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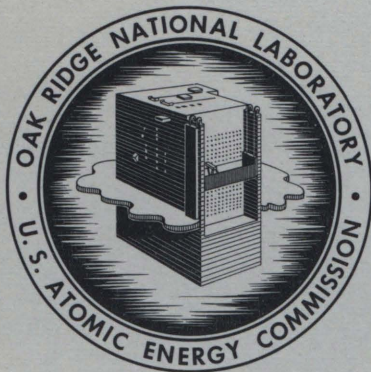
Section 2.11

SMOOTHED THERMOCOUPLE TABLES OF  
EXTENDED SIGNIFICANCE (°C)

Volume 2

Section 2.11 Constantan-Copper Cryogenic Thermocouples

R. K. Adams  
E. G. Davisson



**OAK RIDGE NATIONAL LABORATORY**

operated by

UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION

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INSTRUMENTATION AND CONTROLS DIVISION

**SMOOTHED THERMOCOUPLE TABLES OF EXTENDED SIGNIFICANCE (°C)**

R. K. Adams and E. G. Davisson

Volume 2

**SECTION 2.11 CONSTANTAN-COPPER CRYOGENIC THERMOCOUPLES**

MARCH 1965

OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee  
operated by  
UNION CARBIDE CORPORATION  
for the  
U. S. ATOMIC ENERGY COMMISSION



# SMOOTHED THERMOCOUPLE TABLES OF EXTENDED SIGNIFICANCE (°C)

R. K. Adams      E. G. Davisson

## Volume 2

### SECTION 2.11 CONSTANTAN-COPPER CRYOGENIC THERMOCOUPLES

This section contains tables of emf (in absolute millivolts) vs temperature (in degrees Kelvin) for constantan-copper cryogenic thermocouples. The values in these tables, derived from those given by Powell *et al.*,<sup>1</sup> are computed to more significant digits, that is, to the nearest 0.001  $\mu v$ . The techniques of computation are described in Vol. 1 of this report.

Figure 1, a plot of the difference in microvolts between the values in the smoothed table and those in the original table vs temperature, illustrates how the values in the smoothed table compare with those in the original table.

In Table 11 a smoothed emf value is tabulated in absolute millivolts for every degree Kelvin in the range of the table.

In Table 11A the first two columns contain the same information as given in Table 11. To the right of these two columns is a difference table of the millivolt values in column 2. The difference table is expressed in thousandths of microvolts and contains orders 0 through 5. This difference table gives a convenient tabulation of differences for those engaged in temperature difference work.

Although these tables are expressed to the nearest 0.001  $\mu v$ , which is roughly equivalent to 0.0001°K, this in no way implies that temperature measurements to this accuracy are possible. The user of these tables is reminded of the accuracy tolerances on thermocouples published by the American Society for Testing and Materials<sup>2</sup> and the Instrument Society of America.<sup>3</sup> An illustration of the expected accuracy for cryogenic thermocouple materials may be found in an article by Powell *et al.*<sup>4</sup>

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<sup>1</sup>R. L. Powell *et al.*, "Low-Temperature Thermocouples," pp. 65-77 in *Temperature: Its Measurement and Control in Science and Industry*, vol. 6, part 2, *Applied Instruments and Methods*, ed. by A. I. Dahl, Reinhold, New York, 1962; see Table 2, pp. 68-69.

<sup>2</sup>"Temperature Electromotive Force (EMF) Tables for Thermocouples, ASTM E 230-63," *Am. Soc. Testing Mater.*, ASTM Std. 1964, Pt. 30, pp. 646-704; see Table XIII, p. 700.

<sup>3</sup>"Thermocouples and Thermocouple Extension Wires - Terminology, Limits of Error, and Wire Sizes," *Recommended Practice RP 1.3*, Instrument Society of America, Pittsburgh, Pa., 1959.

<sup>4</sup>R. L. Powell *et al.*, *Cryogenics* 1, 142 (1961); see Fig. 3.



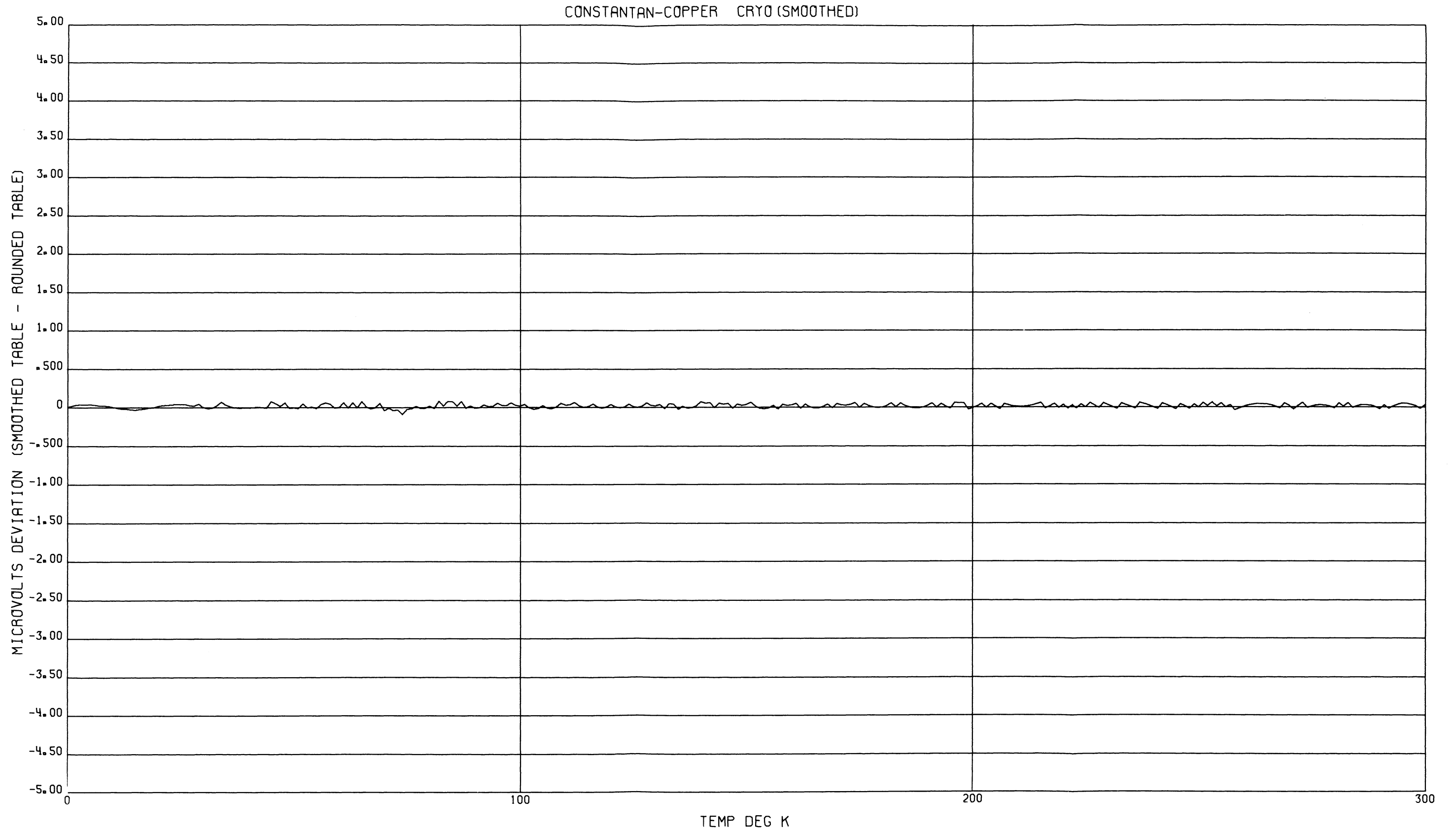


Fig. 1. Deviation of Original Table from Smoothed Table.





CONSTANTAN-COPPER CRYO(SMOOTHED)  
TABLE NO. 11

TEMP=DEG K  
VOLTAGE=MILLIVOLT ABSOLUTE

TEMP	0	1	2	3	4	5	6	7	8	9
					MILLIVOLTS					
0	0	.000183	.000689	.001514	.002653	.004104	.005862	.007922	.010281	.012934
10	.015878	.019108	.022619	.026408	.030471	.034805	.039405	.044269	.049394	.054777
20	.060415	.066306	.072448	.078837	.085472	.092351	.099470	.106827	.114419	.122245
30	.130301	.138584	.147091	.155820	.164768	.173932	.183309	.192896	.202692	.212693
40	.222897	.233301	.243904	.254702	.265695	.276879	.288252	.299812	.311558	.323487
50	.335596	.347885	.360350	.372990	.385803	.398787	.411939	.425258	.438743	.452390
60	.466198	.480165	.494288	.508567	.522997	.537578	.552306	.567180	.582197	.597356
70	.612654	.628089	.643661	.659367	.675206	.691178	.707283	.723519	.739888	.756388
80	.773020	.789785	.806683	.823715	.840880	.858179	.875613	.893181	.910883	.928720
90	.946692	.964797	.983037	1.001410	1.019915	1.038554	1.057324	1.076227	1.095260	1.114424
100	1.133718	1.153142	1.172695	1.192376	1.212187	1.232125	1.252192	1.272386	1.292707	1.313156
110	1.333731	1.354434	1.375263	1.396219	1.417301	1.438509	1.459844	1.481304	1.502891	1.524603
120	1.546441	1.568404	1.590493	1.612707	1.635046	1.657511	1.680102	1.702817	1.725659	1.748626
130	1.771718	1.794937	1.818281	1.841751	1.865347	1.889069	1.912917	1.936892	1.960993	1.985220
140	2.009574	2.034054	2.058661	2.083394	2.108253	2.133238	2.158348	2.183583	2.208943	2.234427
150	2.265033	2.285763	2.311614	2.337586	2.363679	2.389891	2.416223	2.442673	2.469241	2.495926
160	2.522729	2.549649	2.576685	2.603838	2.631107	2.658491	2.685992	2.713609	2.741341	2.769189
170	2.797152	2.825231	2.853425	2.881735	2.910159	2.938697	2.967351	2.996118	3.024999	3.053994
180	3.083101	3.112321	3.141654	3.171099	3.200655	3.230322	3.260101	3.289991	3.319991	3.350102
190	3.380324	3.410655	3.441097	3.471650	3.502312	3.533084	3.563966	3.594958	3.626059	3.657269
200	3.688588	3.720016	3.751552	3.783197	3.814949	3.846808	3.878775	3.910849	3.943029	3.975316
210	4.007709	4.040208	4.072813	4.105524	4.138340	4.171261	4.204286	4.237417	4.270652	4.303991
220	4.337434	4.370980	4.404630	4.438383	4.472240	4.506199	4.540260	4.574425	4.608691	4.643060
230	4.677531	4.712103	4.746778	4.781553	4.816430	4.851408	4.886486	4.921665	4.956944	4.992323
240	5.027801	5.063379	5.099055	5.134831	5.170704	5.206676	5.242746	5.278914	5.315179	5.351542
250	5.388002	5.424559	5.461213	5.497964	5.534811	5.571755	5.608794	5.645930	5.683161	5.720487
260	5.757909	5.795426	5.833037	5.870744	5.908544	5.946439	5.984428	6.022511	6.060687	6.098956
270	6.137318	6.175772	6.214319	6.252958	6.291689	6.330511	6.369425	6.408429	6.447525	6.486710
280	6.525986	6.565353	6.604809	6.644355	6.683990	6.723715	6.763529	6.803432	6.843424	6.883500
290	6.923674	6.963932	7.004279	7.044714	7.085237	7.125849	7.166549	7.207337	7.248214	7.289177
300	7.330230									

TABLE IIA

CONSTANTAN-COPPER CRYO(SMOOTHED)

TEMP	MV	DIFFERENCE ORDER					
		0 TH	1 ST	2 ND	3 RD	4 TH	5 TH
0	0	0					
1	.000183	183	183	323			
2	.000689	689	506	319	-4	-1	
3	.001514	1514	825	314	-5	3	4
4	.002653	2653	1139	312	-2	-3	-6
5	.004104	4104	1451	307	-5	0	3
6	.005862	5862	1758	302	-5	2	2
7	.007922	7922	2060	299	-3	-2	-4
8	.010281	10281	2359	294	-5	2	4
9	.012934	12934	2653	291	-3	-2	-4
10	.015878	15878	2944	286	-5	0	2
11	.019108	19108	3230	281	-5	2	2
12	.022619	22619	3511	278	-3	-1	-3
13	.026408	26408	3789	274	-4	1	2
14	.030471	30471	4063	271	-3	-2	-3
15	.034805	34805	4334	266	-5	3	5
16	.039405	39405	4600	264	-2	-1	-4
17	.044269	44269	4864	261	-3	0	1
18	.049394	49394	5125	258	-3	0	0
19	.054777	54777	5383	255	-3	1	1
20	.060415	60415	5638	253	-2	0	-1
21	.066306	66306	5891	251	-2	-2	-2
22	.072448	72448	6142	247	-4	3	5
23	.078837	78837	6389	246	-1	-1	-4
24	.085472	85472	6635	244	-2	-2	-1
25	.092351	92351	6879	240	-4	2	4
26	.099470	99470	7119	238	-2	-1	-3
27	.106827	106827	7357	235	-3	2	3
28	.114419	114419	7592	234	-1	0	-5
29	.122245	122245	7826	230	-4	-3	4
30	.130301	130301	8056	227	-3	1	-1
31	.138584	138584	8283	224	-3	0	1
32	.147091	147091	8507	222	-2	1	-2
33	.155820	155820	8729	222	-3	-1	1
34	.164768	164768	8948	219	-3	0	0
35	.173932	173932	9164	216	-3	0	0
36	.183309	183309	9377	213	-3	0	2
			9587	210	-1	2	-5

37	.192896	192896		209		-3	
38	.202692	202692	9796	205	-4	2	5
39	.212693	212693	10001	203	-2	-1	-3
40	.222897	222897	10204	200	-3	2	3
41	.233301	233301	10404	199	-1	-3	-5
42	.243904	243904	10603	195	-4	4	7
43	.254702	254702	10798	195	0		-8
44	.265695	265695	10993	191	-4	2	6
45	.276879	276879	11184	189	-2	0	-2
46	.288252	288252	11373	187	-2	1	1
47	.299812	299812	11560	186	-1	-2	-3
48	.311558	311558	11746	183	-3	0	2
49	.323487	323487	11929	180	-3	3	3
50	.335596	335596	12109	180	0	-4	-7
51	.347885	347885	12289	176	-4	3	7
52	.360350	360350	12465	175	-1	-1	-4
53	.372990	372990	12640	175	-2		1
54	.385803	385803	12813	173	-2	0	-1
55	.398787	398787	12984	171	-3	-1	3
56	.411939	411939	13152	168	-1	2	-2
57	.425258	425258	13319	167	-1	0	-3
58	.438743	438743	13485	166	-4	-3	6
59	.452390	452390	13647	162	-1	3	-4
60	.466198	466198	13808	161	-2	-1	0
61	.480165	480165	13967	159	-3	-1	4
62	.494288	494288	14123	156	0	3	-8
63	.508567	508567	14279	156	-5	-5	10
64	.522997	522997	14430	151	0	5	-9
65	.537578	537578	14581	151	-4	-4	7
66	.552306	552306	14728	147	-1	3	-5
67	.567180	567180	14874	146	-3	-2	4
68	.582197	582197	15017	143	-1	2	-4
69	.597356	597356	15159	142	-3	-2	3
70	.612654	612654	15298	139	-2	1	1
71	.628089	628089	15435	137	0	2	-5
72	.643661	643661	15572	137	-3	-3	5
73	.659367	659367	15706	134	-1	2	-1
74	.675206	675206	15839	133	0	1	-1
75	.691178	691178	15972	133	0	0	-2
76	.707283	707283	16105	133	-2	-2	6
77	.723519	723519	16236	131	2	4	-8
			16369	133	-2	-4	7

78	.739888	739888	16500	131	1	3	-3
79	.756388	756388	16632	132	1	0	-1
80	.773020	773020	16765	133	0	-1	2
81	.789785	789785	16898	133	1	1	-3
82	.806683	806683	17032	134	-1	-2	4
83	.823715	823715	17165	133	1	2	-2
84	.840880	840880	17299	134	1	0	-2
85	.858179	858179	17434	135	-1	-2	3
86	.875613	875613	17568	134	0	1	0
87	.893181	893181	17702	134	1	1	-2
88	.910883	910883	17837	135	0	-1	-1
89	.928720	928720	17972	135	-2	-2	6
90	.946692	946692	18105	133	2	4	-8
91	.964797	964797	18240	135	-2	-4	5
92	.983037	983037	18373	133	-1	1	2
93	1.001410	1001410	18505	132	2	3	-8
94	1.019915	1019915	18639	134	-3	-5	10
95	1.038554	1038554	18770	131	2	5	-10
96	1.057324	1057324	18903	133	-3	-5	9
97	1.076227	1076227	19033	130	1	4	-6
98	1.095260	1095260	19164	131	-1	-2	3
99	1.114424	1114424	19294	130	0	1	-2
100	1.133718	1133718	19424	130	-1	-1	1
101	1.153142	1153142	19553	129	-1	0	3
102	1.172695	1172695	19681	128	2	3	-8
103	1.192376	1192376	19811	130	-3	-5	10
104	1.212187	1212187	19938	127	2	5	-9
105	1.232125	1232125	20067	129	-2	-4	6
106	1.252192	1252192	20194	127	0	2	-1
107	1.272386	1272386	20321	127	1	1	-4
108	1.292707	1292707	20449	128	-2	-3	7
109	1.313156	1313156	20575	126	2	4	-8
110	1.333731	1333731	20703	128	-2	-4	7
111	1.354434	1354434	20829	126	1	3	-5
112	1.375263	1375263	20956	127	-1	-2	3
113	1.396219	1396219	21082	126	0	1	0
114	1.417301	1417301	21208	126	1	1	-4
115	1.438509	1438509	21335	127	-2	-3	7
116	1.459844	1459844	21460	125	2	4	-8
117	1.481304	1481304	21587	127	-2	-4	7
118	1.502891	1502891	21712	125	1	3	-5

119	1.524603	1524603	126	-1	-2	4
120	1.546441	1546441	21838	1	2	-4
121	1.568404	1568404	21963	-1	-2	3
122	1.590493	1590493	22089	0	1	0
123	1.612707	1612707	22214	1	1	-2
124	1.635046	1635046	22339	0	-1	-1
125	1.657511	1657511	22465	-2	-2	7
126	1.680102	1680102	22591	3	5	-10
127	1.702817	1702817	22715	-2	-5	7
128	1.725659	1725659	22842	0	2	0
129	1.748626	1748626	22967	2	2	-6
130	1.771718	1771718	23092	-2	-4	7
131	1.794937	1794937	23219	1	3	-4
132	1.818281	1818281	23344	0	-1	1
133	1.841751	1841751	23470	0	0	0
134	1.865347	1865347	23596	0	0	1
135	1.889069	1889069	23722	1	1	-3
136	1.912917	1912917	23848	-1	-2	3
137	1.936892	1936892	23975	0	1	0
138	1.960993	1960993	24101	1	1	-3
139	1.985220	1985220	24227	-1	-2	4
140	2.009574	2009574	24354	1	2	-4
141	2.034054	2034054	24480	-1	-2	3
142	2.058661	2058661	24607	0	1	-1
143	2.083394	2083394	24733	0	0	-1
144	2.108253	2108253	24859	-1	-1	2
145	2.133238	2133238	24985	0	1	-1
146	2.158348	2158348	25110	0	0	-1
147	2.183583	2183583	25235	-1	-1	0
148	2.208943	2208943	25360	-2	-1	5
149	2.234427	2234427	25484	2	4	-9
150	2.260033	2260033	25606	-3	-5	8
151	2.285763	2285763	25730	0	3	-3
152	2.311614	2311614	25851	0	0	-2
153	2.337586	2337586	25972	-2	-2	5
154	2.363679	2363679	26093	1	3	-6
155	2.389891	2389891	26212	-2	-3	5
156	2.416223	2416223	26332	0	2	-3
157	2.442673	2442673	26450	-1	-1	3
158	2.469241	2469241	26568	1	2	-4
159	2.495926	2495926	26685	-1	-2	2
160	2.522729	2522729	26803	-1	0	2
			26920			



161	2.549649	2549649	27036	116		2	
162	2.576685	2576685	27153	117	1	-2	-4
163	2.603838	2603838	27269	116	-1	0	2
164	2.631107	2631107	27384	115	-1	3	3
165	2.658491	2658491	27501	117	2	-3	-6
166	2.685992	2685992	27617	116	-1	0	3
167	2.713609	2713609	27732	115	-1	2	2
168	2.741341	2741341	27848	116	1	-2	-4
169	2.769189	2769189	27963	115	-1	2	4
170	2.797152	2797152	28079	116	1	-2	-4
171	2.825231	2825231	28194	115	-1	2	4
172	2.853425	2853425	28310	116	1	-3	-5
173	2.881735	2881735	28424	114	-2	2	5
174	2.910159	2910159	28538	114	0	2	0
175	2.938697	2938697	28654	116	2	-5	-7
176	2.967351	2967351	28767	113	-3	4	9
177	2.996118	2996118	28881	114	1	-1	-5
178	3.024999	3024999	28995	114	0	-2	-1
179	3.053994	3053994	29107	112	-2	3	5
180	3.083101	3083101	29220	113	1	-1	-4
181	3.112321	3112321	29333	113	0	-1	0
182	3.141654	3141654	29445	112	-1	0	1
183	3.171099	3171099	29556	111	-1	0	1
184	3.200655	3200655	29667	111	0	1	0
185	3.230322	3230322	29779	112	1	-2	-3
186	3.260101	3260101	29890	111	-1	0	2
187	3.289991	3289991	30000	110	-1	2	2
188	3.319991	3319991	30111	111	1	-1	-3
189	3.350102	3350102	30222	111	0	-2	-1
190	3.380324	3380324	30331	109	-2	4	6
191	3.410655	3410655	30442	111	2	-2	-6
192	3.441097	3441097	30553	111	0	-2	0
193	3.471650	3471650	30662	109	-2	3	5
194	3.502312	3502312	30772	110	1	-1	-4
195	3.533084	3533084	30882	110	0	0	1
196	3.563966	3563966	30992	110	0	-1	-1
197	3.594958	3594958	31101	109	-1	1	2
198	3.626059	3626059	31210	109	0	0	-1
199	3.657269	3657269	31319	109	0	0	0
200	3.688588	3688588	31428	109	0	0	-1
201	3.720016	3720016	31536	108	-1	2	3
202	3.751552	3751552	31645	109	1	-3	-5
					-2		5

203	3.783197	3783197		107		2	
204	3.814949	3814949	31752	107	0	1	-1
205	3.846808	3846808	31859		1		-3
206	3.878775	3878775	31967	108	-1	-2	2
			32074	107		0	
207	3.910849	3910849		106	-1	2	2
			32180		1		-4
208	3.943029	3943029	32287	107	-1	-2	3
209	3.975316	3975316	32393	106	0	1	-1
210	4.007709	4007709	32499	106	0	0	0
211	4.040208	4040208	32605	106	0	0	-1
212	4.072813	4072813	32711	106	-1	-1	2
213	4.105524	4105524	32816	105	0	1	-2
214	4.138340	4138340	32921	105	-1	-1	4
215	4.171261	4171261	33025	104	2	3	-7
216	4.204286	4204286	33131	106	-2	-4	6
217	4.237417	4237417	33235	104	0	2	-2
218	4.270652	4270652	33339	104	0	0	-1
219	4.303991	4303991	33443	104	-1	-1	3
220	4.337434	4337434	33546	103	1	2	-4
221	4.370980	4370980	33650	104	-1	-2	4
222	4.404630	4404630	33753	103	1	2	-5
223	4.438383	4438383	33857	104	-2	-3	5
224	4.472240	4472240	33959	102	0	2	0
225	4.506199	4506199	34061	102	2	2	-7
226	4.540260	4540260	34165	104	-3	-5	10
227	4.574425	4574425	34266	101	2	5	-8
228	4.608691	4608691	34369	103	-1	-3	3
229	4.643060	4643060	34471	102	-1	0	3
230	4.677531	4677531	34572	101	2	3	-8
231	4.712103	4712103	34675	103	-3	-5	10
232	4.746778	4746778	34775	100	2	5	-8
233	4.781553	4781553	34877	102	-1	-3	3
234	4.816430	4816430	34978	101	-1	0	2
235	4.851408	4851408	35078	100	1	2	-4
236	4.886486	4886486	35179	101	-1	-2	3
237	4.921665	4921665	35279	100	0	1	-2
238	4.956944	4956944	35379	100	-1	-1	3
239	4.992323	4992323	35478	99	1	2	-5
240	5.027801	5027801	35578	100	-2	-3	7
241	5.063379	5063379	35676	98	2	4	-9
242	5.099055	5099055	35776	100	-3	-5	10
243	5.134831	5134831	35873	97	2	5	-8
244	5.170704	5170704	35972	99	-1	-3	4

245	5.206676	5206676		98		1	
246	5.242746	5242746	36070	98	0	-1	-2
247	5.278914	5278914	36168	97	-1	2	3
248	5.315179	5315179	36265	98	1		-4
249	5.351542	5351542	36363	97	-1		3
250	5.388002	5388002	36460	97	0	1	-1
251	5.424559	5424559	36557	97	0	0	0
252	5.461213	5461213	36654	97	0	0	-1
253	5.497964	5497964	36751	97	-1	-1	3
254	5.534811	5534811	36847	96	-1	2	
255	5.571755	5571755	36944	97	1	-3	-5
256	5.608794	5608794	37039	95	-2	4	7
257	5.645930	5645930	37136	97	2		-8
258	5.683161	5683161	37231	95	-2	2	6
259	5.720487	5720487	37326	95	0	2	-1
260	5.757909	5757909	37422	96	1	1	-3
261	5.795426	5795426	37517	96	-1	-2	2
262	5.833037	5833037	37611	95	-1	0	3
263	5.870744	5870744	37707	94	2	3	-8
264	5.908544	5908544	37800	96	-3	-5	10
265	5.946439	5946439	37895	93	2	5	-8
266	5.984428	5984428	37989	95	-1	-3	4
267	6.022511	6022511	38083	94	0	1	-2
268	6.060687	6060687	38176	94	-1	-1	2
269	6.098956	6098956	38269	93	0	1	-1
270	6.137318	6137318	38362	93	0	0	-1
271	6.175772	6175772	38454	93	0	-1	3
272	6.214319	6214319	38547	92	-1	2	-4
273	6.252958	6252958	38639	93	1	-2	3
274	6.291689	6291689	38731	92	-1	1	-2
275	6.330511	6330511	38822	92	0		3
276	6.369425	6369425	38914	91	-1	2	
277	6.408429	6408429	39004	92	1		-5
278	6.447525	6447525	39096	92	-2	-3	7
279	6.486710	6486710	39185	90	2	4	
280	6.525986	6525986	39276	92	2		-9
281	6.565353	6565353	39367	89	-3	-5	10
282	6.604809	6604809	39456	89	2	5	
283	6.644355	6644355	39546	91	2		-7
284	6.683990	6683990	39635	91	0	-2	0
285	6.723715	6723715	39725	91	-2	-2	5
286	6.763529	6763529	39814	89	1	3	
			39903	90	-2	-2	-5
			39993	89	-1	2	4
				89	1		-4
				89	-1	-2	3
				89	0	1	
				89	0	0	-1
					0		-1

287	6.803432	6803432		89		-1	
288	6.843424	6843424	39992	88	-1	3	4
289	6.883504	6883504	40080	90	2	-4	-7
290	6.923674	6923674	40170	88	-2	3	7
291	6.963932	6963932	40258	89	1	-2	-5
292	7.004279	7004279	40347	88	-1	1	3
293	7.044714	7044714	40435	88	0	1	0
294	7.085237	7085237	40523	89	1	-2	-3
295	7.125849	7125849	40612	88	-1	1	3
296	7.166549	7166549	40700	88	0	1	0
297	7.207337	7207337	40788	89	1	-3	-4
298	7.248214	7248214	40877	87	-2	3	6
299	7.289178	7289178	40964	88	1		
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