating in some cases a metallic luster. A fluid of the consistency of glycerine dropped from the dead fish when lifted from the solution. The eyes seemed not affected. The mouth was partly open; the gill chambers were relaxed; and the gills were strongly attacked. Bleeding occurred in $n/500$ and $n/1000$ solutions; it was slight, however, and the blood was soon coagulated.

In a $n/10$ NaCl solution, a shiner survives for several hours. It will be seen from the table that $n/1$, $n/2$, and $n/4$ solutions were used. A $n/1$ solution of NaCl kills the shiner in about the same time that a $n/250$ solution of HNO_3 does. A $n/2$ solution of NaCl is, however, considerably less toxic than a $n/500$ HNO_3 solution, while $n/4$ NaCl is less harmful than $n/2000$ HNO_3 . Shiners killed in NaCl solutions remain normal in appearance. Hemorrhages do not occur; the gills retain their normal appearance; the mouth is closed, but not tightly.

The tremendous toxic power of the solutions of the nitrate and sulphate of silver as compared with the other solutions tested is at once evident from the table. It further appears that the sulphate and nitrate of silver have about the same toxic action;

that is, of course, readily ascribed to that which they have in common, namely, their silver content. In terms of the dissociation theory it is the Ag ion that here exerts the toxic effect, since these salts are both practically completely dissociated at these high dilutions (see table) and since the anions are practically harmless at such high dilutions. Fishes killed in these silver solutions assumed a pinkish hue. The mouth was closed. Bleeding did not occur. The gill chambers were tightly closed and the gills were corroded, being of a dirty gray appearance. In solutions stronger than $n/1000$ the specimens were killed very quickly, so that no very accurate measurements of the time that they survive could be made.

Table III. now follows, giving the results obtained with brook-trout. It will be observed that a larger variety of solutions was tested with this species.

TABLE III
Brook-trout (*salvelinus fontinalis*)

Length	Weight	Solution	Time required to produce death
51 mm	2.35 gram	$n/100$ HCl	55 sec
76 "	2.30 "	$n/1000$ HCl	8 min
64 "	2.85 "	distilled water	7 hrs 20 min
89 "	4.10 "	$n/50$ $\text{CH}_3\text{CO.OH}$	3 min 25 sec
38 "	1.90 "	" "	3 " 25 "
Aver. 64 "	3.00 "		3 " 25 "
38 "	1.85 "	$n/100$ $\text{CH}_3\text{CO.OH}$	12 " 35 "
38 "	1.75 "	" "	11 " 46 "
Aver. 38 "	1.80 "		12 " 10 "
51 "	2.30 "	$n/1000$ $\text{CH}_3\text{CO.OH}$	36 "
64 "	2.75 "	$n/10$ HF	40 "
76 "	3.12 "	" "	40 "
Aver. 70 "	2.93 "		40 "

Length	Weight	Solution	Time required to produce death
76 mm	3.26 gram	$n/100$ HF	4 min 15 sec
64 "	2.84 "	" "	3 " 50 "
Aver. 70 "	3.05 "		4 " 2 "
76 "	3.35 "	$n/500$ HF	15 "
89 "	3.86 "	" "	13 " 30 "
Aver. 83 "	3.60 "		14 " 15 "
76 "	3.36 "	$n/10$ Na_2CO_3	7 "
64 "	2.78 "	$n/100$ Na_2CO_3	4 " 15 "
38 "	1.86 "	" "	4 " 10 "
Aver. 51 "	2.32 "		4 " 12 "
89 "	4.35 "	$n/10$ $\text{Na}_2\text{B}_4\text{O}_7$	6 "
76 "	3.11 "	" "	5 "
Aver. 83 "	3.73 "		5 " 30 "
89 "	4.42 "	$n/1$ NaCl	60 "
64 "	2.86 "	" "	55 "
Aver. 71 "	3.64 "		57 "
76 "	3.24 "	$n/2$ NaCl	2 " 50 "
64 "	2.90 "	" "	2 " 45 "
Aver. 70 "	3.07 "		2 " 47 "
102 "	5.24 "	$n/1$ KCl	55 "
64 "	3.00 "	" "	50 "
Aver. 83 "	4.12 "		52 "
64 "	2.94 "	$n/2$ KCl	2 " 10 "
76 "	3.25 "	" "	2 " 5 "
Aver. 70 "	3.09 "		2 " 7 "

Length	Weight	Solution	Time required to produce death	
76 mm	3.32 gram	$n/4$ KCl	31	min
64 "	3.25 "	" "	30	"
Aver. 70 "	3.28 "		30	"
89 "	4.25 "	$n/10$ KClO ₃	27	"
76 "	3.65 "	" "	25	"
Aver. 83 "	3.95 "		26	"
76 "	3.50 "	$n/100$ KCN	1	" 10 sec
64 "	2.80 "	" "	1	" 5 "
Aver. 70 "	3.10 "		1	7
102 "	5.20 "	$n/1000$ KCN	1	" 45 "
38 "	1.90 "	" "	1	" 25 "
Aver. 70 "	3.55 "		1	" 32 "
102 "	5.10 "	$n/10000$ KCN	2	" 20 "
76 "	3.45 "	" "	2	" 10 "
Aver. 89 "	4.27 "		2	" 15 "
89 "	3.85 "	$n/50000$ KCN	4	" 20 "
89 "	3.76 "	" "	4	" "
Aver. 89 "	3.80 "		4	10
89 "	4.30 "	$n/10$ CaCl ₂	4	" 45 "
64 "	2.85 "	" "	4	" 30 "
Aver. 76 "	3.57 "		4	" 37 "
64 "	2.94 "	$n/100$ CaCl ₂	2 hrs 40 min	
64 "	2.95 "	$n/1$ MgSO ₄	23	min
64 "	2.65 "	" "	24	" 30 sec
Aver. 64 "	2.80 "		23	" 45 "
64 "	2.95 "	$n/100$ ZnSO ₄	1 hr 20 min	

Length	Weight	Solution	Time required to produce death
64 mm	2.88 gram	$n/100$ CdSO_4	45 min
76 "	3.50 "	$n/100$ NiSO_4	65 "
89 "	4.12 "	" "	75 "
Aver. 87 "	3.81 "		70 "
76 "	3.20 "	$n/100$ CuSO_4	27 "
51 "	2.45 "	" "	25 "
Aver. 63 "	2.82 "		26 "
64 "	2.75 "	$n/500$ CuSO_4	40 "
76 "	3.30 "	$n/100$ HgCl_2	1 " 25 sec
76 "	3.45 "	" "	1 " 40 "
Aver. 76 "	3.37 "		1 " 32 "
102 "	5.50 "	$n/1000$ HgCl_2	2 " 50 "
64 "	3.10 "	" "	2 " 45 "
Aver. 83 "	4.30 "		2 " 47 "
64 "	2.95 "	$n/10000$ HgCl_2	11 " 15 "
64 "	2.90 "	" "	10 " 30 "
Aver. 64 "	2.92 "		10 " 52 "
89 "	5.20 "	$n/100000$ HgCl_2	1 hr 15 min
89 "	4.75 "	$n/1000$ AgNO_3	1 min 30 sec
76 "	4.00 "	" "	1 " 35 "
Aver. 83 "	4.37 "		1 " 32 "
76 "	3.65 "	$n/10000$ AgNO_3	4 " 30 "
76 "	3.45 "	" "	4 " 30 "
Aver. 76 "	3.55 "		4 " 30 "
76 "	3.30 "	$n/100000$ AgNO_3	17 "
115 "	5.50 "	(0.1 g Atropine per l)	7 " 10 "
64 "	3.20 "	(0.1 g Strychnine "1)	7 " 40 "

The results in Table III. show that brook-trout survives longer in $n/100$ and $n/1000$ HCl solutions than does shiner, but not as long as rock-bass. The results obtained with acetic acid are interesting. They show that $n/50$ acetic acid solution is much more toxic in character than $n/1000$ HCl. Inasmuch as the electrical conductivity of solutions of acetic acid shows that $n/50$ acetic acid is electrolytically dissociated to the extent of about 2.9 percent, such a solution contains 1 gram H ions in 1724 liters. Now if toxicity depended solely upon the H ions in the case of this acid, $n/50$ acetic acid should have the same effect as a $n/1724$ HCl solution; as a matter of fact, it has a much greater toxic effect than $n/1000$ HCl, as already stated. The general appearance of fishes killed with acetic acid is about the same as that of those destroyed with mineral acids. No hemorrhage was observed. The gills were dark brown, having a dirty gray fringe.

Fishes killed in HF solutions also had about the same appearance as those that were acted upon by the other acids mentioned. Bleeding did not occur. The results in Table III. show that HF solutions are not nearly as toxic in their action as are solutions of HCl. It was further observed that a fish 64 mm long lived over an hour in $n/1000$ HF solution, which clearly shows the relatively weak poisonous character of this acid. It is of interest to note in this connection that Paul and Krönig¹ found that in stronger solutions HF is a much more powerful disinfectant than the other mineral acids.

Sodium carbonate solutions have about the same destructive power as HF solutions of equivalent strength, which is evident from a comparison of the figures in the last column of Table III. for $n/100$ solutions of these substances. A fish killed in Na_2CO_3 solutions retains in general its normal appearance. The mouth and gill chambers are closed, though not tightly, and the gills have a maroon color. Just before the fish succumbs to the action of the solution the gill chambers and mouth open wider, the gills separate somewhat, and all finally becomes rigid.

¹ Zeit. phys. Chem. 21, 414 (1896).

The same general behavior was also noted in the case of solutions of ZnSO_4 , CdSO_4 , NiSO_4 , and CuSO_4 .

From Table III. it appears that a $n/10$ borax solution is somewhat less toxic than $n/100 \text{ Na}_2\text{CO}_3$. The fishes destroyed by the borax solution have about the same appearance as those acted upon by dilute solutions of sodium carbonate.

The data obtained with common salt solutions show that brook-trout are more strongly affected by brine than are shiners. Further, the table shows that KCl solutions are slightly more destructive than are NaCl solutions of equivalent strength. Brook-trout killed in KCl or NaCl solutions retain their normal appearance. The gills are blood red, the mouth and gill chambers are closed; and no hemorrhage occurs.

A $n/10 \text{ KClO}_3$ solution exercises a slightly greater destructive effect than a $n/4 \text{ KCl}$ solution. The post-mortem appearances of the specimens are about the same as those in the case of KCl solutions.

The extremely toxic action of KCN solutions is evident from the table. Here as in the case of the action of KOH on shiners (Table II.), the length of time that the fish survives increases relatively slightly with the dilution of the solution. Table III. shows that $n/50000 \text{ KCN}$ is more destructive than $n/10000 \text{ AgNO}_3$. In the case of *Lupinus albus* it was found that AgNO_3 is much more poisonous than KCN. Brook-trout killed in KCN solutions have a normal appearance, except that they acquire a somewhat darker luster.

Calcium chloride solutions are more harmful than potassium chloride solutions, as is evident from Table III. The general post-mortem appearances of the specimens are the same as those of the KCl solutions, except that the gills have slightly gray edges. In $n/1 \text{ CaCl}_2$ solutions, brook-trout die in from 15 to 45 seconds.

According to Table III., it takes over 23 minutes for a brook-trout to succumb in a $n/1 \text{ MgSO}_4$ solution, from which fact the relatively slight destructive action of this salt is evident. The post-mortem appearances are nearly the same as in the case of NaCl.

Zinc sulphate solutions are not very toxic, as is evident from the fact that a trout lived for over an hour in a $n/100$ solution. The mouth of the dead fish was wide open; the gill chambers were relaxed; the body was rather limp and had more of a metallic luster; the gills were of a grayish color. The table further indicates that CdSO_4 is more poisonous than NiSO_4 , and that CuSO_4 is more powerful in its destructive effects than either of these. A trout killed in CdSO_4 solution had purplish gill chambers; its mouth was wide open; its gills were grayish; its body was flexible and had a somewhat metallic luster. Trout that succumbed in NiSO_4 solution had maroon gills, partly opened mouths, relaxed gill chambers. Their bodies became darker after a time. Specimens killed by CuSO_4 solutions had wide open mouths and gills with a slightly bluish tinge. Their bodies also became darker after a time as in the case of the victims of the NiSO_4 solutions.

Solutions of AgNO_3 are more toxic than equivalent solutions of HgCl_2 . The same was found to be true in the case of *Lupinus albus*. While HgCl_2 is less active than AgNO_3 , it nevertheless is extremely destructive as the results show. Trout killed in HgCl_2 solutions acquired a grayish metallic luster and were surrounded by a translucent coating. The mouths and gill chambers were wide open. As in the case of the silver salts, HgCl_2 destroys the protective tissues of the gills. Hemorrhage does not result.

To enable those that may desire to do so to make a comparison of the toxic action of the various solutions with the effect of solutions of the alkaloids, two tests were made, one with atropine and the other with strychnine. The strength of the solutions was 0.01 percent in each case. It will be observed that their toxicity is not very different. The trout swam about violently in the solutions, especially in the strychnine solution. After death, the bodies of the fish became rigid and the mouths and gill chambers were wide open. The gills were blood-red. No hemorrhage was observed.

The results of the few experiments that were performed with perch are given in Table IV.

TABLE IV
Perch (*perca flavescens*)

Length	Weight	Solution	Time required to produce death
127 mm	26 grams	$n/1000$ HCl	55 min
" "	27.5 "	$n/1000$ HNO ₃	50 "
" "	26 "	$n/1000$ H ₂ SO ₄	1 hr 40 min
" "	32.5 "	$n/2000$ HNO ₃	6 " 40 "
" "	32.5 "	distilled water	7 " 40 "

It will be noticed that the perch were much heavier than the specimens previously used and that they survived much longer in the $n/1000$ solutions of the strong mineral acids than did the fish in the other cases. Here, too, HNO₃ and HCl have approximately the same toxic power, while H₂SO₄ is apparently only one-half as effective. According to the explanation that the theory of electrolytic dissociation gives of the poisonous properties of these acids, namely that their effect is due to H ions, H₂SO₄ in $n/1000$ solutions ought to have nearly the same effect as the equivalent solutions of HCl and HNO₃.

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