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ENTHALPIES AND SPECIFIC HEATS OF ALKALI AND ALKALINE EARTH HYDROXIDES AT HIGH TEMPERATURES

W. D. Powers
G. C. Blalock

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by

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ENTHALPIES AND SPECIFIC HEATS OF ALKALI AND ALKALINE EARTH HYDROXIDES AT HIGH TEMPERATURES

SUMMARY

The enthalpies and heat capacities of lithium, potassium, strontium, and barium hydroxides in the liquid and solid state have been determined with a Bunsen Ice Calorimeter; sodium hydroxide and the lithium-sodium hydroxide eutectic in the liquid state were also studied. Estimates of the heat of fusion have been made. General empirical equations have been developed which represent the enthalpy and heat capacity of the hydroxides in the liquid state.

INTRODUCTION

Samples of the hydroxides heated to constant and uniform temperatures were dropped into Bunsen ice calorimeters. The differences in the heat contents of the samples at constant pressure between the furnace temperature and $0^{o}C$ were measured by observing the change in volume of the ice-water mixture in the calorimeter. The enthalpy was thus obtained directly. The derivative of the enthalpy with respect to temperature yielded the heat capacity.

The design of the apparatus has been described fully elsewhere (1). It was a modification of the device used by the National Bureau of Standards (2). Ease of construction and simplicity in use were the prime objectives in the design.

Briefly, the apparatus consisted of two parts, the furnace and the calorimeter (Figure I). During this investigation the furnaces were changed from 12 to 24 inch long units. The longer furnaces gave more reproducible results than did the 12 inch furnaces. The samples were contained in tapered metal capsules. They were sealed by heliarc welding in an inert gas filled dry box to avoid any possible contamination with water and carbon dioxide. The temperatures of the samples were measured by platinum, platinum-rhodium thermocouples. The capsules were dropped into the calorimeter by electrically fusing a short length of wire on which they were suspended in the furnaces.

The calorimeter was of the Bunsen type in which the heat liberated by the sample was absorbed by an ice-water mixture. The change in volume measured by a system of burets gave the amount of heat liberated (one ml. change in volume is equivalent to 878.7 cal. as calculated from the density of ice and water and the heat of fusion)(1)(2). The calorimeter was surrounded by flaked ice except for the alundum tube through which the sample dropped from the furnace. Freezing of the copper water lines between the buret assembly and the calorimeter was experienced when the flaked ice was in direct contact with the copper tubing. A steel shell was made which eliminated this trouble by providing an air gap between the ice and the calorimeter through which the copper tubing passed.

The total heat measured by the calorimeter was the sum of the heat liberated by the sample and capsule and the heat leakage from the surroundings into the calorimeter down the alundum tube through which the sample dropped. The contribution of the capsule was found from the enthalpy temperature

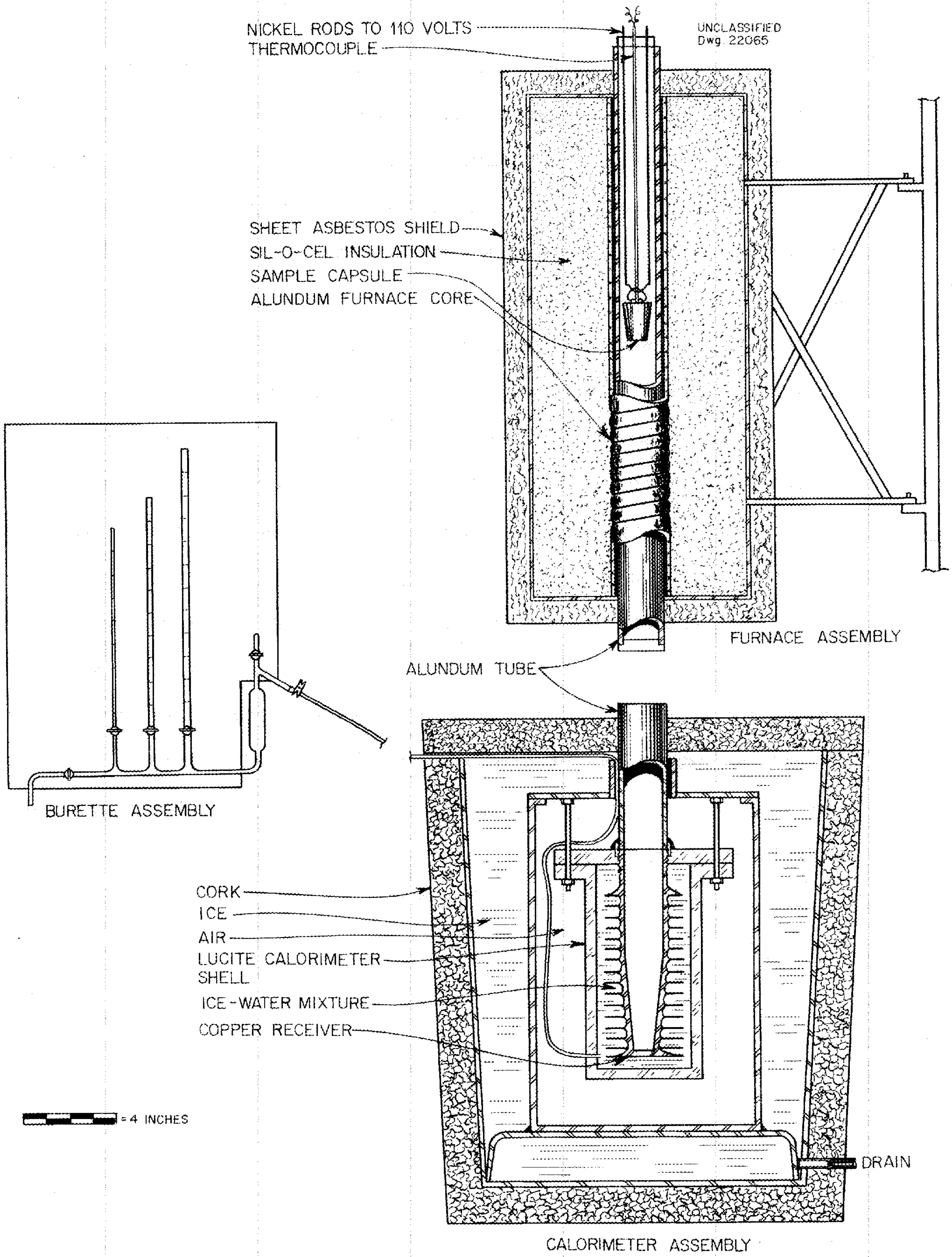

Fig. 1. Schematic Diagram of Bunsen Ice Calorimeter

relationship of empty capsules; the heat leakage was determined from the heat leakage measurements made before the capsule was dropped and after equilibrium was established. At 500°C the heat liberated by the sample and capsule was of the order of 15000 calories, 50 to 70% of which came from the sample. The heat leakage from the surroundings was 100 to 200 calories for the hour in which the measurements were made.

The linear dependence of enthalpy on temperature of the samples was calculated by least squares; the scatter of the data was large enough so that representing the data by a higher power relation was not warranted. Thus the reported heat capacities are not temperature dependent. The standard deviation of the heat capacity was calculated. This was used to determine the 95% confidence limits on the reported heat capacity.

At the start of this investigation the only high temperature data reported in the literature were those for sodium hydroxide (3). The preliminary results of the heat capacity research on the several hydroxides at Oak Ridge National Laboratory have been reported in a series of memoranda (4); some of these were obtained using 12 inch furnaces. Recently the National Bureau of Standards has reported data for sodium hydroxide (5) which are compared to the results previously determined at ORNL.

ALUMINUM OXIDE DETERMINATIONS

Enthalpy and specific heat determinations have been made for pure aluminum oxide. It has been proposed as a high temperature calorimetric standard by the Bureau of Standards (6). One hundred and three determinations at ORNL over the temperature range of 400-900°C (average temperature 664°C) agree with the NBS results within 3.3% for the enthalpy and 1.3% for the heat capacity as shown in Table I.

TABLE I

ENTHALPY AND HEAT CAPACITY
OF ALUMINUM OXIDE

	ORNL	NBS	% Deviation
H_{500^oC}, (cal./gm)	126	122	3.3
$H_{800^oC} - H_{0^oC}$	214	209	2.4
c_p at 664°C, (cal./gm. °C)	0.294 ± 0.013	0.2901	1.3

CHEMICAL PURITY OF THE HYDROXIDES

Pure hydroxides of low water and carbonate content were used in this investigation. A summary of the analytical data is shown in Table II.

The low total alkalinity of the lithium hydroxide and of the strontium hydroxide after use was due to the corrosion of the metal capsule and consequent metallic impurities. These particular capsules were used at higher temperatures more often than the other capsules analyzed. Most of the capsules were run until the hydroxide leaked through the capsule (in most cases at the

welded joint). Final analyses were made only on samples which had not ruptured. The error due to the solution of metal in the hydroxide is believed to be within the error of the determination as any reaction products between the sample and the capsule would have enthalpies and heat capacities approximating the original materials. No significant change of enthalpy was noted after prolonged use of the capsules at high temperatures.

TABLE II

ANALYSIS OF MATERIALS

Material	NaOH	KOH	LiOH	LiOH NaOH	$Sr(OH)_2$	$Ba(OH)_2$
Capsule	YW	YV	ZI	ZN	ZK	ZR
Capsule material	Nickel	Nickel	Inconel	Inconel	Inconel	Inconel
Original Analysis (% by Wt.)						
% Total Alkalinity	99.97	100.00	*	*	99.80	100.4
% Metal Carbonate	.13	.12			.47	.43
Final Analysis						
% Total Alkalinity	99.46	98.68	96.6	99.73	94.1	99.81
% Metal Carbonate	.28	.37	.05	.28	.19	.30

*No original analysis was made on this material. The purity of the lithium hydroxide is of the same order of purity as the other hydroxides. A typical analysis is 99.90% total alkalinity, 0.13% Li_2CO_3.

SODIUM HYDROXIDE

The individual results of the enthalpies of sodium hydroxide are listed in the appendix and plotted in Figure II. Capsule YW was run in the 24 inch furnaces, the others in the 12 inch furnaces. The enthalpies obtained by the different furnaces agreed within 5% of each other. The enthalpy and heat capacity of liquid sodium hydroxide are represented by the following equations:

$$H_T - H_{0^oC} = 65.8 + 0.494T$$

$$c_p = 0.49 \pm 0.02$$

where H is the enthalpy in cal./g.

T is the temperature ^oC

c_p is the heat capacity in cal./g. ^oC

No attempt was made to determine the properties of the solid phases because of the insufficient data in that region. The results obtained by NBS for the liquid and solid phases are plotted in Figure II together with the results of this investigation obtained below the melting point.

POTASSIUM HYDROXIDE

The individual results of the enthalpies of potassium hydroxide are listed in the appendix and plotted in Figure III. Capsule YV was run in the 24 inch furnaces, the others in the 12 inch furnaces. The enthalpy and heat capacity of liquid potassium hydroxide are represented by the following equations:

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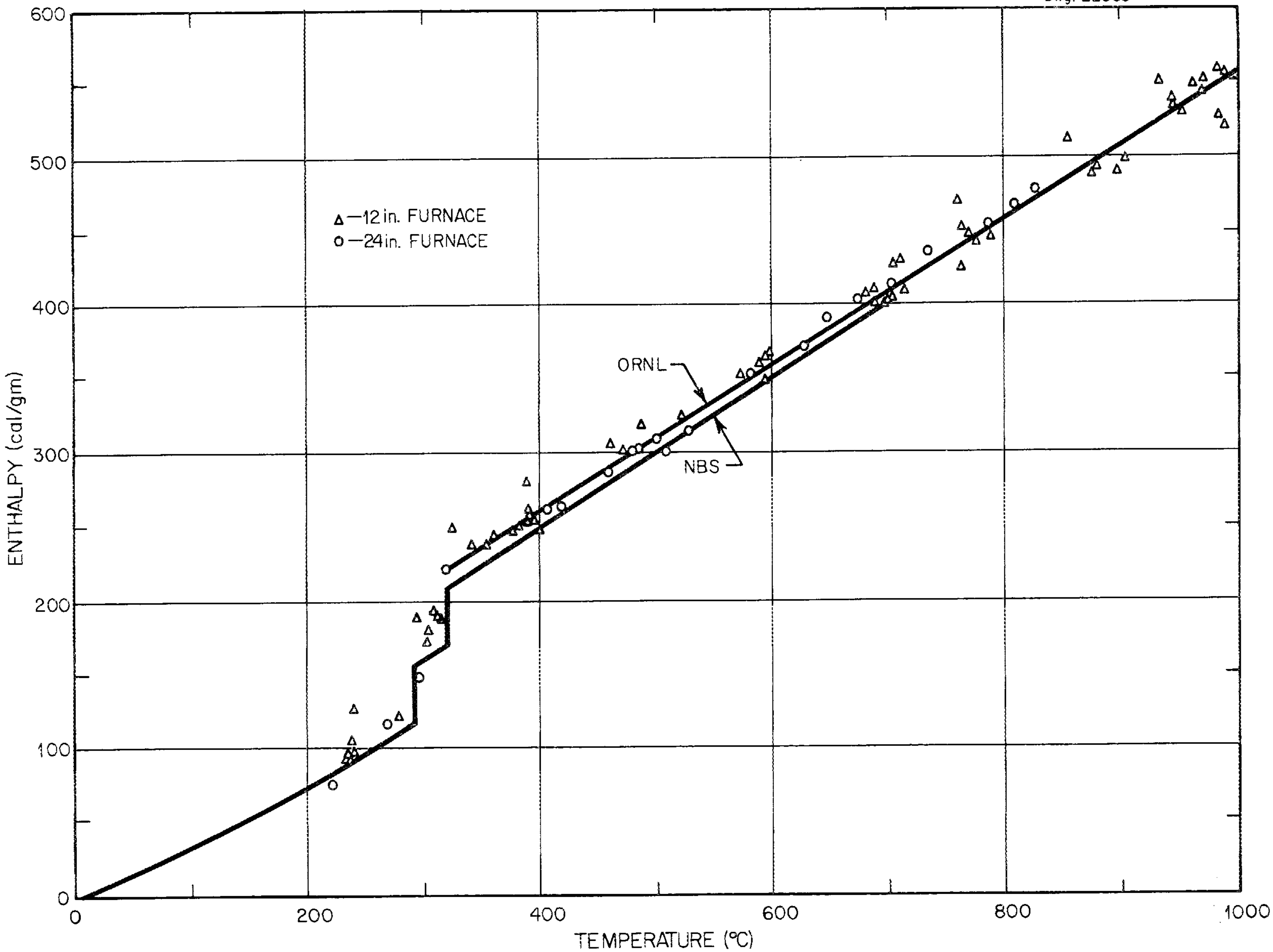

Fig. 2. Temperature vs. Enthalpy for Sodium Hydroxide

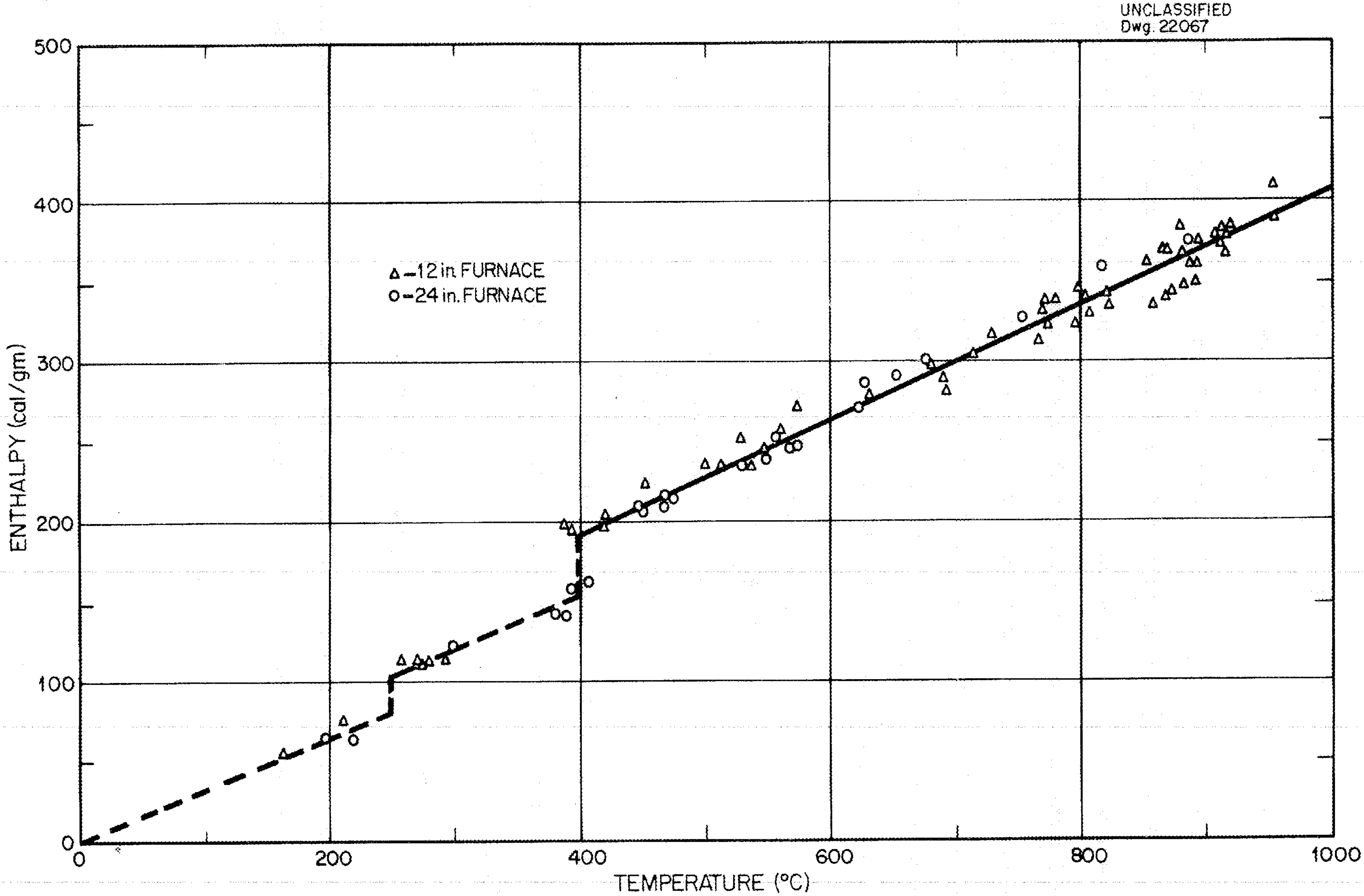

Fig. 3. Temperature vs. Enthalpy for Potassium Hydroxide

$$H_T - H_{0^oC} = 52.5 + 0.354T$$

$$c_p = 0.35 \pm 0.02$$

The heats of transition of the two solid states of potassium hydroxide ($\alpha \gtrless \beta$ at 249°C) and the heat of fusion (400°C) may be roughly estimated from the data below the melting point. A linear relationship between the enthalpy and temperature was calculated for the low temperature form from 0°C to the transition point. A mean heat capacity between the α form and the liquid was used for the β form. The enthalpy points at 379°C and above for the β form were considered subject to error since they were near the melting point. The following equations were calculated

$$H_T(\alpha) - H_{0^oC} = 0.32T$$

$$H_T(\beta) - H_{0^oC} = 20.2 + .335T$$

$$H_{249^o}(\beta) - H_{249^o}(\alpha) = 24$$

$$H_{400^o}(\text{liquid}) - H_{400}(\beta) = 40$$

These agree within the experimental error of previously reported values of the heat of transition (7), 27 cal./g. and heat of fusion 32.6 cal./g. (7) (8).

LITHIUM HYDROXIDE

The individual results of lithium hydroxide are listed in the appendix and plotted in Figure IV. All the capsules were run in the 24 inch furnaces.

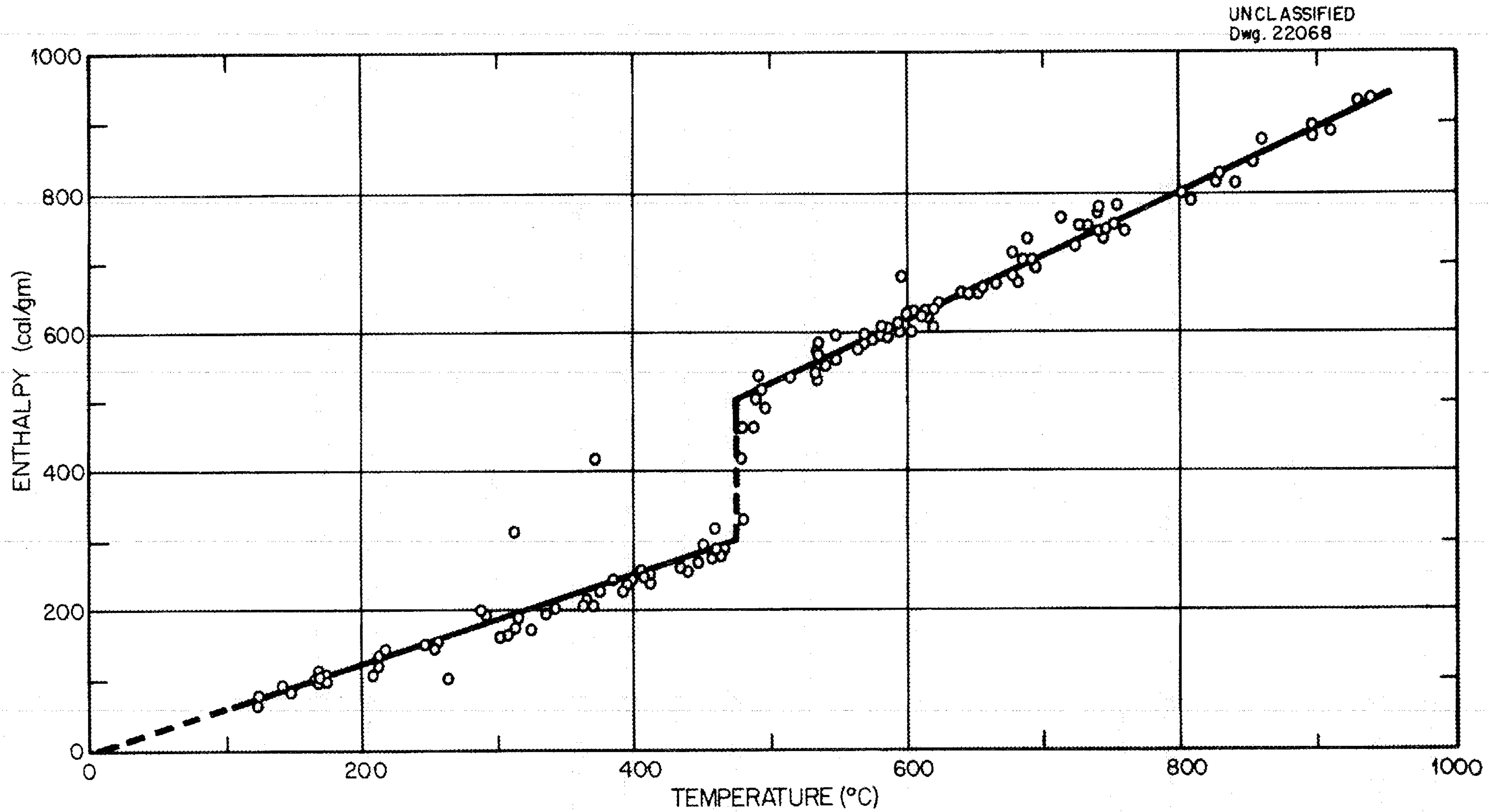

Fig. 4. Temperature vs. Enthalpy for Lithium Hydroxide

The enthalpy and heat capacity of the liquid lithium hydroxide are represented by the following equations:

$$H_T - H_{0^oC} = 64 + 0.923$$

$$c_p = 0.92 \pm 0.04$$

The enthalpy and heat capacity of the solid are represented by the following equations:

$$H_T - H_{0^oC} = -5 + 0.627$$

$$c_p = 0.63 \pm 0.04$$

The heat of fusion at 473°C is 210 cal./g.

EUTECTIC OF LITHIUM AND SODIUM HYDROXIDES

The individual results of the enthalpies of lithium-sodium hydroxide eutectic (27 Mole % LiOH) are listed in the appendix and plotted in Figure V. All capsules were run in the 24 inch furnaces. The enthalpy and heat capacity of the liquid mixture are represented by the following equations:

$$H_T - H_{0^oC} = 44.3 + 0.599T$$

$$c_p = 0.60 \pm 0.02$$

The melting point is at 218° ± 5°C. There is also a transition point at 180° ± 5°C. Because of the small amount of data no estimate is made of the heat of fusion.

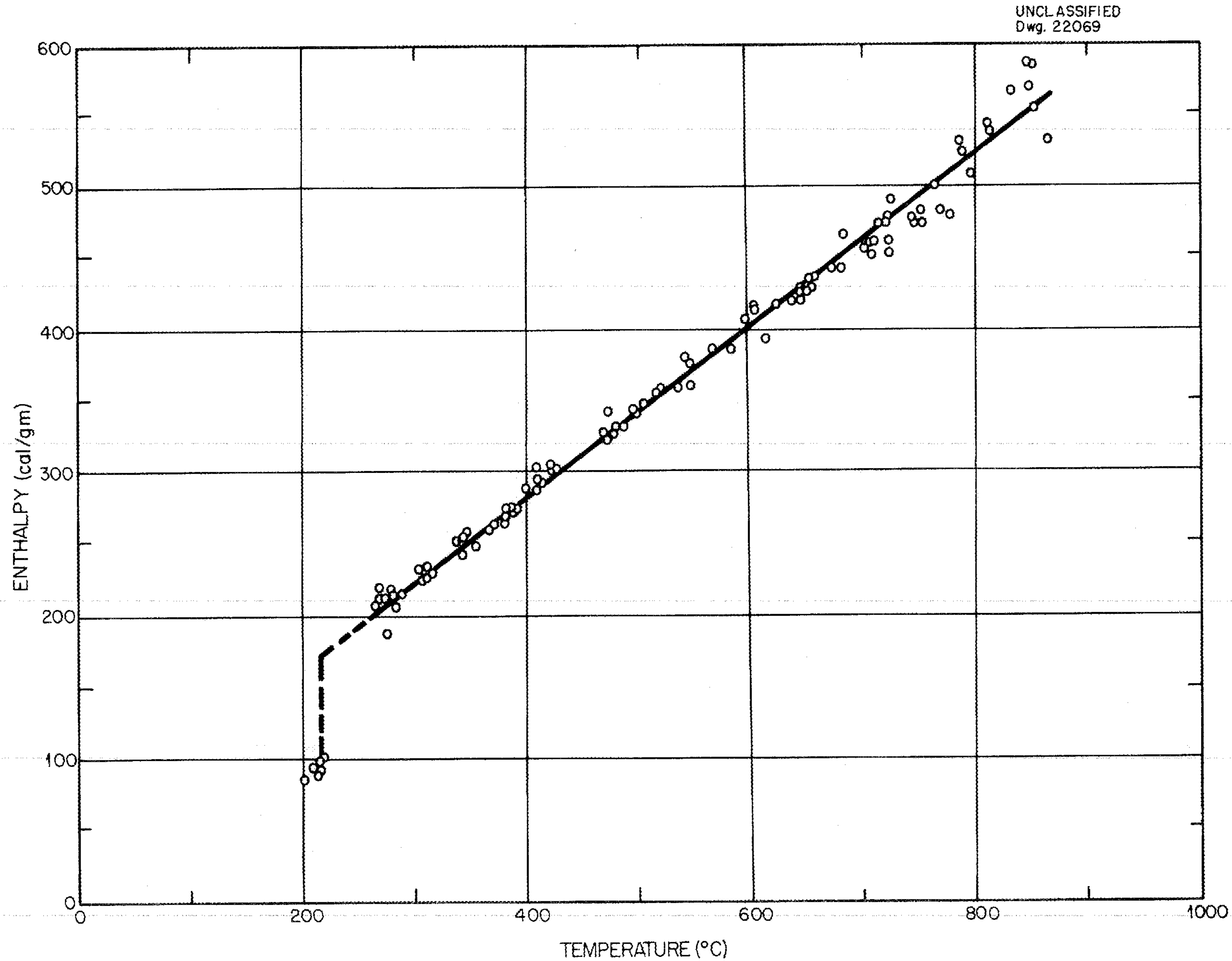

Fig. 5. Temperature vs. Enthalpy for Lithium — Sodium Hydroxide Eutectic

STRONTIUM HYDROXIDE

The individual results of the enthalpies of strontium hydroxide are listed in the appendix and plotted in Figure VI. All the capsules were run in the 24 inch furnaces. The enthalpy and the heat capacity of the liquid are represented by the following equations:

$$H_T - H_{0^\circ C} = -13.5 + 0.314T$$
$$c_p = 0.31 \pm 0.02$$

The enthalpy and heat capacity for the solid from 272°C to 470°C are represented by the following equations:

$$H_T - H_{0^\circ C} = -17.6 + 0.239T$$
$$c_p = 0.24 + 0.04$$

The heat of fusion is 43 cal./g. at 510°C.

BARIUM HYDROXIDE

The individual results of the enthalpies of barium hydroxide are listed in the appendix and plotted in Figure VII. Capsules ZB and ZC were run in 12 inch furnaces, capsules ZP, ZR, ZX and ZY in the 24 inch furnaces.

The enthalpy and the heat capacity of the liquid are represented by the following equations:

$$H_T - H_{0^\circ C} = 11.7 + 0.195$$
$$c_p = 0.195 \pm 0.02$$

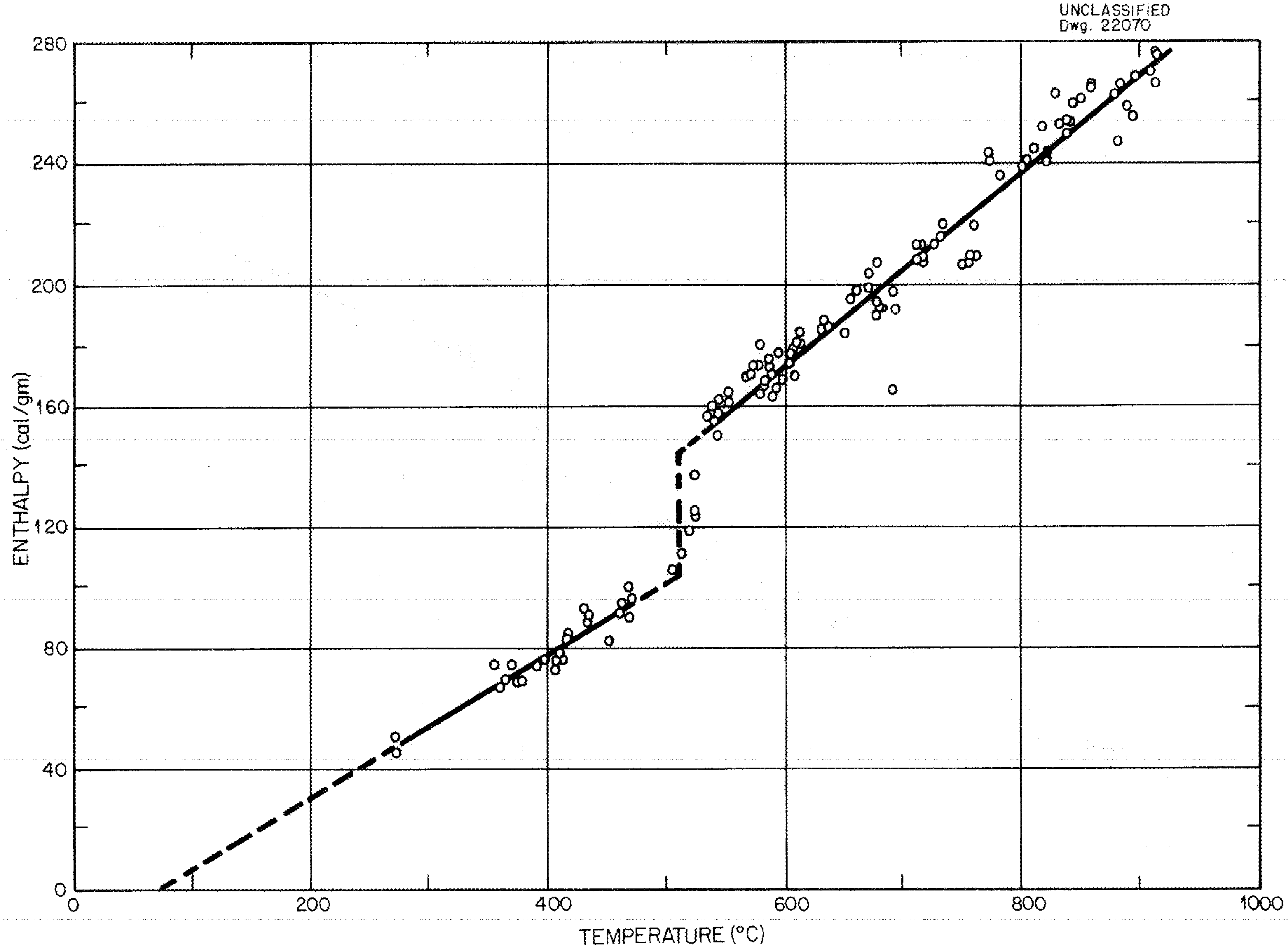

Fig. 6. Temperature vs. Enthalpy for Strontium Hydroxide

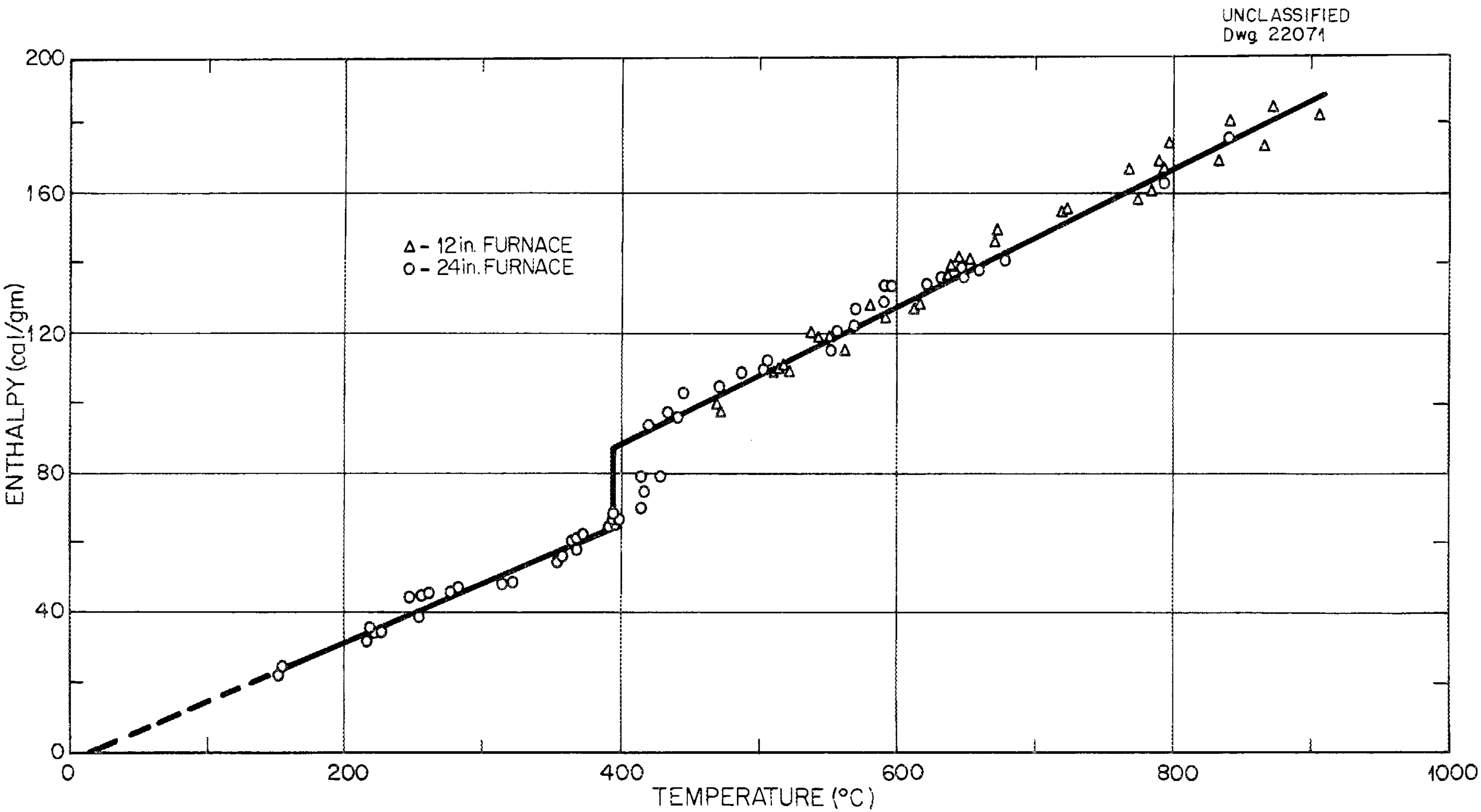

Fig. 7. Temperature vs. Enthalpy for Barium Hydroxide

The enthalpy and heat capacity for the solid from 150°C to 395°C are represented by the following equations:

$$H_T - H_{0^oC} = -2.0 + 0.168T$$

$$c_p = 0.17 \pm 0.02$$

The heat of fusion is 24 cal./g. at 395°C. Seward (9) reported 20 cal./g.

DISCUSSION OF RESULTS

It is of interest to find general relationships between the enthalpies and heat capacities of the various hydroxides. For most of the solid elements the heat capacity at constant volume is equal to 3R or 6 cal./°C per gram atom. The more modern theories of Einstein and Debye have the same value as a limit which is reached at normal temperatures for most elements (10). At constant pressure the heat capacities are found to be greater, being about 6.4 cal./°C per gram atom (Dulong and Petit's law). The Debye equation also predicts correctly the heat capacity of some compounds, these being the compounds that crystalize in the cubic system. The equation may be modified to predict compounds that do not crystalize in the cubic lattice. In 1865 Kopp suggested that the molar heat capacity of a compound is approximately equal to the sum of the atomic heat capacities of its constituent elements.

In the case of liquid compounds which have no definite group of atoms or radicals such as the sulfate or hydroxide ion it has been found empirically

that each atom contributes approximately 8 cal/°C to the molar heat capacity of the compound (11). Molar heat capacities for the hydroxides were found to be 6.86 cal/°C per atom for the alkali hydroxides and 7.20 cal/°C per atom for the alkaline earth hydroxides. Groups of atoms would be expected to lower the molar heat capacity of the compound. Molar heat capacities for the hydroxides were found to be 11.0 cal/°C per ion for both classes of hydroxides.

In Figure VIII the comparison between the enthalpies of the different hydroxides on the mean gram atom basis is shown. The hydroxides form two groups, the alkalies and the alkaline earths. For the alkali hydroxides the molar enthalpy may be represented by

$$\underline{H}_T - \underline{H}_{0^\circ C} = N(795 + 6.86T) \qquad (1)$$

and for the alkaline earth hydroxides by

$$\underline{H}_T - \underline{H}_{0^\circ C} = N(10 + 7.20T) \qquad (2)$$

where N is the number of atoms per molecule

$\underline{H}$ is the enthalpy in cal./gram mole

T is the temperature °C

In Table III are shown the calculated and observed heat capacities of the liquid hydroxides and their deviation together with the deviations between the observed and calculated enthalpies at various temperatures.

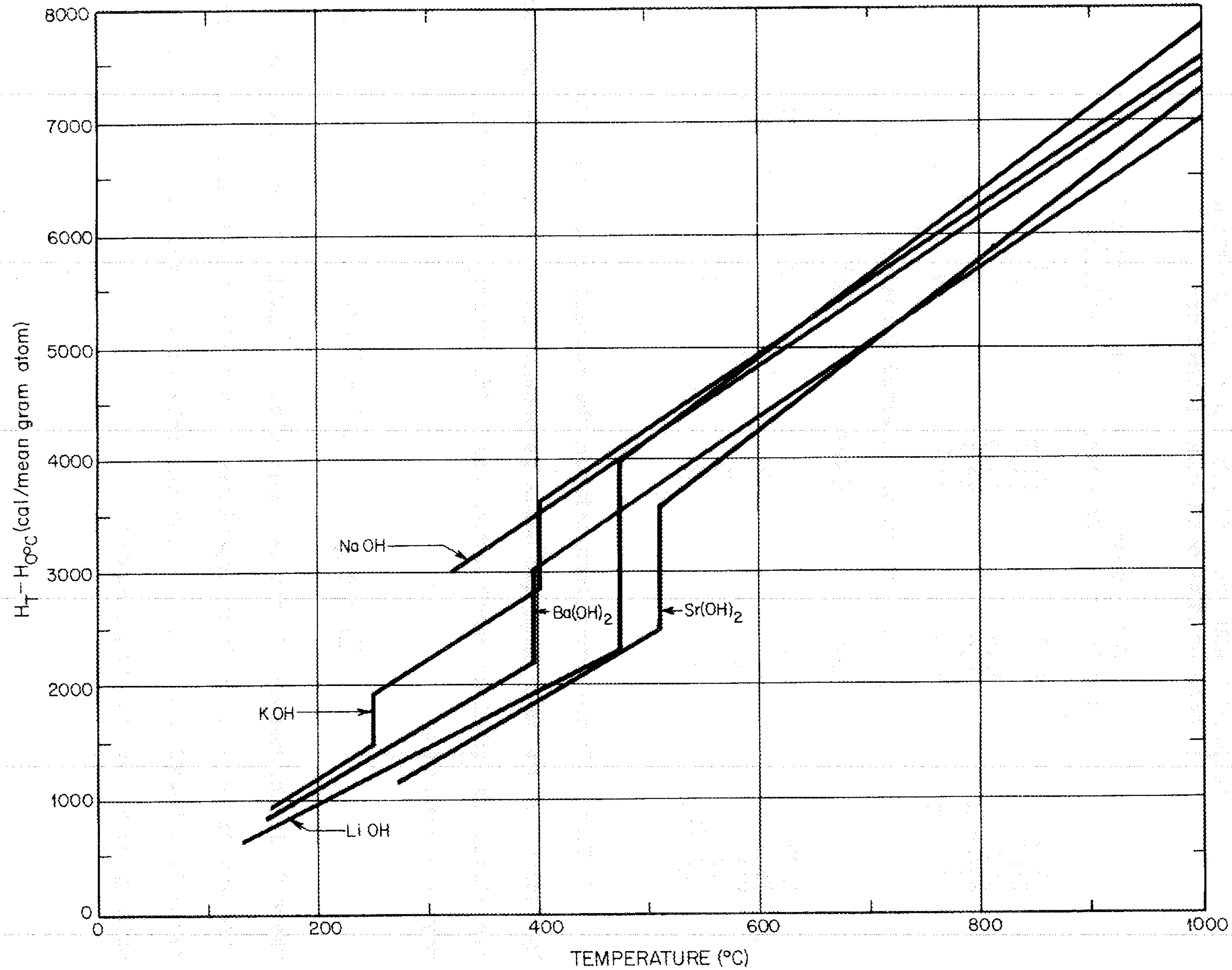

Fig. 8. Comparison of Hydroxides (Enthalpy per Mean Gram Atom)

TABLE III

CALCULATED AND OBSERVED HEAT CAPACITY AND ENTHALPY BASED ON MEAN GRAM ATOM (Equations 1, 2)

	Heat Capacity Calculated	Observed	cal./g. mole °C Deviation
LiOH	20.6	22.1	7%
NaOH	20.6	19.8	-4
KOH	20.6	19.9	-3
$Sr(OH)_2$	36.0	38.2	6
$Ba(OH)_2$	36.0	33.4	-7

Deviation of Observed Enthalpy

	400°C	600°C	800°C	1000°C
LiOH	----	1%	2%	3%
NaOH	-1%	-2	-2	-2
KOH	3	1	0	-1
$Sr(OH)_2$	----	-2	0	1
$Ba(OH)_2$	6	2	0	-2

In Figure IX the comparison between the enthalpies of the different hydroxides on the mean gram ion basis is shown. There is no difference between the alkali and alkaline earth hydroxides. The enthalpies of all the hydroxides may be expressed as

$$\underline{H}_T - \underline{H}_{0^\circ C} = N' \; (710 + 11.0T) \qquad (3)$$

where N' is the number of ions per molecule. In Table IV are shown the observed and calculated heat capacities of the liquid hydroxides and their deviations together with the deviations between observed and calculated enthalpies at various temperatures.

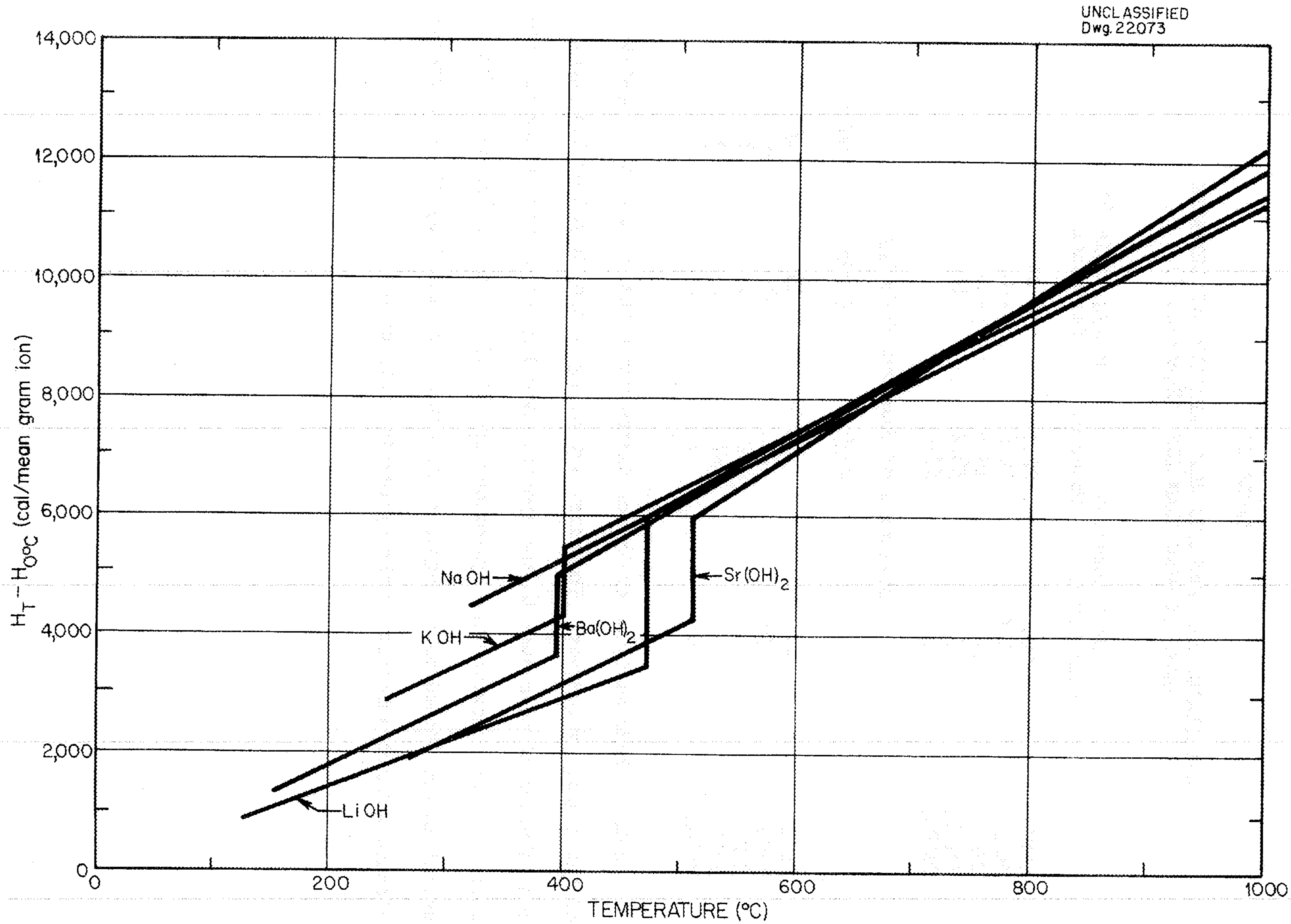

Fig. 9. Comparison of Hydroxides (Enthalpy per Mean Gram Ion)

TABLE IV

CALCULATED AND OBSERVED HEAT CAPACITY AND ENTHALPY
BASED ON MEAN GRAM ION (Equation 3)

	Heat Capacity		cal./g. mole °C
	Calculated	Observed	Deviation
LiOH	22.0	22.1	0%
NaOH	22.0	19.8	-10
KOH	22.0	19.9	-10
$Sr(OH)_2$	33.0	38.2	16
$Ba(OH)_2$	33.0	33.4	1

Deviation of Observed Enthalpy

	400°C	600°C	800°C	1000°C
LiOH	----	1%	1%	1%
NaOH	3%	-1	-3	-4
KOH	7	2	-1	-3
$Sr(OH)_2$	----	-3	1	4
$Ba(OH)_2$	0	1	1	1

Both methods satisfactorily correlated the enthalpy and heat capacity of the liquid hydroxides. The first set of equations (based on the equal contribution of each atom to the specific heat) gives better values for the specific heat. However the hydroxides are divided into two groups. The second method (based on the equal contribution of each ion) gives an overall picture without subdividing the hydroxides into groups.

The heat capacity of the eutectic mixture of lithium and sodium hydroxide is additive, i.e., it is the sum of the product of the individual heat capacities and mole fraction. The enthalpies are not additive, however. The observed enthalpy is lower indicating a heat of solution of the order of 20-30 calories per gram of solution.

TABLE V

	Observed	Calculated
c_p (cal./g. $^{\circ}$C)	0.60	0.59
$H_{500^{\circ}} - H_{0^{\circ}C}$ (cal./g.)	344.	373.
$H_{800^{\circ}} - H_{0^{\circ}C}$ (cal./g.)	525.	550.

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SODIUM HYDROXIDE
INDIVIDUAL ENTHALPIES

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
YW	1	220	77		
YH	4	231	93		
YH	4	233	97		
YH	3	235	95		
YH	3	236	106		
YH	1	239	98		
YH	1	240	127		
YW	1	268	118		
YH	1	281	122		
YH	3	293	189		
YW	1	296	149		
YH	2	303	178		
YH	3	304	171		
YH	1	309	192		
YH	1	311	189		
YH	2	314	187		
YH	3	326	259*		
YH	4	342	238	235	3
YH	5	354	238	241	-3
YH	2	361	243	244	-1
YI	4	376	247	251	-4
YH	4	380	249	253	-4
YH	1	386	253	256	-3
YH	1	386	281	256	25
YH	4	389	256	258	-2
YH	4	390	256	258	-2
YH	3	391	260	259	1
YI	4	394	255	260	-5
YI	1	398	250	262	-12
YW	1	407	262	267	-5
YW	1	421	264	274	-10
YH	3	458	307	292	15
YW	3	460	288	293	-5
YH	2	472	302	299	3
YW	2	473	298	299	-1
YW	1	479	302	302	0
YI	4	484	304	305	-1

*This measurement was not used in the least-squares analysis.

SODIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
YH	4	486	319	306	13
YW	1	500	309	313	-4
YW	2	506	301	316	-15
YH	5	524	326	324	2
YW	1	528	316	326	-10
YL	3	572	353	348	5
YW	2	582	354	353	1
YJ	4	588	359	356	3
YH	4	594	364	359	5
YH	1	595	348	360	-12
YH	4	596	365	360	5
YW	1	600	361	362	-1
YW	5	628	372	376	-4
YW	3	646	391	385	6
YW	3	673	405	398	7
YH	2	680	408	402	6
YL	3	688	401	405	-4
YH	3	688	410	405	5
YL	4	696	400	409	-9
YH	4	697	400	410	-10
YI	1	702	405	412	-7
YW	2	702	415	412	3
YH	5	704	428	413	15
YL	5	710	431	416	15
YH	1	712	409	417	-8
YW	3	734	437	428	9
YH	5	760	456	441	15
YL	5	761	452	441	11
YH	1	763	426	442	-16
YH	3	770	444	446	-2
YL	3	775	443	448	-5
YW	2	784	455	453	2
YH	1	788	446	455	-9
YW	4	808	468	465	3
YW	5	826	479	474	5
YH	2	854	513	487	26
YL	4	875	489	498	-9
YH	4	876	492	498	-6
YW	5	891	533	506	27

SODIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc.
YH	1	896	490	508	-18
YL	1	904	499	512	-13
YL	5	934	553	527	26
YL	3	943	538	531	7
YH	3	944	535	532	3
YL	3	953	530	536	-6
YL	3	962	548	541	7
YL	1	969	543	544	-1
YL	4	970	553	545	8
YH	1	984	528	552	-24
YH	4	984	560	552	8
YL	4	986	558	553	5
YL	1	990	521	555	-34

POTASSIUM HYDROXIDE
INDIVIDUAL ENTHALPIES

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc.
YK	1	162	54	52	2
YK	1	196	63	63	0
YK	5	212	74	68	4
YV	1	218	63	70	-7
YK	3	259	112	107	5
YV	1	269	114	110	4
YK	4	272	112	111	1
YK	4	274	111	112	-1
YK	4	277	111	113	-2
YK	1	292	112	118	-6
YV	1	298	122	120	2
YV	4	379	142*		
YV	5	388	140*		
YK	2	388	197*		
YK	2	392	194*		
YV	1	392	157*		
YV	1	406	162*		
YK	2	418	197	200	-3
YK	5	420	203	201	2
YV	1	422	204	202	2
YV	3	446	209	210	-1
YV	2	450	205	212	-7
YK	2	452	221	212	9
YV	1	466	215	217	-2
YV	2	467	210	218	-8
YV	1	475	214	221	-7
YK	5	495	288*		
YK	2	500	235	229	6
YK	1	512	234	234	0
YK	2	527	250	239	11
YV	1	528	234	239	-5
YU	4	536	233	242	-9
YU	4	546	244	246	-2
YV	2	548	239	246	-7
YV	2	557	251	250	1
YK	3	560	257	251	6
YV	2	568	244	253	-9
YK	5	572	270	255	15
YK	4	572	226*		

*This measurement was not used in the least-squares analysis.

POTASSIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature	$H_T - H_{0^oC}$	$H_T - H_{0^oC}$	Diff. Obs-Calc
YV	1	574	246	256	-10
YV	5	624	271	273	-2
YV	3	627	286	274	12
YU	1	633	278	276	2
YV	3	652	289	283	6
YK	2	663	150*		
YV	2	676	300	292	8
YU	4	681	296	293	3
YK	2	691	289	297	-8
YK	1	692	281	297	-16
YU	3	714	305	305	0
YV	3	714	307	305	2
YK	4	726	314	309	5
YU	3	732	187*		
YV	2	754	327	319	8
YU	1	765	311	323	-12
YK	4	769	331	325	6
YU	5	770	337	325	12
YK	3	774	322	326	-4
YK	3	781	337	329	8
YU	5	794	321	333	-12
YK	3	798	344	335	9
YU	3	802	339	336	3
YK	2	806	329	338	-9
YV	5	806	335	338	-3
YV	4	814	359	341	18
YK	2	822	334	343	-9
YU	4	822	341	343	-2
YU	3	852	361	354	7
YU	2	857	334	356	-22
YK	3	863	369	358	11
YU	3	865	370	359	11
YU	3	867	340	359	-19
YU	5	874	342	362	-20
YU	2	878	384	363	21
YU	3	880	367	364	3
YU	5	880	346	364	-18
YU	1	886	360	366	-6
YV	5	886	375	366	9
YU	3	891	349	368	-19
YU	4	893	359	368	-9

*This measurement was not used in the least-squares analysis.

POTASSIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0^oC}$ cal./g. Obs.	$H_T - H_{0^oC}$ Calc.	Diff. Obs.-Calc.
YU	3	894	375	369	6
YU	3	900	236*		
YU	4	907	379	373	6
YU	3	910	383	374	9
YU	4	910	372	374	-2
YU	1	912	382	375	7
YU	4	916	379	377	2
YU	4	916	366	377	-11
YU	3	918	383	377	6
YU	4	933	240*		
YU	4	953	409	390	19
YU	2	955	388	390	-2

*This measurement was not used in the least-squares analysis.

LITHIUM HYDROXIDE
INDIVIDUAL ENTHALPIES

Capsule	Calorimeter	Temperature	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff Obs-Calc
ZI	3	124	82	73	9
YS	3	124	70	73	-3
YS	3	142	92	84	8
ZI	3	149	87	84	3
YS	3	164	103	98	5
YS	3	167	104	99	5
YS	3	168	109	100	9
ZI	3	168	100	100	0
ZI	3	172	104	103	1
ZI	3	172	100	103	-3
YS	3	207	110	125	-15
YS	3	210	120	126	-6
ZI	3	212	136	128	8
ZI	3	215	142	130	12
YS	3	244	151	148	3
YS	3	254	148	154	-6
ZI	3	254	155	154	1
ZI	3	263*	103		
YS	3	288	201	175	26
ZI	3	292	195	178	17
YS	3	302	164	184	-20
YS	4	306	165	187	-22
YS	4	312*	314		
YS	3	313	178	191	-13
ZI	3	314	183	192	-9
ZI	3	325	175	198	-23
YS	1	336	199	205	-6
YS	3	341	205	209	-4
ZI	1	362	210	222	-12
YS	1	365	216	224	-8
ZI	1	372	212	228	-16
YS	4	374*	419		
ZT	3	374	231	229	2
YS	4	386	244	237	7
YS	4	393	236	241	-5
YS	4	394	240	242	-2

*This measurement was not used in the least-squares analysis.

LITHIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
YS	3	396	245	243	2
YS	3	404	260	248	12
ZW	2	408	250	250	0
YS	4	410	251	252	-1
ZI	3	410	247	252	-5
ZI	4	434	267	267	0
ZI	3	440	256	271	-15
ZT	4	445	270	274	-4
ZU	4	450	284	277	7
YS	4	451	298	277	21
ZT	4	456	276	281	-5
ZI	4	460	319	283	36
ZW	4	462	289	284	5
ZT	4	463	290	285	5
ZU	4	464	283	286	-3
ZI	4	478	423		
YS	4	479	466		
ZT	3	480	333		
ZU	4	488	466		
ZI	4	490	505		
ZU	3	493	540		
YS	4	494	520		
ZW	2	496	492		
ZT	3	517	537	541	-4
ZU	3	534	576	557	19
ZW	2	534	532	557	-25
ZW	2	534	537	557	-20
ZT	5	536	580	559	21
ZU	5	538	570	559	11
ZS	5	542	552	562	-10
ZT	5	551	560	571	-11
ZW	4	552	596	572	24
ZW	3	564	574	583	-9
ZT	5	570	599	588	11
ZW	3	571	586	589	-3
ZU	5	575	588	592	-4
ZW	5	582	610	601	9
ZW	3	582	599	601	-2
ZT	4	585	610	604	6
ZW	3	586	596	605	-9

LITHIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZT	2	593	614	611	3
ZT	4	596	610	614	-4
ZS	5	597	682*		
ZT	2	598	611	616	-5
ZT	5	600	624	618	6
ZU	4	605	631	622	9
ZW	2	605	606	622	-16
ZT	3	611	623	628	5
ZT	2	614	624	631	-7
ZU	3	614	637	631	6
ZU	2	622	634	638	-4
ZW	2	622	604	638	-34
ZU	4	624	643	640	3
ZU	3	640	659	655	4
ZT	2	644	653	658	-5
ZT	5	652	657	666	-9
ZT	2	656	664	669	-5
ZW	3	666	671	679	-8
ZT	1	676	719	688	31
ZU	2	678	682	690	-8
ZU	2	678	677	690	-13
ZW	4	686	733	697	36
ZW	4	686	707	697	10
ZT	2	692	702	703	-1
ZU	2	694	694	704	-10
ZT	3	714	764	723	41
ZW	5	724	724	732	-8
ZW	5	729	754	737	17
ZT	3	733	753	740	13
ZU	3	737	771	744	27
ZW	5	740	782	747	35
ZW	1	744	742	751	-9
ZT	1	744	735	751	-16
ZU	2	746	748	752	-4
ZW	1	753	783	759	24
ZT	2	753	755	759	-4
ZW	2	758	745	764	-19
ZT	2	802	799	804	-5
ZU	2	807	790	809	-19

*This measurement was not used in the least-squares analysis.

LITHIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc.
ZU	3	828	823	828	-5
ZT	3	828	818	828	-10
ZT	5	840	816	839	-23
ZW	4	854	842	852	-10
ZW	3	860	879	858	21
ZT	4	896	881	891	-10
ZU	4	898	893	893	0
ZU	2	906	890	900	-10
ZT	1	934	930	926	4
ZW	1	940	935	931	4

LITHIUM-SODIUM HYDROXIDE EUTECTIC
INDIVIDUAL ENTHALPIES

Capsule	Calorimeter	Temperature °C	$H_T - H_{0^\circ C}$ cal./g. Obs.	$H_T - H_{0^\circ C}$ Calc.	Diff. Obs-Calc
ZN	3	202	86		
ZO	3	210	95		
ZN	3	214	89		
ZN	3	214	99		
ZO	3	215	92		
ZO	3	218	102		
ZN	3	264	208	202	6
ZO	3	268	220	205	15
ZN	3	268	213	205	8
ZN	3	274	213	208	5
ZN	3	275	188	209	-21
ZO	3	278	220	211	9
ZN	3	282	214	213	1
ZO	3	283	207	214	-7
ZO	3	289	216	217	-1
ZN	3	304	233	226	7
ZN	3	305	225	227	-2
ZO	3	310	232	230	2
ZO	3	310	234	230	4
ZO	3	312	226	231	-5
ZN	3	312	227	231	-4
ZN	3	315	229	233	-4
ZN	3	336	252	246	6
ZN	4	342	243	249	-6
ZO	4	344	255	250	5
ZM	5	346	260	252	8
ZN	3	354	250	256	-6
ZO	3	366	260	264	-4
ZM	1	372	264	267	-3
ZN	3	380	264	272	-8
ZN	3	382	269	273	-4
ZM	1	382	275	273	2
ZO	3	387	275	276	-1
ZO	3	388	272	277	-5
ZO	3	392	275	279	-4
ZN	3	400	290	284	6
ZN	3	408	289	289	0
ZM	4	408	304	289	15

LITHIUM-SODIUM HYDROXIDE EUTECTIC (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZO	1	410	295	290	5
ZO	3	415	293	293	0
ZO	4	423	306	298	8
ZN	4	426	302	300	2
ZN	1	426	302	300	2
ZO	5	470	328	326	2
ZO	1	474	344	328	16
ZM	2	475	323	329	-6
ZN	5	478	327	331	-4
ZN	3	481	333	333	0
ZN	3	487	332	336	-4
ZO	3	497	345	342	3
ZO	3	497	343	342	1
ZM	5	499	342	343	-1
ZM	3	506	348	348	0
ZM	1	516	356	354	2
ZL	1	520	360	356	4
ZM	2	536	359	366	-7
ZM	5	542	380	369	11
ZL	5	546	377	372	5
ZM	3	548	361	373	-12
ZM	1	566	388	383	5
ZM	4	584	387	394	-7
ZM	1	590	557*		
ZM	5	596	407	401	-6
ZM	4	599	503*		
ZM	5	603	418	406	12
ZN	3	605	413	407	6
ZM	1	615	394	413	-19
ZO	3	624	417	418	-1
ZM	3	638	420	427	-7
ZM	4	646	429	431	-2
ZM	1	646	425	431	-6
ZM	1	647	421	432	-11
ZM	5	652	426	435	-9
ZM	4	655	436	437	-1

*This measurement was not used in the least-squares analysis.

LITHIUM-SODIUM HYDROXIDE EUTECTIC (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZM	1	656	430	437	-7
ZM	1	660	437	440	-3
ZM	1	674	444	448	-4
ZM	1	684	444	454	-10
ZN	3	686	466	455	11
ZM	1	703	457	466	-9
ZM	4	708	462	469	-7
ZN	3	710	463	470	-7
ZM	1	710	453	470	-17
ZN	3	714	473	472	1
ZM	3	721	475	476	-1
ZN	3	722	478	477	1
ZM	4	724	462	478	-16
ZM	1	725	454	479	-25
ZM	4	726	491	479	12
ZN	3	744	478	490	-12
ZM	5	747	475	492	-17
ZO	3	751	502	494	8
ZM	3	754	495	496	-1
ZM	4	766	521	503	18
ZM	5	770	503	506	-3
ZM	5	778	500	511	-11
ZM	4	787	532	516	16
ZM	4	789	525	517	8
ZM	4	798	508	523	-15
ZM	4	813	543	532	11
ZM	4	814	538	532	6
ZM	4	834	567	544	23
ZM	4	848	586	553	33
ZM	4	850	568	554	14
ZM	4	852	553	555	-2
ZM	4	853	586	556	30
ZM	4	866	532	563	-31

STRONTIUM HYDROXIDE
INDIVIDUAL ENTHALPIES

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZJ	3	272	50	47	3
ZK	3	272	45	47	-2
ZK	4	354	74	67	7
ZJ	4	359	67	68	-1
ZJ	3	364	69	69	0
ZK	3	368	74	70	4
ZJ	3	374	69	72	-3
ZK	3	376	69	72	-3
ZJ	1	390	74	76	-2
ZK	1	398	76	77	-1
ZJ	2	406	73	79	-6
ZK	2	408	76	80	-4
ZJ	2	408	76	80	-4
ZK	2	408	78	80	-2
ZJ	1	416	85	82	3
ZK	1	416	83	82	1
ZJ	2	425	85	84	1
ZK	5	431	93	85	8
ZK	2	434	88	86	2
ZJ	5	435	90	86	4
ZK	4	451	82	90	-8
ZJ	2	461	91	92	-1
ZK	2	462	94	93	1
ZJ	4	466	90	94	-4
ZK	4	468	100	94	6
ZJ	4	470	96	95	1
ZJ	2	506	106		
ZK	1	512	111		
ZK	1	518	120		
ZK	1	518	119		
ZJ	1	523	125		
ZJ	2	524	137		
ZK	2	524	123		
ZJ	1	535	156	155	1
ZK	1	538	160	156	4
ZK	5	540	158	156	2
ZK	2	540	155	156	-1
ZJ	5	542	157	157	0
ZK	2	542	150	157	-7

STRONTIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZJ	2	542	162	157	5
ZK	2	552	164	160	4
ZJ	2	552	161	160	1
ZJ	2	566	169	164	5
ZJ	4	570	170	166	4
ZK	2	574	173	167	6
ZK	4	576	180	167	13
ZK	2	578	173	168	5
ZJ	4	580	164	169	-5
ZK	5	582	166	169	-3
ZK	4	584	168	170	-2
ZJ	2	586	175	171	4
ZK	2	586	172	171	1
ZJ	2	587	170	171	-1
ZJ	5	590	163	171	-8
ZK	2	593	166	173	-7
ZK	2	594	177	173	4
ZJ	2	596	168	174	-6
ZJ	2	604	174	176	-2
ZK	1	604	177	176	1
ZJ	2	606	179	177	2
ZJ	1	607	170	177	-7
ZK	2	610	181	178	3
ZJ	1	611	181	178	3
ZK	1	612	184	179	5
ZJ	1	629	185	184	1
ZK	1	633	188	185	3
ZK	4	637	186	187	-1
ZJ	4	650	182	191	-9
ZJ	4	656	195	193	2
ZK	4	658	198	193	5
ZJ	1	667	199	196	3
ZK	1	670	203	197	6
ZK	2	676	190	199	-9
ZK	1	676	194	199	-5
ZK	4	678	207	199	8
ZJ	1	680	192	200	-8
ZJ	2	681	192	200	-8
ZJ	4	692	198	204	-6

STRONTIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs.-Calc.
ZK	2	692	165	204	39
ZJ	2	693	192	204	-12
ZK	4	710	213	210	3
ZJ	2	712	208	210	-2
ZK	2	714	208	211	-3
ZJ	4	716	213	211	2
ZJ	1	716	209	211	-2
ZK	1	726	213	215	-2
ZK	1	732	216	216	0
ZJ	1	734	220	217	3
ZJ	4	750	206	222	-16
ZJ	1	755	207	224	-17
ZK	4	756	210	224	-14
ZK	1	760	219	225	-6
ZJ	1	763	210	226	-16
ZK	4	772	244	229	15
ZJ	4	774	240	230	10
ZJ	2	781	236	232	4
ZK	1	800	239	238	1
ZJ	1	804	241	239	2
ZK	4	810	245	241	4
ZK	4	816	252	243	9
ZK	2	822	241	245	-4
ZJ	4	822	243	245	-2
ZJ	2	822	242	245	-3
ZK	2	822	245	245	0
ZJ	4	822	244	245	-1
ZK	4	828	263	247	18
ZK	2	832	253	248	5
ZJ	2	838	254	250	4
ZJ	4	838	250	250	0
ZK	1	840	254	250	4
ZJ	1	844	260	252	8
ZJ	4	850	261	254	7
ZK	4	858	265	256	9
ZJ	4	858	266	256	10
ZJ	1	879	263	263	0
ZK	1	883	266	264	2
ZJ	2	883	247	264	-17

STRONTIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZJ	1	890	259	266	-7
ZK	2	894	255	267	-12
ZK	1	896	269	268	1
ZJ	4	908	281	272	9
ZJ	2	910	270	272	-2
ZK	2	912	277	273	4
ZK	4	914	266	274	-8
ZK	1	914	276	274	2

BARIUM HYDROXIDE
INDIVIDUAL ENTHALPIES

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZX	5	152	23	24	-1
ZY	5	153	24	24	0
ZY	5	216	32	35	-3
ZX	5	218	36	35	1
ZP	3	220	34	35	-1
ZR	3	226	35	36	-1
ZY	1	248	45	40	5
ZP	3	253	39	41	-2
ZR	3	254	45	41	4
ZX	1	257	45	42	3
ZX	4	277	46	45	1
ZY	4	281	47	46	1
ZP	3	314	48	51	-3
ZR	3	322	49	52	-3
ZX	2	356	54	58	-4
ZY	2	358	56	58	-2
ZX	5	364	60	59	1
ZX	3	366	58	60	-2
ZY	1	367	61	60	1
ZY	3	368	58	60	-2
ZX	1	372	62	61	1
ZY	5	391	64	64	0
ZX	2	395	67	65	2
ZX	5	395	68	65	3
ZX	3	396	66	65	1
ZY	3	397	65	65	0
ZX	2	415	78		
ZP	4	415	70		
ZY	2	416	75		
ZX	4	421	94		
ZP	2	431	79		
ZY	4	436	97	97	0
ZX	2	442	96	98	-2
ZR	4	446	103	99	4
ZC	2	470	99	103	-4
ZB	2	472	98	104	-6
ZP	4	472	105	104	1
ZR	4	488	109	107	2
ZP	1	504	110	110	0

BARIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZR	1	506	112	110	2
ZB	1	512	108	111	-3
ZC	1	514	109	112	3
ZB	1	516	109	112	-3
ZC	1	522	109	113	-4
ZB	5	540	120	117	3
ZC	5	546	119	118	1
ZC	5	552	119	119	0
ZR	1	554	115	120	-5
ZP	1	554	120	120	0
ZB	5	565	115	122	-7
ZP	3	570	122	123	-1
ZX	4	574	127	123	4
ZB	4	582	128	125	3
ZY	4	585	131	126	5
ZY	4	590	133	127	6
ZR	3	590	129	127	2
ZC	4	593	125	127	-2
ZX	4	593	133	127	6
ZB	2	615	127	132	-5
ZC	2	618	127	132	-5
ZP	3	622	134	133	1
ZP	3	634	135	135	0
ZB	3	637	136	136	0
ZC	3	640	139	136	3
ZB	5	646	142	138	4
ZP	1	647	139	138	1
ZR	1	648	136	138	-2
ZC	5	654	141	139	2
ZP	2	658	138	140	-2
ZC	1	672	146	143	3
ZB	1	674	149	143	6
ZR	2	680	141	144	-3
ZC	4	719	155	152	3
ZB	4	720	155	152	3
ZB	3	770	167	162	5
ZB	3	776	158	163	-5
ZC	2	784	161	165	-4
ZB	1	791	168	166	2
ZC	5	794	167	166	1
ZR	4	794	163	166	-3

BARIUM HYDROXIDE (Con't.)

Capsule	Calorimeter	Temperature °C	$H_T - H_{0°C}$ cal./g. Obs.	$H_T - H_{0°C}$ Calc.	Diff. Obs-Calc
ZC	3	799	174	167	7
ZB	2	834	169	174	-5
ZB	5	842	181	176	5
ZR	5	842	176	176	0
ZC	5	867	174	181	-7
ZC	1	874	185	182	3
ZB	4	908	182	189	-7