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*Measurements of the Electrical Conductivity of Seawater*¹

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ABSTRACT

Measurements of the absolute specific conductance of solutions prepared from a sample of Red Sea water are described. Conductivity was measured at 2°C temperature intervals from -1°C to 35°C and at 1‰ chlorinity intervals from 16‰ to 22‰. Precision of individual measurements was 0.001 millimho/cm in conductivity, 0.002‰ in chlorinity, and 0.001°C in temperature.

Introduction. Thomas, Thompson, and Utterback (1934) measured the absolute specific conductance of seawater as a function of chlorinity and temperature. Their work was generally regarded as the best available until Pollak (1954) pointed out that their results contained two errors. One error was caused by their use of the Parker and Parker (1924) potassium chloride solutions for calibration rather than the accepted standards of Jones and Bradshaw

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(1933). The other was attributed to their use of Washburn pipet-type conductivity cells, which are alleged to show the Parker effect. A positive correction may be applied to correct for the use of Parker and Parker standards, but the positive errors in conductivity due to the Parker effect vary nonlinearly with decreasing solution conductivity and cannot be reliably corrected.

Brown and Hamon (1961) described the construction and calibration of an inductive salinometer. These authors avoided the use of absolute measurements of conductivity by measuring the ratio of the conductivity of an unknown seawater to that of Normal water. They determined the temperature and salinity dependence of the conductivity ratio by using conductivity measurements on natural samples and on gravimetric dilutions of Normal water at various temperatures. These values differ from conductivity ratios calculated from the results of Thomas et al. Salinometers of this general design are widely used for precise and rapid measurements of salinity.

Cox, Culkin, Greenhalgh, and Riley (1962) showed that a plot of relative conductivity versus chlorinity for widely distributed samples has a standard deviation expressed in equivalent chlorinity of 0.012‰ . They found that a plot of salinity computed from conductivity versus relative density has a standard deviation of 0.0034‰ in equivalent chlorinity; their finding has caused a Joint Panel on the Equation of State of Sea Water to consider redefining salinity in terms of conductivity and density (UNESCO 1962, 1963). Measurements of the relative conductivity and density, chlorinity, and major element composition of a large number of seawater samples from all oceans are in progress at the National Institute of Oceanography and the University of Liverpool. New absolute determinations of specific conductance and density will be made.

This paper describes new absolute measurements of the specific conductance of solutions prepared from a sample of Red Sea water. Conductivity was measured at 2°C temperature intervals from -1°C to 35°C and 1‰ chlorinity intervals from 16‰ to 22‰ . Similar measurements on two lots of Normal water are included. The results obtained are compared with those of Thomas et al., and a table of conductivity temperature coefficients is given.

The absolute measurements of the present investigation are not to be interpreted as representative of all seawaters. The results of Cox et al. show that the composition of the ocean is not constant to the precision of measurements in this study, so the results cannot represent the ocean with an accuracy comparable to the experimental precision. However, the present data may be used to calculate reliable temperature coefficients, which are hopefully applicable to all seawaters. The limits of variation of conductivity temperature coefficients in the ocean will be investigated in the future.

Conductivity Measurement. Conductivity was measured with an inductively coupled conductivity indicator constructed at the Chesapeake Bay Institute.

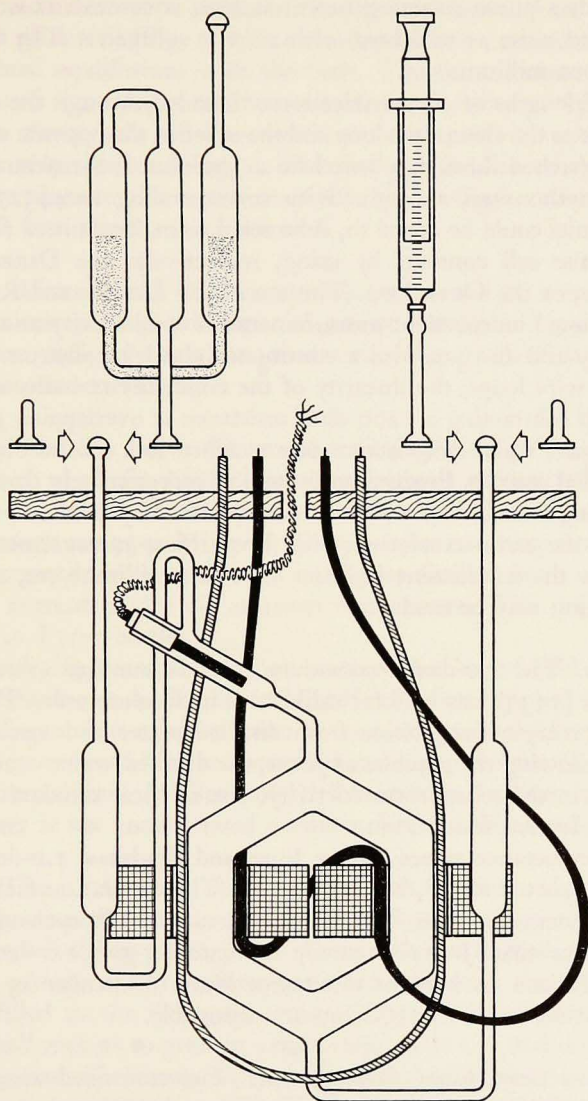


Figure 1. Conductivity Cell. REVERSE loop (solid) and DIRECT loop (striped) are shown.

This instrument operates at an excitation frequency of 5000 c/s and is nulled by using a flux-null technique (Brown and Hamon 1961). A hexagonal sample cell of Pyrex tubing joins two toroidally wound magnetic cores (Fig. 1). Flux-null is achieved by alternate adjustment of a ratio transformer and a phasing capacitor in parallel with the sample cell until zero in in-phase signal,

measured with a phase-detecting null indicator, is coincident with minimum quadrature and noise as measured with an a-c voltmeter. The instrument is precise to 0.001 millimho/cm.

Two equal lengths of copper wire were threaded through the cores, one in the same sense as the electrolyte loop and the other in the opposite sense (Fig. 1). They were attached through a switch to a 300-ohm low-reactance resistor of manganin. In this way, a conductivity corresponding to 44327 ratio-transformer dial units could be added to, subtracted from, or omitted from the conductivity of the cell contents by using, respectively, the DIRECT loop, the REVERSE loop, or the OPEN loop. The use of the DIRECT and REVERSE loops allowed additional independent measurements of conductivity at a temperature and chlorinity and also provided a continuous check on instrument linearity.

Using the wire loops, the linearity of the conductivity indicator was tested by adding and subtracting a 1200-ohm resistance at overlapping points on the ratio-transformer scale. A resistance box attached to a second direct loop was used to set a dial reading. Proceeding in steps of approximately 10 millimho/cm, the dial reading was found to increase and decrease by the same amount over the range of the ratio-transformer dial. From these measurements, one may conclude that the instrument is linear to 0.001 millimho/cm, and a single-point calibration may be used.

Calibration. The 1.0-demal potassium chloride standard solution of Jones and Bradshaw (1933) was used for calibration in absolute units. The potassium chloride was recrystallized twice from distilled water and was fused before weighing. Following the practice of Jones, the distilled-water conductivity was subtracted from the solution conductivity. Use of these standards gives results based on the International Ohm.

Specific conductance values for the Jones and Bradshaw 1.0-demal standard solution are reported for 0°, 18°, and 25°C. The calibration factor computed from measurements at these three temperatures showed no change with temperature greater than Jones' accuracy estimate for the 1.0-demal standard, 0.005 millimho/cm. In light of this temperature independence, extrapolation of the calibration factor to 35°C appears reasonable.

Temperature Control and Measurement. The controlled-temperature bath consisted of a cylindrical stainless-steel container heated and cooled by a proportionally controlled Peltier-effect unit. The bath was stirred internally and contained silicone oil (General Electric Silicone Products Dept., SF-96[10]). Temperature was continuously variable from -5°C to 40°C and could be held constant to within 0.002°C.

Temperature was measured with a small platinum resistance thermometer (Rosemount Engineering Company, model 162 d) calibrated by the National Bureau of Standards. A Leeds and Northrup G-2 Mueller bridge and model

2284-d galvanometer were used to measure resistance. The thermometer, mounted in a glass well (Fig. 1) with a sleeve of silicone rubber tubing, rapidly reached thermal equilibrium with the bath. The time necessary for thermal equilibration of the sample cell was established by displacing a volume of solution from the sample cell into the thermometer well by using the syringe and trap assembly shown in Fig. 1. Thermal equilibration of the sample was shown by the absence of a temperature change on displacement of a portion of the sample into the thermometer well.

Chlorinity Measurement. Chlorinity was determined by a weight titration with silver nitrate, using a differential potentiometric end point (Reeburgh and Carpenter 1964). Normal water was used for standardizing, and results were precise to 0.002‰.

Seawater. Red Sea water (DISCOVERY St. 5236, 21°36'N, 38°11'E, surface) was used to obtain high chlorinities without extensive concentration. The water was stored and shipped in a polyethylene container. Following filtration through a 0.45- μ Millipore filter, samples covering a range of chlorinity were prepared either by dilution with glass-distilled water or by evaporation with a current of dry air at room temperature. The prepared samples were stored in Pyrex bottles.

High-salinity, high-temperature bottom water has been found in the vicinity of this DISCOVERY station. At 21°17'N, 38°02'E, Swallow and Crease (1965) reported finding a depression at 2000 m containing water of 270‰ salinity and 44°C. Less extreme high temperatures and high salinities have been found by previous expeditions (Miller 1964). Preliminary analyses have indicated that this water is not concentrated seawater, but possibly a connate water.

Practice. The conductivity cell was dried with a current of dry air and was filled by siphoning the sample through dry Tygon tubing attached by ball sockets to the cell-filling tubes. The cell was allowed to flush for at least one cell volume, taking care to avoid trapping air bubbles in the cell. The filling tubes were filled to the limit, covered with polyethylene sheet, and capped with sealed ball sockets to prevent evaporation. The cell and cores were lowered into the controlled-temperature bath and conductivity was measured at 2°C intervals from 35°C to -1°C. Following thermal equilibration at each temperature, conductivity and temperature were measured simultaneously through several thermostat cycles until both conductivity and temperature assumed constant values. At the conclusion of a run, measurements were repeated at 15°C and 25°C, the cell was raised from the bath, and the caps were removed. As an additional guard against contamination from evaporation, about 1 ml of sample was removed from the top of each filling tube with a small plastic tube. The sample was then transferred from the cell through dry

Tygon tubing into a weight buret. A sample was taken for immediate pH measurement, and chlorinity samples were weighed. Chlorinities were determined within one week.

The REVERSE-loop, DIRECT-loop, and OPEN-loop measurements were checked for obvious errors. A zero reading obtained from measurements on a clean dry cell at 5°, 15°, 25°, and 35°C was subtracted from the OPEN-loop reading. These values were multiplied by an experimentally determined calibration factor,

$$\frac{\text{conductivity of prepared standard}}{\text{dial reading} - \text{distilled water reading}},$$

to obtain the values given in Table I.

The occurrence of bubbles at temperatures above ambient was minimized by equilibrating the uncovered samples overnight at 35°C. Bubbles occurred with increasing frequency at high temperatures if the interior of the cell was

TABLE I. DATA. MEASURED VALUES OF SPECIFIC CONDUCTANCE, TEMPERATURE, AND CHLO-

Altered Red Sea water									
A		B		C		D		E	
Cl = 15.830‰		Cl = 16.979‰		Cl = 17.984‰		Cl = 18.936‰		Cl = 20.055‰	
θ	κ	θ	κ	θ	κ	θ	κ	θ	κ
35.009	53.264	34.998	56.677	34.995	59.651	35.001	62.452	34.991	65.598
32.999	51.433	32.991	54.732	32.991	57.611	33.003	60.326	32.999	63.469
31.005	49.631	31.001	52.821	30.992	55.594	30.995	58.203	30.992	61.240
29.002	47.835	28.994	50.911	28.997	53.596	28.998	56.112	28.999	59.047
26.988	46.047	27.000	49.028	26.992	51.605	26.998	54.036	26.990	56.856
25.004	44.302	24.997	47.155	24.995	49.643	25.000	51.981	24.997	54.702
22.997	42.555	23.001	45.307	22.991	47.691	22.999	49.944	22.993	52.558
20.989	40.825	20.997	43.471	20.994	45.768	21.003	47.934	20.997	50.446
18.993	39.127	18.998	41.663	18.998	43.868	18.997	45.938	18.998	48.353
17.001	37.453	17.012	39.889	16.998	41.990	16.989	43.964	17.003	46.292
15.002	35.795	15.004	38.119	14.998	40.135	14.985	42.020	15.002	44.253
12.996	34.154	13.000	36.376	12.994	38.303	12.996	40.118	12.997	42.238
10.996	32.542	10.994	34.656	10.991	36.497	10.996	38.235	10.996	40.255
8.988	30.950	8.993	32.971	9.002	34.735	9.005	36.388	8.998	38.307
6.977	29.398	6.989	31.311	6.993	32.985	7.000	34.559	6.992	36.388
4.996	27.865	4.999	29.690	4.996	31.275	4.990	32.758	4.998	34.508
2.989	26.358	2.981	28.081	2.992	29.591	2.997	31.009	2.995	32.657
1.000	24.894	0.996	26.524	0.995	27.948	0.990	29.283	0.995	30.847
-0.009	24.162	-0.008	25.751	-0.014	27.131	-0.002	28.443	-0.005	29.959
-1.000	23.452	-1.006	24.990	-1.017	26.329	-1.003	27.601	-1.007	29.075
*15.002	35.793	*15.004	38.118	*14.998	40.134	*14.985	42.024	*15.002	44.254
*25.004	44.301	*24.997	47.155	*24.995	49.642	*25.000	51.982	*24.997	54.703
pH = 8.19		pH = 8.20		pH = 8.20		pH = 8.16		pH = 8.15	

* Measurements repeated at conclusion of run.

not wet by water. This nonwetting condition was remedied by washing the cell with a saturated sodium hydroxide-ethanol solution followed by a distilled-water rinse to minimum conductivity. The cell was washed with this solution between all samples. To avoid evaporation, Normal-water runs were made without the benefit of a 35°C equilibration.

Data. Table I gives the measured specific conductances, temperatures, and chlorinities for seven samples prepared from the Red Sea water (A-G), for one unaltered sample of Red Sea water, and for two lots of Normal water. In Table II, the data from samples A through G in Table I are interpolated to integer values of temperature and chlorinity. Table III presents conductivity temperature coefficients obtained from the same data.

Comparisons. In order to compare two conductivity measurements at a given temperature and chlorinity, the following method was used to interpolate the Red Sea values at a temperature to a desired chlorinity. A large-scale plot

CHLORINITY. CONDUCTIVITY IN INTERNATIONAL MILLIMHO/CM.

F		G		Unaltered Red Sea water		Normal water			
Cl = 20.930‰		Cl = 21.820‰		Cl = 21.436‰		P-37		P-39	
θ	κ	θ	κ	θ	κ	θ	κ	θ	κ
34.994	68.231	34.997	70.791	35.000	69.695	35.000	63.738	35.003	63.754
32.995	65.908	32.999	68.381	30.000	63.807	33.001	61.568	32.996	61.573
31.006	63.616	30.990	65.986	25.002	58.042	31.004	59.414	31.003	59.426
28.991	61.316	29.002	63.632	20.000	52.420	30.000	58.341	29.999	58.349
26.992	59.052	26.987	61.265	15.001	46.966	29.000	57.271	29.002	57.282
25.001	56.820	25.007	58.964	10.000	42.056	26.996	55.150	27.004	55.168
23.003	54.601	23.001	56.654	5.000	36.644	25.002	53.057	25.000	53.064
20.991	52.393	20.987	54.361	0.000	31.825	23.000	50.979	22.995	50.979
18.998	50.229	18.994	52.120			21.000	48.922	20.994	48.921
16.998	48.084	16.998	49.902	*15.001	46.965	20.000	47.905	20.002	47.916
14.998	45.969	14.989	47.696	*25.002	58.042	18.999	46.893	19.000	46.902
12.993	43.876	12.998	45.543	* 5.000	36.644	17.003	44.889	17.000	44.897
10.997	41.826	10.986	43.400			15.000	42.908	15.000	42.921
8.993	39.799	8.995	41.311			13.001	40.956	12.996	40.964
6.998	37.813	6.993	39.245			10.997	39.030	11.000	39.044
5.001	35.864	4.994	37.223			10.000	38.083	10.002	38.096
3.001	33.946	3.000	35.241			9.000	37.141	9.004	37.156
0.988	32.056	0.997	33.291			7.005	35.285	6.998	35.287
-0.006	31.138	-0.001	32.334			5.000	33.452	5.001	33.459
-1.005	30.222	-1.007	31.379			3.000	31.662	2.997	31.669
*14.998	45.970	*14.989	47.696			1.000	29.904	0.995	29.908
*25.001	56.822	*25.007	58.964			0.000	29.039	-0.001	29.043
						-1.008	28.176	-0.995	28.192
						*14.999	42.907	*15.000	42.919

pH = 8.20

pH = 8.15

*14.999 42.907 *15.000 42.919

TABLE II. SPECIFIC CONDUCTANCE OF RED SEA WATER AT INTEGER VALUES OF TEMPERATURE AND CHLORINITY (SAMPLES A-G). CONDUCTIVITY IN INTERNATIONAL MILLIMHO/CM.

θ	Chlorinity, ‰						
	16.000	17.000	18.000	19.000	20.000	21.000	22.000
35	53.761	56.744	59.702	62.636	65.548	68.437	71.306
33	51.923	54.807	57.666	60.502	63.317	66.110	68.883
31	50.099	52.884	55.645	58.384	61.102	63.800	66.478
29	48.290	50.976	53.640	56.283	58.906	61.509	64.093
27	46.497	49.086	51.653	54.201	56.728	59.237	61.728
25	44.721	47.213	49.685	52.138	54.572	56.987	59.386
23	42.964	45.360	47.737	50.096	52.437	54.760	57.067
21	41.225	43.526	45.810	48.076	50.325	52.557	54.774
19	39.507	41.714	43.905	46.079	48.237	50.380	52.507
17	37.810	39.925	42.024	44.108	46.176	48.229	50.268
15	36.136	38.159	40.168	42.162	44.142	46.107	48.058
13	34.485	36.418	38.338	40.244	42.136	44.015	45.880
11	32.859	34.703	36.535	38.354	40.160	41.954	43.734
9	31.258	33.016	34.761	36.494	38.216	39.925	41.622
7	29.685	31.356	33.017	34.666	36.304	37.930	39.545
5	28.139	29.726	31.303	32.870	34.426	35.971	37.505
3	26.622	28.127	29.622	31.108	32.583	34.048	35.503
1	25.135	26.560	27.975	29.380	30.777	32.163	33.540
0	24.403	25.788	27.164	28.530	29.888	31.236	32.575
-1	23.679	25.025	26.362	27.689	29.008	30.318	31.619

TABLE III. CONDUCTIVITY TEMPERATURE COEFFICIENT (SAMPLES A-G). $(1/\kappa)(d\kappa/d\theta) \cdot 100$.

θ	16.000	17.000	18.000	19.000	20.000	21.000	22.000
35	1.715	1.713	1.711	1.709	1.708	1.706	1.705
33	1.763	1.761	1.759	1.757	1.755	1.754	1.752
31	1.813	1.811	1.809	1.807	1.805	1.803	1.802
29	1.865	1.863	1.861	1.859	1.857	1.855	1.853
27	1.919	1.917	1.915	1.912	1.910	1.908	1.907
25	1.976	1.973	1.971	1.969	1.966	1.964	1.962
23	2.035	2.032	2.030	2.027	2.025	2.023	2.021
21	2.097	2.094	2.091	2.089	2.086	2.084	2.082
19	2.161	2.159	2.156	2.153	2.150	2.148	2.146
17	2.229	2.226	2.223	2.221	2.218	2.215	2.213
15	2.301	2.298	2.294	2.291	2.288	2.285	2.283
13	2.376	2.373	2.369	2.366	2.363	2.359	2.357
11	2.455	2.451	2.448	2.444	2.441	2.437	2.434
9	2.539	2.535	2.531	2.527	2.523	2.520	2.516
7	2.627	2.623	2.618	2.614	2.610	2.607	2.603
5	2.721	2.716	2.711	2.707	2.702	2.698	2.695
3	2.821	2.815	2.810	2.805	2.800	2.796	2.792
1	2.927	2.920	2.914	2.909	2.904	2.899	2.895
0	2.983	2.975	2.969	2.963	2.958	2.954	2.949
-1	3.040	3.032	3.026	3.020	3.015	3.010	3.005

TABLE IV. UNALTERED RED SEA WATER COMPARISON. CONDUCTIVITY VALUES FROM PREPARED SAMPLES INTERPOLATED TO UNALTERED RED SEA WATER CHLORINITY (21.436‰).

Cl ⁰ / ₀₀ prepared	Cl ⁰ / ₀₀ RS	T	κ _{obs.}	κ _{interp.}	κ _{RS}	κ _{interp.} - κ _{RS}	Δκ in equiv. Cl ⁰ / ₀₀
21.820	21.436	35.000	70.795	69.696	69.695	+ .001	.0004
		25.000	58.956	58.036	58.042	- .006	.0025
		15.000	47.708	46.961	46.966	- .005	.0026
		5.000	37.229	36.641	36.644	- .003	.0020
		0.000	32.335	31.822	31.825	- .003	.0022
20.930	21.436	35.000	68.238	69.693	69.695	- .002	.0007
		25.000	56.819	58.036	58.042	- .006	.0025
		15.000	45.971	46.960	46.966	- .006	.0031
		5.000	35.863	36.641	36.644	- .003	.0019
		0.000	31.144	31.823	31.825	- .002	.0015

of $\Delta\kappa/\Delta\text{Cl}$ versus mean values of successive observed chlorinities was made for each integer value of observed temperature. Smoothed values of $\Delta\kappa/\Delta\text{Cl}$ were taken from the curve at chlorinities corresponding to the mean of the nearest observed chlorinity and the desired value of chlorinity. An additive correction was obtained by multiplying the value of $\Delta\kappa/\Delta\text{Cl}$ by the difference between the nearest measured chlorinity and the desired chlorinity.

The conductivity of an unaltered sample of Red Sea water was measured at 5°C temperature intervals to provide a means of checking fits of the data. The unaltered water is compared with the prepared samples in Table IV. The differences expressed in equivalent chlorinity averaged 0.002‰, giving some indication of the over-all precision.

Measurements from the present investigation were interpolated to the chlorinities of Thomas et al. Comparisons were possible at 25°, 15°, 5°, and 0°C. Since Thomas et al. standardized their chlorinity titration with specially purified sodium chloride (1932 atomic weights), they measured chlorine-equivalent in terms of 1932 atomic weights instead of chlorinity. Lyman and Fleming (1940) gave the ratio of chlorine-equivalent to chlorinity as

$$\frac{0.3286707}{0.3285233} = 1.00045,$$

where the numerator is the ratio of the 1940 atomic weights of chlorine to silver and the denominator is the ratio of chlorinity (Jacobsen and Knudsen 1940) to the mass of silver necessary to precipitate the halides in one kilogram of seawater. Since the atomic weight values of sodium, chlorine, and silver did not change between 1932 and 1940 (Baxter et al. 1932, 1940), the above relation may be used to convert the chlorine-equivalent measurements of

TABLE V. THOMAS, THOMPSON, AND UTTERBACK COMPARISON. CONDUCTIVITY VALUES FROM PREPARED SAMPLES INTERPOLATED TO THOMAS ET AL. (TTU) CHLORINITIES.

T	TTU Sample no.	TTU Cl ^o / _{oo} (reported)	TTU Cl ^o / _{oo} (actual)	TTU κ obs.	WSR Cl ^o / _{oo}	WSR κ obs.	WSR κ obs. interp. to TTU Cl ^o / _{oo}	$\kappa_R - \kappa_{TTU}$	$\Delta\kappa$ in equiv. Cl ^o / _{oo}
25	10	16.750	16.743	46.575	16.979	47.158	46.572	-.003	.001
15				37.673		38.115	37.639	-.034	.017
5				29.348		29.691	29.318	-.030	.019
0				25.438		25.757	25.431	-.007	.005
25	9	18.998	18.990	52.128	18.936	51.981	52.113	-.015	.006
15				42.155		42.034	42.141	-.014	.007
5				32.898		32.767	32.852	-.046	.029
0				28.492		28.445	28.519	-.027	.020
25	5	19.227	19.218	52.671	18.936	51.981	52.670	-.001	.0004
15				42.602		42.034	42.594	-.008	.004
5				33.258		32.767	33.208	-.050	.032
0				28.868		28.445	28.829	-.039	.029
25	1	16.753	16.746	46.572	16.979	47.158	46.579	+.005	.002
25	2	17.261	17.253	47.830	16.979	47.158	47.837	+.007	.003
25	3	18.598	18.590	51.121	18.936	51.981	51.134	+.013	.005
25	4	16.240	16.233	45.287	15.830	44.298	45.305	+.018	.007
25	13	21.381	21.371	57.855	20.930	56.819	57.880	+.025	.010
25	14	15.226	15.219	42.744	15.830	44.298	42.767	+.023	.009
25	18	21.398	21.388	57.901	20.930	56.819	57.921	+.020	.008
25	19	19.069	19.060	52.286	18.936	51.981	52.284	-.002	.0008
25	21	17.512	17.504	48.455	17.984	49.648	48.464	+.009	.003

Thomas et al. to chlorinity. Table V gives the results of the conductivity comparison. Because the interpolation formulae reported by Thomas et al. are based on chlorine-equivalent measurements, it is not possible to compare their integer-value table with Table II.

In Table VI, measurements on the Red Sea water are interpolated to the Normal-water chlorinities. Differences averaged 0.007‰ in equivalent chlorinity. Because of these differences, the alkalinity of each was measured. Differences in the specific alkalinity were such that the alkalinity of the Red Sea water was low by 0.2 millequivalents/liter at the Normal-water chlorinity. Assuming that the lower Red Sea alkalinity is the result of carbonate precipitation, Park's (1964 a, b) value for the partial equivalent conductance of calcium bicarbonate may be used to calculate the conductivity difference. The calculated conductivity difference of 0.007 millimho/cm does not entirely account for the 0.016 millimho/cm difference observed at 23°C. This point should be the subject of further study. Salinities obtained by entering the new Unesco conductivity ratio tables with conductivity ratios computed from Red Sea

TABLE VI. NORMAL-WATER COMPARISON. CONDUCTIVITY VALUES FROM PREPARED SAMPLES INTERPOLATED TO NORMAL-WATER CHLORINITIES.

T	(D) $\kappa_{\text{obs.}}$	P-37				$\Delta\kappa$ in equiv. Cl $^{\circ}/_{\text{oo}}$	P-39			
		$\kappa_{\text{interp.}}$	κ_{nw}	$\kappa_{\text{interp.}}$ $-\kappa_{\text{nw}}$	$\kappa_{\text{interp.}}$		κ_{nw}	$\kappa_{\text{interp.}}$ $-\kappa_{\text{nw}}$	$\Delta\kappa$ in equiv. Cl $^{\circ}/_{\text{oo}}$	
35	62.451	63.717	63.738	-.021	.007	63.726	63.751	-0.025	.009	
33	60.323	61.546	61.567	-.021	.007	61.554	61.577	-0.023	.008	
31	58.208	59.389	59.410	-.021	.008	59.397	59.423	-0.026	.010	
29	56.114	57.252	57.271	-.019	.007	57.260	57.280	-0.020	.008	
27	54.038	55.136	55.154	-.018	.007	55.143	55.164	-0.021	.008	
25	51.981	53.038	53.055	-.017	.007	53.045	53.064	-0.019	.008	
23	49.945	50.961	50.979	-.018	.008	50.968	50.984	-0.016	.007	
21	47.931	48.909	48.922	-.013	.006	48.915	48.927	-0.012	.005	
19	45.941	46.878	46.894	-.016	.007	46.885	46.902	-0.017	.008	
17	43.975	44.873	44.886	-.013	.006	44.880	44.897	-0.017	.008	
15	42.034	42.843	42.908	-.015	.008	42.900	42.921	-0.021	.011	
13	40.122	40.943	40.955	-.012	.006	40.950	40.968	-0.018	.010	
11	38.239	39.024	39.033	-.009	.005	39.029	39.044	-0.015	.008	
9	36.383	37.130	37.141	-.011	.006	37.135	37.152	-0.017	.010	
7	34.559	35.264	35.280	-.011	.007	35.274	35.289	-0.015	.009	
5	32.767	33.443	33.452	-.009	.006	33.448	33.458	-0.010	.006	
3	31.012	31.652	31.662	-.010	.007	31.657	31.672	-0.015	.010	
1	29.292	29.898	29.904	-.006	.004	29.902	29.913	-0.011	.008	
0	28.445	29.035	29.039	-.004	.003	29.039	29.044	-0.005	.004	
-1	27.604	28.177	28.183	-.006	.005	28.181	28.187	-0.006	.005	

water and Normal water are lower than those computed from the measured chlorinity, indicating that the Red Sea water lies off the mean line in a conductivity-chlorinity plot.

Conclusions. Cox et al. have shown that comparison of the conductivity of seawater samples having identical chlorinities and different origins is meaningful to no closer than about 0.04‰ in equivalent chlorinity. Criticism of deviations smaller than this in previous work is impossible unless identical samples are investigated.

For the same reason, differences between the values of Thomas et al. and those obtained in this investigation allow no conclusions regarding the presence or absence of errors due to the Parker effect or calibration methods. Converting the Thomas et al. chlorine-equivalent measurements to chlorinity gives fair agreement with the present results.

The Thomas et al. comparison shows that differences expressed in equivalent chlorinity vary with temperature in the same sample. In contrast, the Normal-water comparisons show a constant difference in equivalent chlorinity with varying temperature. Since Thomas et al. obtained agreement of 0.01‰ between triplicate measures of conductivity and since the precision of their

chlorinity determination was high, it appears that the variation in differences is due to temperature control and measurement. Differences observed between their thermometers (0.02°C) could produce the observed differences in equivalent chlorinity.

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