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COMPARATIVE TESTS OF CHEMICAL GLASSWARE

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Bureau of Standards

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CONTENTS

	Page
I. Introduction	3
II. Materials examined	4
1. Sources and identification	4
2. Kinds of pieces tested	4
III. Composition	6
1. Methods of chemical analysis	6
2. Analyses of ware tested	8
3. Conclusions	9
IV. Tests	9
1. Physical tests	9
(a) Methods	9
Coefficient of expansion	9
Refractive index	9
Strain	9
Evaporation test	10
Heat-shock tests	10
Drop test	11
(b) Results	11
(c) Conclusions	16
2. Chemical tests	16
(a) Methods	16
(b) Results of chemical tests	18
(c) Conclusions	18
V. Summary	22

I. INTRODUCTION

Prior to the summer of 1914 the greater part of the chemical laboratory glassware used in this country was imported from Germany and Austria.

The cutting off of imports from these countries caused a very serious shortage of glassware in this country, which is not yet entirely overcome. However, within the past two years a number of American manufacturers have increased their production of such ware, or are manufacturing grades of chemical glassware that they did not produce before. It is probable that practically our whole available supply at this time is of domestic manufacture, much of which is ware sold under brand names which were unknown a short time ago. In order to furnish to chemists information regarding such domestic brands, it was decided to compare them with those of foreign make.

II. MATERIALS EXAMINED

1. SOURCES AND IDENTIFICATION

No information of real value can be obtained from glassware which does not bear a manufacturer's permanent trade-mark, a jobber's trade-mark being of practically no value. There are, therefore, included in these tests only brands which bona fide manufacturers are willing to openly claim as their products. Two kinds of foreign ware (Jena and Kavalier) were included for purpose of comparison, since these represent what has been generally considered high-grade ware of the two most commonly used types. The five brands of domestic ware included all that were known to bear manufacturer's trade-marks, though it is possible that others may now be on the market. Beakers and flasks of the different makes which approximated, in size, the 400 cc Jena beaker and the 400 cc Jena flask were selected.

2. KINDS OF PIECES TESTED

The following details serve to establish the history of the samples so far as known to us. Unless otherwise stated the wares were purchased in the open market.

Kavalier.—Thirty-nine beakers (400 cc) were received December 17, 1915 (one broken). Nine beakers (400 cc) were received January 3, 1916. No flasks could be secured.

Macbeth Evans Glass Co.—Forty-eight beakers (400 cc) were received January 21, 1916 (one broken, one cracked, one with lip broken). Forty-eight flasks (400 cc) were received January 21, 1916.

Pyrex.—Forty-eight beakers (400 cc) were received December 17, 1915 (one with lip broken). Forty-eight flasks (400 cc) were received January 3, 1916.

Jena.—Forty-eight beakers (400 cc) were received December 17, 1915. A uniform set of flasks could not be purchased at that time and 48 flasks (400 cc) were selected from stock on hand in the Bureau of Standards.

Nonsol.—Forty-eight beakers (350 cc) and 48 flasks (250 cc) were received January 3, 1916.

Fry.—Forty-eight beakers (400 cc) and 48 flasks (400 cc) were received January 3, 1917.

Libbey.—Forty-eight beakers (400 cc) and 49 flasks (300 cc) were received March 30, 1916.

FIG. 2.—*Flasks*

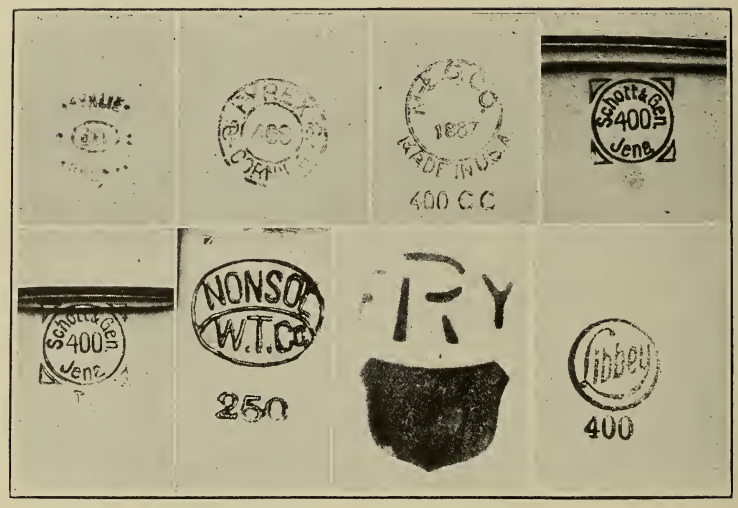

FIG. 3.—*Brand marks*

Fig. 1 is a photograph of representative beakers and Fig. 2 of representative flasks, showing the brand marks. Fig. 3 shows the brand marks on a somewhat larger scale.

Table 1 summarizes observations made on the wares as received. The capacity as claimed and as determined from one sample chosen at random is given. Each sample was weighed and the average, maximum, and minimum weights are given.

TABLE 1 .—Data Regarding Glassware

BEAKERS

Trade-mark	Capacity		Weight		
	Claimed	Determined	Maximum	Minimum	Average
	cc	cc	g	g	g
Kavalier N (B&L) S Bohemia	400	410	76	42	54
M. E. G. Co. 1887 Made in USA 400 cc	400	420	94	57	77
Pyrex 400 Corning	400	405	133	62	82
Schott & Gen 400 Jena	400	425	76	51	60
Nonsol W T Co 350	350	405	67	42	52
Fry	400	390	76	48	60
Libbey 400	400	475	77	46	61

FLASKS

Trade-mark	Capacity		Weight		
	Claimed	Determined	Maximum	Minimum	Average
	cc	cc	g	g	g
M. E. G. Co. 1864 Made in USA 400 cc	400	465	86	64	74
Pyrex 400 Corning	400	425	90	70	79
Schott & Gen 400 Jena N	400	450	78	49	66
Nonsol W T Co 250	250	310	55	44	50
Fry	400	440	89	55	68
Libbey 300	300	340	66	40	51

III. COMPOSITION

1. METHODS OF CHEMICAL ANALYSIS

In the main, the procedures recommended by Hillebrand [1] were followed, making blank determinations on the reagents.

Silica, Alumina, Iron Oxide, Zinc Oxide, Lime, and Magnesia.—One gram of the powdered sample was fused with anhydrous normal sodium carbonate and silica determined, eliminating boric acid by the addition of methyl alcohol and hydrochloric acid.[2] Platinum and other metals precipitable by hydrogen sulphide were removed from the filtrate from the silica by means of hydrogen sulphide and the precipitate was rejected. The filtrate was oxidized with potassium chlorate and the iron and aluminum were precipitated three times with ammonia, washing each time with 2 per cent ammonium chloride solution as recommended by Blum.[3] Small amounts of iron and aluminum were recovered from the combined filtrates. The silica in the ignited oxides was recovered and the iron was determined by reducing with hydrogen sulphide and titrating with permanganate. The alumina was obtained by difference, after deducting the recovered silica, and phosphoric anhydride if present.

In the filtrate from the iron and aluminum the zinc was precipitated by hydrogen sulphide by the formic-acid method of Waring.[4] The precipitate was redissolved in dilute hydrochloric acid and the precipitation repeated. The zinc sulphide so obtained was dissolved in dilute hydrochloric acid and the zinc determined as pyrophosphate. In some determinations the zinc sulphide was dissolved in hydrochloric acid, evaporated, and the zinc precipitated by sodium carbonate and weighed as zinc oxide, as described in Treadwell-Hall's "Quantitative analysis." The combined filtrates from the zinc sulphide were evaporated to expel formic acid and any manganese present was precipitated by ammonium sulphide. Zinc was also determined by decomposing a separate portion of the sample with hydrofluoric and sulphuric acids, precipitating as sulphide by the Waring method, and finally igniting the sulphide to oxide.

In the filtrate, calcium was determined by double precipitation and weighed as oxide after correcting for traces of alumina.

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[1] Bull. 422, U. S. Geological Survey, The Analysis of Silicate and Carbonate Rocks.

[2] J. W. Mellor, A Treatise on Quantitative Inorganic Analysis, p. 589 (1913); Jannasch, Z. anorg. Chem., **12**, p. 208, 1896; Z. anal. Chem., **36**, p. 383, 1897.

[3] Determination of Aluminium as Oxide, Scientific Paper No. 286, Bureau of Standards; J. Am. Chem. Soc., **38**, pp. 1282–1297; 1916.

[4] J. Am. Chem. Soc., **29**, p. 265; 1907.

Magnesium was determined by double precipitation in the united filtrates from the calcium oxalate and weighed as the pyrophosphate. The precipitate was examined for calcium and manganese.

Alkalies were determined on 0.5 gram of sample by the J. Lawrence Smith method.

Manganese was determined on a 2-gram sample by the bismuthate method,[5] decomposing the sample with hydrofluoric and sulphuric acids. The potassium-permanganate solution was standardized against sodium oxalate.[6]

Arsenic, Antimony, and Lead.—Three grams of the powdered sample were decomposed with hydrofluoric and nitric (or sulphuric) acids according to Mellor.[7]

The cold cake was dissolved in hydrochloric acid and water, heated, a little potassium iodide solution added to reduce the arsenic acid,[8] and saturated with hydrogen sulphide gas. After standing overnight in a corked flask, the precipitate was filtered off and washed with water containing hydrogen sulphide, then treated with hot sodium sulphide solution. The lead sulphide remaining on the filter was dissolved in hot dilute nitric acid, sulphuric acid added, and the lead determined as lead sulphate in the usual manner. The sodium sulphide solution was evaporated nearly to dryness, and the residue was digested with hydrochloric acid and potassium chlorate. In the absence of antimony, the arsenic was determined directly as pyroarsenate by Levol's method.[9] In the absence of arsenic and lead, the hydrogen sulphide precipitate was filtered on a Gooch crucible, washed, dried, ignited in a current of carbon dioxide, and the antimony trisulphide weighed.[10] Antimony was also determined by decomposing the sample by heating with hydrofluoric and oxalic acids as recommended by Sullivan and Taylor,[11] finally weighing as the trisulphide. Arsenic was also determined by decomposing a sample with hydrofluoric and sulphuric acids, transferring to a Gutzeit apparatus, and passing the generated arsine into mercuric chloride solution, finally weighing the mercurous chloride formed.[12] Lead was also determined in the filtrate from the silica obtained by the sodium carbonate fusion method.

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[5] Blair, The Chemical Analysis of Iron, p. 121; 1908.

[6] Blum, J. Am. Chem. Soc., 34, p. 1379; 1912.

[7] J. W. Mellor, A Treatise on Quantitative Inorganic Analysis, p. 271; 1913.

[8] L. L. de Koninck, Bull. soc. belg. chim., 23, pp. 88–94; 1909.

[9] Treadwell-Hall, Quantitative Analysis.

[10] J. W. Mellor, A Treatise on Quantitative Inorganic Analysis, pp. 297–298; 1913; Gooch, Representative Procedures in Quantitative Chemical Analysis, pp. 101–104; 1916.

[11] J. Ind. Eng. Chem., 6, p. 897; 1914.

[12] Claude R. Smith, U. S. Dept. Agr., Bur. of Chem. Circular No. 102; 1912.

Boric Acid was determined by Sullivan and Taylor's modification of Wherry's method.[13]

Sulphuric Anhydride.—One gram of the sample was fused with 6 grams of sodium carbonate, treated with water and hydrochloric acid, and the silica removed in the usual manner by evaporation. Sulphuric anhydride was precipitated in the filtrate as barium sulphate.

Phosphoric Anhydride was determined by the method described by Lunge.[14]

Selenium and *Fluorine* were tested for qualitatively.[15]

2. ANALYSES OF WARE TESTED

The marks on both beakers and flasks were identical in the case of all the wares examined except Jena, in which an "N" appeared below the main body of the trade mark on the flasks but did not appear on the beakers. Therefore, with the Jena ware analyses were made of both beakers and flasks, but with the other wares the flasks were not analyzed. It is evident from the results that there is no difference in composition between the Jena beakers and flasks. Table 2 shows analyses of the wares tested.

TABLE 2.—Analyses

Ware	Kavalier beaker	M. E. G. Co. beaker	Pyrex beaker	Jena beaker	Jena flask	Nonsol beaker	Fry beaker	Libbey beaker
Al_2O_3	0.14	1.0	2.0	4.2	4.2	2.5	2.7	2.1
Fe_2O_3	0.08	0.35	0.25	0.25	0.27	0.23	0.22	0.44
ZnO	.....	5.6	.....	10.9	10.9	7.8	3.6	.....
PbO	.....	.....	.....	.....	.....	.....	.....	1.0
MnO	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.03
CaO	8.7	0.66	0.29	0.63	0.56	0.79	2.6	0.42
MgO	0.17	4.3	0.06	0.21	0.25	3.4	2.6	0.08
Na_2O	7.1	10.8	4.4	7.5	7.8	10.9	9.8	8.2
K_2O	7.9	0.30	0.20	0.37	0.31	0.30	1.5	0.67
SiO_2	75.9	73.0	80.5	64.7	64.7	67.3	68.6	75.9
B_2O_3	.....	3.6	11.8	10.9	10.6	6.2	8.1	10.8
P_2O_5	0.08	.....	.....	.....	.....	.....	.....	.....
SO_3	0.20	0.02	.....	.....	.....	.....	.....	.....
As_2O_5	Trace	0.02	0.70	0.14	0.19	Trace	0.18	0.36
Sb_2O_3	.....	0.60	.....	.....	.....	0.62	.....	.....
Total	100.29	100.27	100.21	99.81	99.79	100.05	99.93	100.00

Selenium and fluorine were not found, but lithium was detected spectroscopically by Paul W. Merrill in all the samples.

[13] J. Ind. Eng. Chem., 6, p. 899; 1914.

[14] Lunge-Keane, Technical Methods of Chemical Analysis, 1, p. 654; 1908.

[15] Lunge-Keane, Technical Methods of Chemical Analysis, 1, pp. 642–643; 1908.

3. CONCLUSIONS

These analyses indicate that the Kavalier ware is a calcium, potassium, sodium silicate with only inappreciable amounts of other elements. The Macbeth Evans Glass Co. ware is a sodium, zinc, magnesium borosilicate containing some antimony. The Pyrex ware is a very acid sodium, aluminium borosilicate containing some arsenic. The Jena ware is a zinc, sodium, aluminium borosilicate. The Nonsol ware is a sodium, zinc, magnesium, aluminium borosilicate with very little arsenic but some antimony. The Fry ware is a sodium, zinc, magnesium, calcium, aluminium borosilicate. The Libbey ware is a sodium, aluminium, lead borosilicate containing some arsenic.

The analyses may be of help when extreme care must be taken to avoid introducing small amounts of certain substances from the glass used. For example, the Kavalier is the only ware free from boron, and the Kavalier, Pyrex, and Libbey are the only wares free from zinc. No conclusions as to relative values of the different wares for general laboratory use can be drawn from these analyses.

IV. TESTS

1. PHYSICAL TESTS

(*a*) METHODS.—*Coefficient of Expansion.*[16]—The absolute coefficient of linear expansion was determined on pieces cut from the side of a Kavalier beaker, and on cylinders cut from the necks of flasks of all the other brands, by the Fizeau-Pulfrich interference method [17] for the temperature interval 10° to 55° C. Observations were made with both rising and falling temperatures, the average figures being reported.

Refractive Index.[18]—The refractive indices for monochromatic light (n_D) and dispersion ($n_F - n_C$) were measured on pieces from all the kinds of glass, using a Pulfrich refractometer.

Strain.[19]—Plane polarized light was obtained by reflection from a plane glass plate and changed to circularly polarized light by passing it through a quarter-wave plate of mica. The sample to be examined was then placed in the path of the circularly polarized light. If the sample was strained, the circularly polarized light was divided into two beams at right angles, which were then

[16] Determination made by C. G. Peters, Bureau of Standards.
[17] Fizeau, Ann. de Chim. et de Phys., 4, (2), p. 146; Pulfrich, Zeit. für Instrumentenk., September, 1898.
[18] Determinations made by H. I. Shultz, Bureau of Standards.
[19] Tests made by H. I. Shultz, Bureau of Standards.

changed to plane polarized light by a small quarter-wave plate. Behind this quarter-wave plate was the analyzing prism, with which interference between the two portions of light was viewed.[20] With no strain no interference is visible. A slight amount of strain shows up as a grayish color, which becomes dark brown (almost black) with increasing strain. If the strain is very strong, interference colors from blue to red appear. A grayish color is called a slight strain, somewhat brownish moderate, and a dark color, approaching blue, strong.

The quarter-wave plate nearest the eye, since it is close to the eye and does not diminish the field, is small (1 cm in diameter). The quarter-wave plate on the other side of the specimen is about 10 by 13 cm, enabling the operator to observe a large portion of the specimen at once.

Evaporation Test.—Unweighed beakers containing 100 cc of a 10 per cent solution of sodium chloride were heated on a steam bath with full head of steam until the residue was completely dry. The beakers with the residue of dry salt were then heated overnight on a plate heated by steam at about 120 pounds' pressure. After cooling they were washed and dried by heating at 100° C. for two hours and the bottoms carefully examined for minute cracks. This treatment was repeated 12 times, four beakers of each kind of glass being subjected to this test.

Heat-Shock Tests.—Vessels containing 200 cc of boiling water were plunged into ice water.

Vessels containing 200 cc of ice water (0° C to 4° C) were supported on nichrome triangles and heated to boiling as rapidly as possible by direct application of the flame of a burner of Meker type 3 cm in diameter at the top of the burner. The flame was 20 cm high and the top of the burner 2½ cm below the bottom of the beaker or flask. Beakers were covered with watch glasses during the heating, but the flasks were uncovered.

Vessels containing 200 cc of melted paraffin were heated on a hot plate until a thermometer in the paraffin indicated a temperature of about 160° C, then removed from the plate and the paraffin stirred with the thermometer until the temperature fell to 150° C. They were then plunged into ice water.

Vessels containing 200 cc of melted paraffin were heated to about 215° C, removed from the hot plate, the paraffin stirred

[20] Coker, Engineering, 91, pp. 1–4; 1911.

with the thermometer until the temperature fell to 200° C, and the vessels plunged into ice water.

Drop Test.—Beakers were dropped bottom down on a board 1½ inches thick resting on a table with a wooden top 1 inch thick, from heights varying by 5 inches until the piece tested broke or stood a fall of 45 inches.

(*b*) RESULTS.—Table 3 gives the coefficient of linear expansion, refractive index, and dispersion of the ware tested.

TABLE 3.—Linear Expansion and Optical Properties

Glass	Coefficient of linear expansion per degree centigrade from 10 to 55	Refractive index n_D	Dispersion $n_F - n_C$
Kavalier	0.00000759	1.5077	0.00841
M. E. G. Co.	.00000600	1.5090	.00878
Pyrex	.00000334	1.4754	.00738
Jena (flask)	.00000479	1.5079	.00840
Jena (beaker)		1.5069	.00840
Nonsol	.00000640	1.5142	.00822
Fry	.00000596	1.5114	.00826
Libbey	.00000506	1.4963	.00789

Table 4 gives a summary of the observations on strain.

TABLE 4.—Strain Tests

[Number of pieces showing various degrees of strain]

Ware	Degree of strain	Beakers					Flasks					
		Entire beaker	Bottom	Sides	Rim	Lip	Entire flask	Bulb	Neck	Rim	Bottom	Junction of neck and bulb
Kavalier (48 beakers and no flasks tested)	None	3	3	5	16	8	----	----	----	----	----	----
	Slight	37	4	39	25	34	----	----	----	----	----	----
	Medium	5	0	4	4	4	----	----	----	----	----	----
	Strong	3	0	0	3	2	----	----	----	----	----	----
M. E. G. Co. (46 beakers and 48 flasks tested)	None	3	46	33	28	4	0	48	0	48	24	48
	Slight	39	0	11	17	40	48	0	48	0	24	0
	Medium	3	0	1	1	2	0	0	0	0	0	0
	Strong	1	0	1	0	0	0	0	0	0	0	0
Pyrex (48 beakers and 41 flasks tested)	None	2	2	23	23	46	0	36	0	0	34	41
	Slight	19	15	19	18	1	15	4	14	15	7	0
	Medium	21	26	3	7	1	16	1	17	16	1	0
	Strong	6	5	3	0	0	10	0	10	10	0	0
Jena (48 beakers and 33 flasks tested)	None	11	28	18	45	33	5	17	14	31	24	28
	Slight	27	15	19	3	9	19	12	10	1	4	2
	Medium	9	4	11	0	6	5	2	5	0	3	1
	Strong	1	1	0	0	0	4	2	4	1	2	2
Nonsol (48 beakers and 35 flasks tested)	None	21	37	42	32	33	12	21	18	32	33	35
	Slight	27	11	6	16	15	18	14	12	2	2	0
	Medium	0	0	0	0	0	4	0	4	1	0	0
	Strong	0	0	0	0	0	1	0	1	0	0	0
Fry (48 beakers and 48 flasks tested)	None	10	33	43	40	20	1	48	1	20	39	48
	Slight	28	7	3	8	21	36	0	37	25	4	0
	Medium	6	5	1	0	3	9	0	8	3	3	0
	Strong	4	3	1	0	4	2	0	2	0	2	0
Libbey (43 beakers and 49 flasks tested)	None	13	41	30	39	19	0	34	5	17	26	49
	Slight	11	1	2	0	9	3	0	6	0	3	0
	Medium	9	0	5	0	5	10	1	12	2	2	0
	Strong	10	1	6	4	10	36	14	26	30	18	0

All the pieces tested stood the evaporation test without developing cracks.

Table 5 shows the results of all heat shock and drop tests, the results of the strain tests on the individual pieces subjected to these tests being included in this table.

TABLE 5.—Heat-Shock Tests and Drop Test

Ware	Water at 4° heated to boiling over direct flame				Boiled water and plunged into ice water				150° paraffin test			
	Beakers		Flasks		Beakers		Flasks		Beakers		Flasks	
	Strain in piece tested	Result of test	Strain in piece tested	Result of test	Strain in piece tested	Result of test	Strain in piece tested	Result of test	Strain in piece tested	Result of test	Strain in piece tested	Result of test
Kavalier	Slight	Uninjured			Slight	Uninjured			Slight	Cracked		
	Do	Cracked			Strong	do			Strong	Uninjured		
	Do	do										
	Do	do										
M. E. G. Co.	Slight	Uninjured	Slight	Cracked	Medium	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured
	Do	do	do	Uninjured	Slight	do	do	do	Medium	Cracked	do	Cracked
			Do	Cracked							do	Uninjured
			Do	Uninjured								
Pyrex	Medium	Uninjured	Slight	Uninjured	Strong	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured
	Do	do	do	do	Slight	do	do	do	Strong	do	do	Do.
Jena	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured
	Strong	do	do	do	do	do	do	do	do	do	do	Do.
Nonsol	Slight	Uninjured	Medium	Uninjured	None	Uninjured	Medium	Uninjured	None	Uninjured	Medium	Uninjured
	None	do	Slight	do	Slight	do	Slight	do	Slight	do	Slight	Do.
Fry	Slight	Uninjured	Medium	Uninjured	Slight	Uninjured	Medium	Uninjured	Slight	Uninjured	Slight	Uninjured
	Do	do	Slight	do	do	do	Slight	do	None	do	Medium	Cracked
									Slight	do	Slight	Uninjured
									(?)	Cracked	Strong	Do.
Libbey	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured	Slight	Uninjured
	Strong	do	Strong	do	Strong	do	Strong	do	Strong	do	Strong	Do.
									Do	do	Medium	Do.
									Do	do	do	Do.

TABLE 5.—Heat-Shock Tests and Drop Test—Continued.

Ware	200° paraffin test				Drop test, beakers only	
	Beakers		Flasks			
	Strain in piece tested	Result of test	Strain in piece tested	Result of test	Strain in piece tested	Result of test
Kavalier	Slight	Broke			Slight	Broke at 5 inches
	Do	do			do	Do.
	Do	do			do	Do.
	Strong	do			do	Do.
					Strong	Broke at 10 inches
					Slight	Do.
M. E. G. Co	Slight	Broke	Slight	Broke	Slight	Broke at 10 inches
	Do	do	do	do	do	Do.
	Do	do	do	do	do	Broke at 5 inches
	None	do			do	Broke at 10 inches
					Do	Broke at 5 inches
					Strong	Do.
Pyrex	Medium	Uninjured	Medium	Uninjured	Slight	Broke at 30 inches
	Do	do	Slight	do	do	Broke at 15 inches
	Strong	do	do	Cracked	Medium	Stood 25 inches and bounded to floor
	Medium	do	do	do	Strong	Did not break at 45 inches
			Do	Uninjured	do	Do.
					Slight	Broke at 25 inches
Jena	Slight	Broke	None	Broke	Medium	Broke at 10 inches
	Strong	do	Slight	do	Slight	Do.
	Slight	do	do	Uninjured	do	Do.
	Do	Uninjured	do	Broke	do	Broke at 5 inches
					Do	Do.
					Do	Broke at 20 inches
Nonsol	Slight	Uninjured	Strong	Broke	None	Broke at 15 inches
	None	do	Medium	do	do	Broke at 5 inches
	Do	do	Slight	do	do	Do.
	Slight	do	None	do	Slight	Broke at 15 inches
					Do	Broke at 10 inches
					Do	Broke at 5 inches

Fry	None	Broke	Slight	Broke	None	Broke at 20 inches
	Slight	do	Medium	do	Slight	Broke at 5 inches
	Do	do	Slight	do	do	Broke at 10 inches
	Do	do	Strong	do	do	Broke at 20 inches
					Medium	Broke at 10 inches
					Slight	Broke at 30 inches
Libbey	Strong	Uninjured	Strong	Broke	None	Broke at 20 inches (on bound)
	Slight	do	Medium	do	Strong	Broke at 10 inches
	Strong	do	do	do	Medium	Broke at 30 inches
	Do	do	Slight	do	Slight	Broke at 5 inches
					Medium	Broke at 30 inches
					Slight	Broke at 5 inches

(*c*) CONCLUSIONS.—The figures for coefficient of expansion are of interest in that they are all low as compared with plate, crown, and flint glasses, which are reported in Smithsonian Physical Tables (sixth edition), as ranging from 0.00000788 to 0.00000954. The figure for Pyrex glass is unusually low and is in very good agreement with the value, 0.0000032, given by Sullivan and Taylor.[21] The refractive indices and dispersion figures are not of any special interest except that the refractive index of Pyrex glass is very low. It was hoped that the tests for strain would prove useful in giving information as to resistance to changes in temperature and to mechanical shock, but study of Tables 4 and 5 shows that there is apparently no connection between the condition of strain and the resistance to changes in temperature and to mechanical shock. The evaporation test shows that all the ware is superior to several lots of unmarked ware reported[22] 12 years ago. Since none of the samples failed under this test it does not give information as to the relative values of the wares tested. The number of pieces available for the several heat-shock tests and for the drop test was too small to justify drawing any positive conclusions, since applying these tests to several hundred pieces of each kind of ware might give average results radically different from those obtained on the small number tested; but with this reservation, the tests indicate that the Kavalier and M. E. G. Co. wares are less resistant than Jena, Nonsol, and Fry wares, the Libbey ware somewhat more resistant, and the Pyrex ware distinctly more resistant.

2. CHEMICAL TESTS

(*a*) METHODS.—The chemical tests were designed to show the effect of ordinary laboratory operations on the various kinds of glassware tested. The effect of the various treatments was judged in each case by the loss in weight of the piece tested. All pieces to be tested were cleaned by washing with water, strong hydrochloric acid, distilled water, then filled completely with distilled water, and allowed to stand at room temperature for 24 hours, the water then being emptied, the vessels heated at the temperature of boiling water for 2 hours, allowed to stand at room temperature, protected from dust (but not in a desiccator), and weighed. All weighings were made against a tare piece of the same ware, which was cleaned in the manner described above and heated in the same oven as the test piece. The tare pieces

[21] J. Ind. & Eng. Chem., 7, p. 1064; 1915.

[22] J. Am. Chem. Soc., 28, p. 865; 1905.

were always placed in the oven and cooled at the same time and on the same table as the test pieces, but not otherwise subjected to any treatment after the first cleaning. Pieces which had received no treatment except the above-described cleaning were used for each test.

The losses in weight were determined by two observers, using different balances, different pieces of the wares, and different tare pieces. The pieces were sometimes heated in an electrically-heated drying oven and sometimes in a gas-heated oven. Repeated weighings of flasks over a period of 4 days without bringing the ware into contact with reagents, but heating a number of times in both types of ovens, showed that a single observer is liable to an error of about 1 mg in weighing, and as the errors with two observers may be in the opposite direction, duplication within 2 mg is all that can be expected.

In the water test on beakers 300 cc of distilled water was placed in each beaker, which was covered with a platinum dish and heated on a plate heated by steam at boiler pressure (100 to 120 pounds). Water was added from time to time to keep the volume approximately 300 cc. The beakers were removed from the hot plate each evening and allowed to stand at room temperature overnight. The test extended over about 72 hours, of which 24 hours was on the hot plate, and about 48 hours on the laboratory table. The beakers were then washed with water, hydrochloric acid, and again distilled water, dried, and weighed as described above. With flasks 250 cc of water was used throughout; this was allowed to stand for 17 hours at room temperature and then boiled uncovered on a gas-heated hot plate for 5 hours, hot water being added from time to time to keep the volume approximately 250 cc. The vessels were then cleaned, dried, and weighed as above.

With sodium carbonate, potassium carbonate, sodium hydroxide, potassium hydroxide, and sodium phosphate, 100 cc of half-normal solutions were boiled gently for 20 minutes in the covered test vessels. The vessels were then washed with water, hydrochloric acid, and again with water, dried, and weighed as in the preliminary treatment. In the case of beakers, but not with the flasks, after determining the loss by the first treatment another 100 cc of the reagent solution was boiled for 20 minutes, then evaporated to dryness on a plate heated by steam (at 100 to 120 pounds pressure). The beakers were then cleaned, dried, and weighed as above.

With ammonia, 75 cc of strong ammonia (0.9 specific gravity) was placed in the test vessel, which was covered with platinum, and allowed to stand at room temperature for 24 hours. Then 150 cc of distilled water was added, heated to boiling and boiled gently for 30 minutes. The liquid was poured out and the vessel washed with water, hydrochloric acid, and again with water, dried, and weighed as before.

With ammonium sulphide and ammonium chloride, 100 cc of 2N ammonium sulphide and 50 cc 2N ammonium chloride were placed in the test pieces, covered with platinum, allowed to stand at room temperature for 24 hours, then boiled gently for 30 minutes. The liquid was then poured out, the vessel washed with water, a mixture of hydrochloric acid and bromine water, again with water, dried, and weighed as before.

The acid treatment was conducted as follows: 25 cc of a solution containing 4 g sodium chloride and 4 g sodium nitrate per 100 cc was placed in the test pieces. Then 50 cc of sulphuric acid (1.5 specific gravity) was added, the vessel covered and heated to boiling on a gas-heated hot plate. The cover was then removed and heating continued for an hour after fumes of SO_3 appeared. The test piece was allowed to cool, about 100 cc of water added, the liquid poured out, the vessel washed with water, hydrochloric acid, and again with water. It was then dried, cooled, and weighed as before.

(*b*) Results.—Results are shown in Figs. 4, 5, 6, and 7, in which the letters *K*, *M*, *P*, *J*, *N*, *F*, and *L* indicate Kavalier, M. E. G. Co., Pyrex, Jena, Nonsol, Fry, and Libbey, respectively. In these figures individual accepted determinations are shown by dots, determinations which are believed in error and therefore omitted from the averages by circles. The length of the rectangles indicates averages of the accepted values.

(*c*) Conclusions.—In general, it may be observed that where the losses in a given test are small, say, less than 15 mg, the duplicate determinations agree fairly well. The results, however, vary widely when the losses are large.

Considering the tests separately we find that with water the Kavalier ware is unsatisfactory. All the rest show good resistance, and while the determinations show slight superiority of the Pyrex and Libbey glasses over the M. E. G. Co., Jena, Nonsol, and Fry, the differences are so small and the resistance of all of these glasses is so good that it may be concluded that all of the ware examined except the Kavalier is satisfactory in this respect.

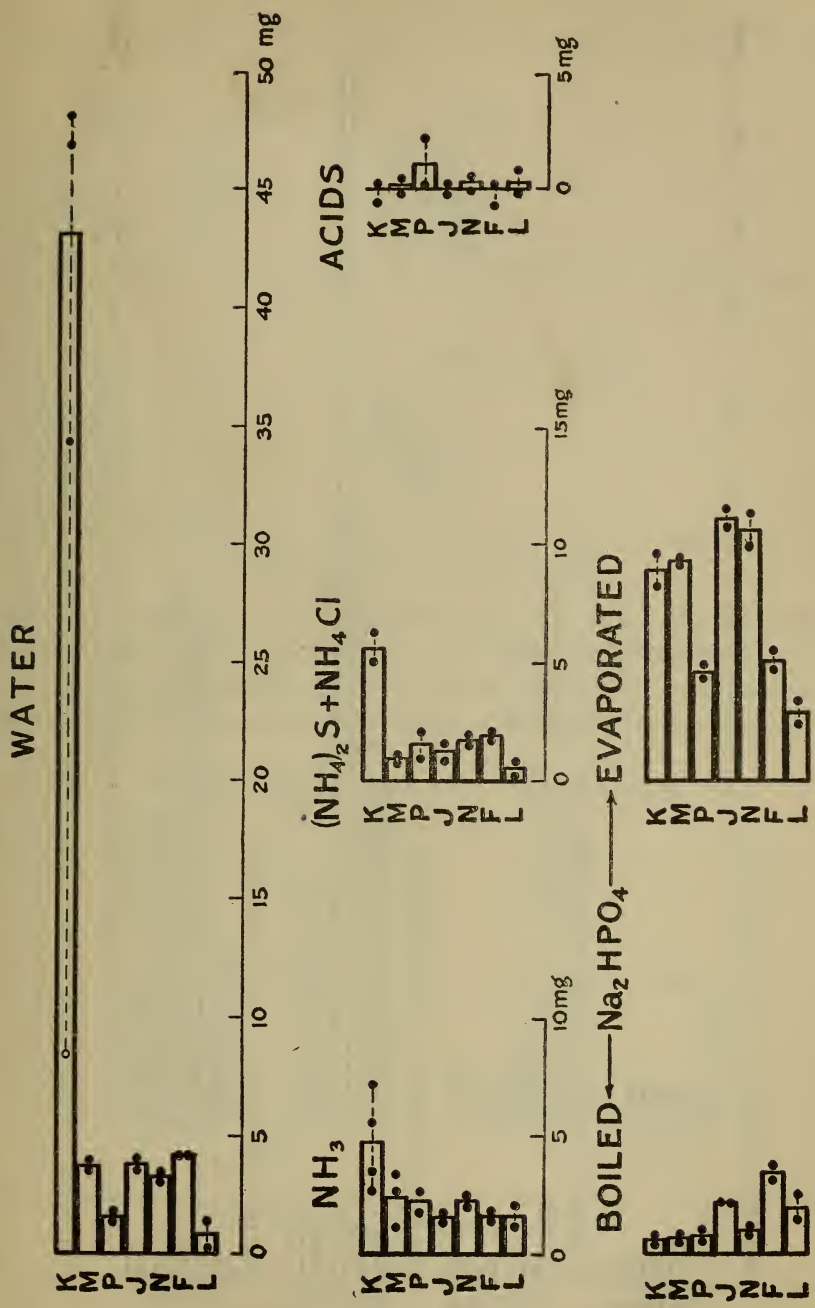

FIG. 4.—*Loss in weight of beakers with water, ammonia, ammonium sulphide and chloride, acids, and sodium phosphate solutions.*

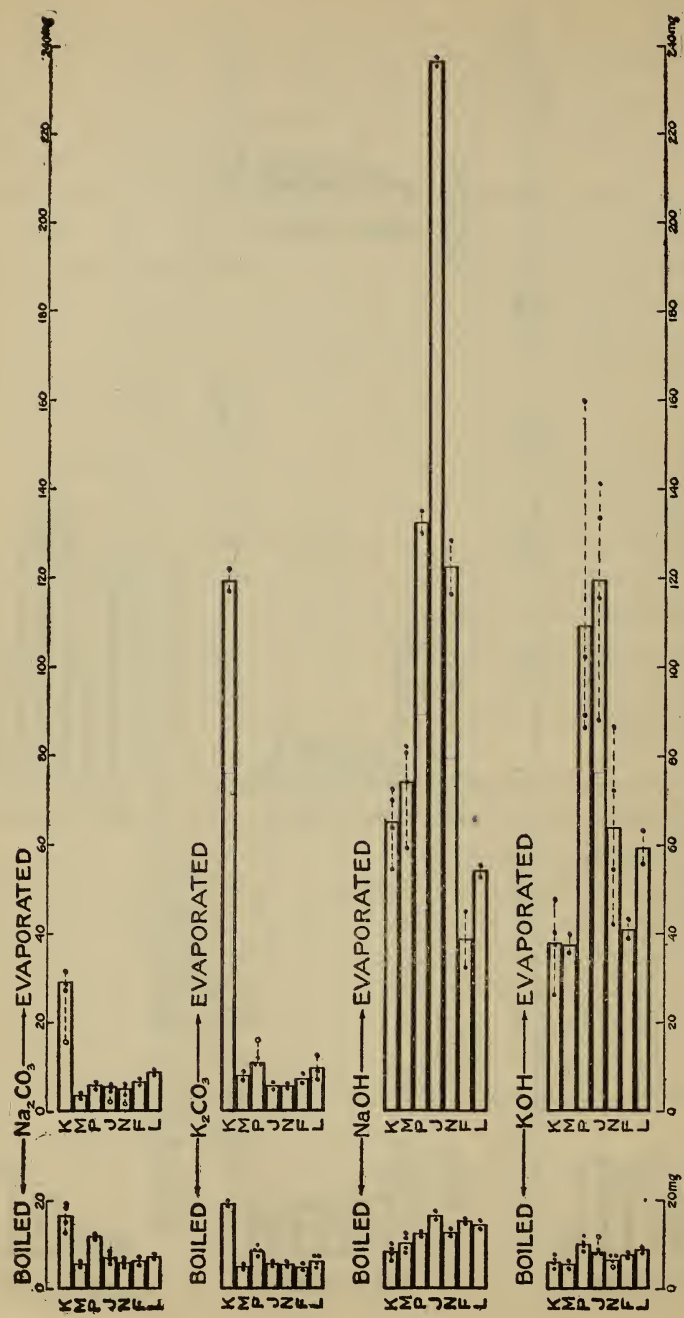

FIG. 5.—*Loss in weight of beakers with sodium carbonate, potassium carbonate, sodium hydroxide, and potassium hydroxide solutions.*

With acids all of the glasses examined show excellent resistance. The acid tests confirm the conclusion of practically all observers that glass in general is more resistant to acid solutions than to alkaline solutions or pure water. The test with boiling alkaline

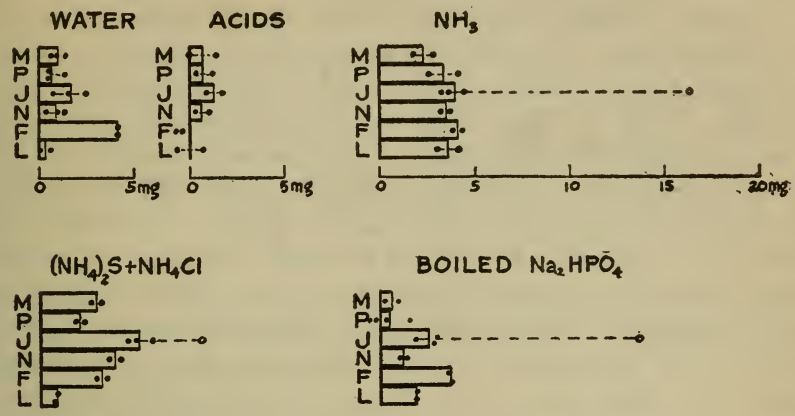

FIG. 6.—*Loss in weight of flasks with water, acids, ammonia, ammonium sulphide and chloride, and sodium phosphate solutions.*

carbonates shows that the Kavalier ware is the least resistant, showing losses above 15 mg; that the Pyrex is intermediate with losses from 8 to 12 mg; and that the M. E. G. Co., Jena, Nonsol, Fry, and Libbey are very nearly equal with losses approximately 5

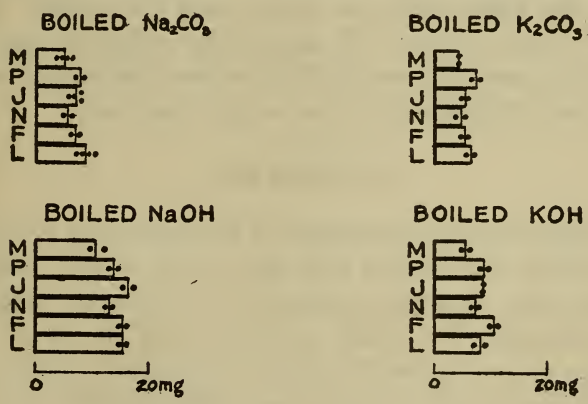

FIG. 7.—*Loss in weight of flasks with sodium carbonate, potassium carbonate, sodium hydroxide, and potassium hydroxide solutions.*

to 7 mg. There is no appreciable difference in the action of sodium and potassium carbonates. With boiling caustic alkalies the Kavalier and M. E. G. Co. wares seem to be slightly more resistant than the others; the differences are not, however, very

great. It may also be noted that sodium hydroxide appears to be somewhat more active than potassium hydroxide. With the evaporation tests it must be remembered that these tests were made on the same beakers that had been used for the determination of the loss on boiling. On evaporation with carbonated alkali the Kavalier beakers showed less action by the sodium than by the potassium salt, but with both salts the losses were so excessive as to indicate that Kavalier ware is not suitable for use with such solutions. With the other wares the losses range from about 5 to 12 mg, no appreciable differences being observed with the sodium and potassium salts. Although great differences will be noted in the results of evaporation with caustic alkalies, the losses with all the wares tested are so great as to clearly indicate that caustic alkalies can not be safely evaporated in any glass of which we have knowledge. Boiling with sodium phosphate has little effect on any of the wares tested. Evaporation with sodium phosphate causes only slight losses, these being comparable with the losses on evaporation with carbonated alkali, except with the Kavalier ware. This on both tests with sodium phosphate compared favorably with the other wares in contrast with the poor resistance to carbonated alkali. The tests with ammonia and with a mixture of ammonium sulphide and chloride show that ammonium compounds have less action than fixed alkali carbonates, and also show that the mixture of ammonium sulphide and chloride has practically the same action as ammonium hydroxide. Cowper,[23] who noted that solutions of ammonium sulphide and chloride attacked glass more vigorously than sodium carbonate, must have used glass very different from the ware tested here.

V. SUMMARY

Table 6 gives a general summary of the resistance to the various solutions and to mechanical and heat shock of the wares tested. In this table the numerical exponents indicate the minor differences in resistance, the lowest number being the most resistant. The absence of an exponent indicates that the differences in resistance are too small to justify any differentiation between the wares graded in the same group. In the rating of resistance to caustic alkalies the boiling tests only have been considered.

[23] J. Chem. Soc., 41, p. 254; 1882.

TABLE 6.—General Summary of Tests

Ware	Resistance to—						
	Water	Mineral acids	Carbonated alkalies	Caustic alkalies	Ammonia and ammonium salts	Heat shock	Mechanical shock
Kavalier	Poor	Good	Poor	Good [2]	Good [2]	Poor	Poor.
M. E. G. Co	Good [3]	Good	Good [1]	Good [1]	Good	Poor	Poor.
Pyrex	Good [2]	Good	Good [3]	Fair	Good	Good [1]	Good.[a]
Jena	Good [4]	Good	Good [2]	Fair	Good	Good [3]	Fair.
Nonsol	Good [3]	Good	Good [1]	Fair	Good	Good [2]	Fair.
Fry	Good [4]	Good	Good [2]	Fair	Good	Poor	Good.
Libbey	Good [1]	Good	Good [3]	Fair	Good	Good [2]	Good.

[a] Far superior to any of the other wares.

These results indicate that all the American-made wares tested are superior to Kavalier and equal or superior to Jena ware for general chemical laboratory use.

WASHINGTON, October 1, 1917.