

ortho and/or *para* to the amine group possess the greatest potential.

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Keyphrases

Reagents—colorimetric analysis
 Amines, substituted—diazonium derivatives
 4-Amino-6-chloro-*m*-benzene-disulfonamide—
 estradiol analysis
 Apparent molar absorptivity values—diazonium reagents
 Colorimetric analysis—spectrophotometry

Potentiometric Determination of Fluoride Ion in Toothpastes by a Specific Ion Activity Electrode

By NORMAN SHANE and DENNIS MIELE

A simple, specific potentiometric method is described for the assay of toothpastes for free fluoride ion in concentrations of about 0.1 percent, equivalent to 0.22 percent sodium fluoride or 0.4 percent stannous fluoride. The ionic fluoride content of the toothpastes is determined by relating the potential obtained with a fluoride electrode in an aqueous dispersion of toothpaste to a calibration curve constructed by adding known scalar amounts of fluoride to a blank toothpaste formulation.

THE DETERMINATION of fluoride ion concentration in toothpastes has ordinarily required steam distillation as a separation procedure and titration by thorium nitrate for the fluoride ion using a colored dye as an indicator. The classical Willard-Winter distillation (1), as modified by Grimaldi *et al.* (2), Singer and Armstrong (3), and Wade and Yamamura (4), has been the basis for most analytical procedures. Following distillation, spectrophotometric methods utilizing the blue complex formed between the fluoride ion and the cerium (III) salt of 3-amino-methyl-alizarin-*N,N*-acetic acid have been employed by Bellack *et al.* (5). Also, Harley and Revinson (6) and Calkins (7) have used high-frequency titration techniques, and other methods are described in review articles by Fishman *et al.* (8). Frant (9) explained the theory and operation of the fluoride ion electrode. In contrast to the potentiometric method as explained in this paper, Lingane (10) showed a titration method for fluoride ion employing the fluoride electrode.

The specific method for free fluoride ion described in this paper requires no separation steps. Fluoride ion is detected in toothpastes in the range of 0.1% F⁻ ion equivalent to 0.22% NaF and 0.40% SnF₂. An important consideration in this analysis is that the fluoride must be present as a free ion. The fluoride ion activity electrode model 94-09, developed by Orion Research, Inc., was used as easily as a conventional pH electrode with an Orion digital meter, model 801. A standard glass sleeve calomel reference electrode was employed in conjunction with the fluoride electrode. The electrodes were immersed in an aqueous mixture of toothpaste

so as to measure the activity of ionized (free) fluoride in terms of concentration. By use of an appropriate calibration curve, the concentrations of F⁻ ion from NaF and SnF₂ were determined.

EXPERIMENTAL

Apparatus and Reagents—Fluoride electrode, model 94-09, obtained from Orion Research, Inc., Cambridge, Mass.; Orion Research meter 801; Beckman calomel electrode (with glass sleeve); 50-ml. Nalgene centrifuge tube; 100-ml. volumetric flask; 150-ml. beaker; Sargent magnetic stirrer.

Stirrer—Made from an electric toothbrush with a special made paddle. This paddle is a 10.1-cm. aluminum shaft and has a 3.2 mm. diameter. Two fins, each 2.5 cm. long and 1.9 cm. wide, are located at the stirring end.

NaF Stock Solution for Calibration Curve—180 mg. NaF/100 ml. aqueous solution (0.18% NaF),¹ 200 mg. NaF/100 ml. aqueous solution (0.20% NaF), 220 mg. NaF/100 ml. aqueous solution (0.22% NaF), 240 mg. NaF/100 ml. aqueous solution (0.24% NaF), 260 mg. NaF/100 ml. aqueous solution (0.26% NaF).

SnF₂ Stock Solution for Calibration Curve—To each solution is added 400 mg. of malic acid as a stabilizer. Deoxygenated water is used so as to further prevent oxidation of the stannous ion. 320 mg. SnF₂/100 ml. aqueous solution (0.32% SnF₂),² 360 mg. SnF₂/100 ml. aqueous solution (0.36% SnF₂), 400 mg. SnF₂/100 ml. aqueous solution (0.40% SnF₂), 440 mg. SnF₂/100 ml. aqueous solution (0.44% SnF₂), 480 mg. SnF₂/100 ml. aqueous solution (0.48% SnF₂).

PROCEDURE

For NaF and SnF₂ Calibration—Weigh approxi-

¹ 1 ml. of these solutions represent 0.18%, 0.20%, etc., of NaF based on 1 g. of paste.

² 1 ml. of these solutions represent 0.32%, 0.36%, etc., of SnF₂ based on 1 g. of paste.

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mately five 1-g. samples of the paste³ without NaF or SnF₂ into five 50-ml. centrifuge tubes. Add 45 ml. of water to each tube. For the SnF₂ calibration, deoxygenated water is required. For the NaF experiment 1 ml. of 0.18%, 0.20%, 0.22%, 0.24%, and 0.26% stock solutions of NaF are added to the five tubes, respectively. For the SnF₂ experiment, 1 ml. of 0.32%, 0.36%, 0.40%, 0.44%, and 0.48% stock solution of SnF₂ is added. Stir each tube vigorously for 1.5 min. with the stirrer to disperse the paste in the solution. Pour this suspended solution into a 100-ml. volumetric flask and dilute to volume with water. In the case of SnF₂ deoxygenated water must be used. Transfer the solution to a 150-ml. beaker containing a magnetic stirring rod and stir to ensure homogeneity. Immerse the fluoride and calomel electrodes into the beaker and record the millivolt reading obtained from the research meter. Temperature control of the meter should be set to ambient conditions. A working curve is obtained by plotting the mv. reading against % NaF or % SnF₂ on one-cycle semi-logarithmic graph paper. A calibration curve should be prepared at least once a day. With the Orion meter, the original calibration curve can be shown on the mv. scale. If the reading on a standard solution changes by a few mv., and experience shows that the slope does not change, readings can then be taken on the REL mv. scale which is adjusted so that the standard still reads the same, and the same curve can be used. The same standard solutions can be used for the calibration curves.

For NaF Samples—Laboratory samples are run in the same manner as explained for the calibration curve. It should be noted that the fluoride electrode should be conditioned to the fluoride concentration that is to be determined. For NaF pastes, the mv. reading will become steady within 1 min.

For SnF₂ Samples—Laboratory samples are analyzed in the same manner as explained for the calibration curve. It takes 4–5 min. to condition the electrode to SnF₂ so as to obtain steady readings. After a long period of time (about 10 min.) the millivolt reading will start to increase, indicating a reduction of the free fluoride ions due to complexation. It is imperative to read the mv. reading at the steady-state condition.

RESULTS

The data obtained for the calibration curves of NaF and SnF₂ pastes are shown in Tables I and II. The results are the average composite of five different experiments; each experiment was done on 5 different days. The toothpastes without the NaF and SnF₂ were used to give the proper background for constant ionic strength conditions. NaF or SnF₂ were then added to the toothpastes and millivolt readings were taken. During a given day, the experiment was repeated and the readings were reproduced. The chart indicates linearity with respect to the semilog plot of mv. versus % NaF or SnF₂ for an average composite of five experiments in both cases (Fig. 1). However, because the method depends on direct measurements, the variability of

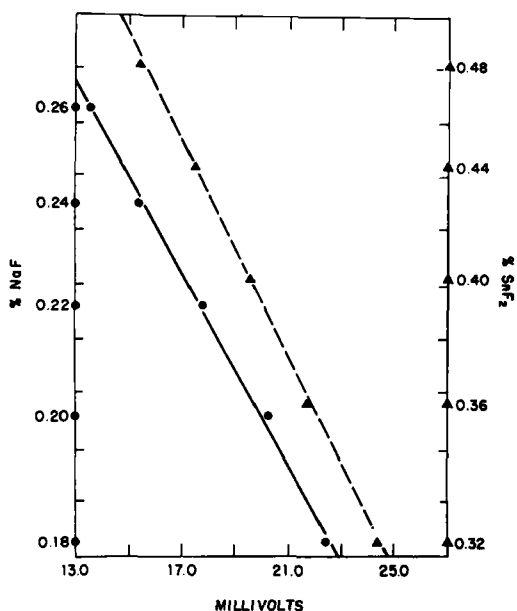


Fig. 1—Semilog plot of the percentage of NaF or SnF₂ versus mv. readings for an average composite of five experiments. Key: —, NaF; ---, SnF₂.

the electrode characteristics, such as change of junction potential, may occur. For this reason, it is advisable to calibrate the meter once every day.

Laboratory samples of the cited toothpastes, including NaF or SnF₂ are shown in Tables I and II, which were run by the standard distillation method of Willard-Winter (1) with thorium nitrate titration using chrome azurol S as the indicator and by the fluoride electrode method. The distillation method for total fluoride, including the titration which, in the authors' opinion, gives a poor end point, takes about 40–45 min. The fluoride electrode method can be completed in 5–9 min. Since the chart is based on the % NaF or % SnF₂ for 1 g. of paste, the calculations for the samples are obtained by the graph reading of the respective percentages divided by the weight of the samples.

The statistical data of the corresponding tests, as shown in Tables I and II, indicate that there is no significant difference between the two methods.

DISCUSSION

The fluoride ion electrode is used to measure the fluoride activity regardless of sample ionic composition or total ionic strength. As described by Kielland (15), the relationship of activity to concentration of the ionized (free) fluoride is obtainable by an appropriate calibration curve. The electrode does not respond to fluorides which are bound or complexed. Since these pastes contain no calcium or other ions capable of removing fluoride, the total fluoride is equivalent to the free fluoride ion level.

A concentration working curve is prepared by plotting potential measurements of known NaF or SnF₂ concentration standards on semilogarithmic graph paper. Since the electrode responds to the activity and not to the concentration of the fluoride ion, the working curve is prepared for fluoride solutions which contain other ions, if the standards approximate the unknowns in composition. The

³ For the NaF paste the formulation is similar to that given in References 11 and 12 as formulation No. 3, shown to be clinically active as anticaries dentifrice (11–13). For the SnF₂ paste the formulation is that given in References 11 and 12 as formulation No. 4, accepted as clinically active anticaries dentifrice (11, 12, 14).

TABLE I—SODIUM FLUORIDE^a

% NaF	mv.
0.18	22.5
0.20	20.2
0.22	17.8
0.24	15.4
0.26	13.6

Samples Analyzed^b

Sample	Wt. of Sample, g.	mv.	Distillation	Fluoride Electrode
A	1.0144	18.3	0.21	0.21
B	1.0331	16.6	0.22	0.22
C	1.0223	17.1	0.23	0.22
D	1.0541	17.7	0.20	0.21
E	1.1621	13.9	0.23	0.22
F	1.0132	20.1	0.19	0.19
G	0.9997	19.5	0.21	0.20
H	1.1356	16.5	0.20	0.20
I	1.1512	17.2	0.19	0.19
J	1.2141	14.0	0.21	0.21
A	0.9987	19.4	0.21	0.21
B	1.0122	18.8	0.22	0.21
C	1.0141	19.4	0.23	0.20
D	0.0185	17.7	0.20	0.21
E	1.1913	14.5	0.23	0.21
F	1.1382	17.0	0.19	0.20
G	1.0415	19.3	0.21	0.20
H	1.1626	17.0	0.20	0.19
I	1.1718	18.6	0.19	0.18
J	1.0859	15.9	0.21	0.22
K	1.2613	16.0	0.19	0.19
L	1.0172	18.4	0.20	0.21
M	1.0185	20.3	0.18	0.20
N	0.9817	21.3	0.19	0.19
O	1.0831	17.8	0.19	0.20

^a Calibration based on average composite of five experiments for 1-g. sample of paste. ^b Calculation for samples analyzed: graph reading/wt. of sample = % NaF; $\bar{x}_1 = 0.2052$; $\bar{x}_2 = 0.2036$; $\bar{a} = 0.0016$; $SD = 0.0020$; t test = 0.8000 for 25 samples.

activity depends on the total ionic strength of the sample. Errors will result if the standards are prepared with pure NaF or SnF₂, and unknowns containing relatively high concentrations of other ions. The calibration curves for the determination of NaF or SnF₂ were based on adding known amounts of the given NaF or SnF₂ to nonfluoride paste in order to fulfill the ionic strength requirement for the calibration curve. The activity of the working curve is a straight line within the working range.

The mathematical relationship of voltage to activity is shown by the Nernst equation:

$$E = E_s + \frac{2.3RT}{F} \log F^-$$

where E = measured potential, E_s = constant due to the system calibrated, $2.3 RT/F$ = Nernst factor, 59.2 mv. at 25°, R and F are constants, T = temperature in °K., F^- = fluoride ion activity in the sample solution.

The Orion meter is readable to ±0.1 mv. Since the voltage is proportional to the log of the fluoride activity by the Nernst equation, the instrument is sensitive to about 0.5 mv. change per 0.01% NaF

TABLE II—STANNOUS FLUORIDE^a

% SnF ₂	mv.
0.32	23.8
0.36	21.8
0.40	19.7
0.44	17.6
0.48	15.5

Samples Analyzed^b

Sample	Wt. of Sample, g.	mv.	Distillation	Fluoride Electrode
A	1.0142	19.6	0.36	0.37
B	0.9998	20.6	0.37	0.37
C	1.0761	19.6	0.36	0.36
D	1.0150	19.4	0.37	0.39
E	1.1012	17.3	0.39	0.40
A	1.1112	19.5	0.36	0.35
B	1.0815	20.0	0.37	0.35
C	1.0514	19.4	0.36	0.37
D	1.0723	19.1	0.37	0.37
E	1.0615	17.0	0.39	0.41
F	1.0431	18.6	0.40	0.40
G	0.9971	17.6	0.40	0.42
H	1.1341	19.2	0.35	0.36
I	1.1562	19.8	0.36	0.34
J	1.1314	18.1	0.40	0.38
F	1.0516	17.9	0.40	0.40
G	1.0723	17.1	0.40	0.41
H	1.1512	18.1	0.35	0.36
I	1.1823	17.6	0.36	0.36
J	1.2114	16.1	0.40	0.38
K	1.2176	17.2	0.37	0.37
L	1.1152	17.7	0.38	0.39
M	1.1921	18.6	0.37	0.35
N	1.1891	17.2	0.40	0.38
O	1.0117	20.8	0.39	0.38

^a Calibration based on average composite of five experiments for 1-g. sample of paste. ^b Calculation for samples analyzed: graph reading/Wt. of sample = % SnF₂; $\bar{x}_1 = 0.3772$; $\bar{x}_2 = 0.3768$; $\bar{a} = 0.0004$; $SD = 0.0027$; t test = 0.1512 for 25 samples.

and 1 mv. per 0.01% SnF₂ in the paste in the region of the analysis.

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Keyphrases

Toothpaste—fluoride ion analysis
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 Fluoride electrode—ion determination