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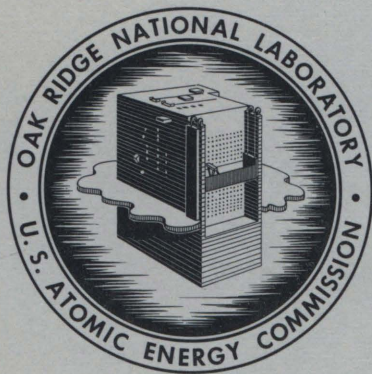
Section 2.10

SMOOTHED THERMOCOUPLE TABLES OF
EXTENDED SIGNIFICANCE (°C)

Volume 2

Section 2.10 Gold-2.1% Cobalt vs 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 2.10 GOLD-2.1% COBALT VS 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 2.10 GOLD-2.1% COBALT VS COPPER CRYOGENIC THERMOCOUPLES

This section contains tables of emf (in absolute millivolts) vs temperature (in degrees Kelvin) for gold-2.1% cobalt vs copper cryogenic thermocouples. The values in these tables, derived from those given by Powell *et al.*,¹ are computed to more significant digits, that is, to the nearest 0.001 μv . 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 10 a smoothed emf value is tabulated in absolute millivolts for every degree Kelvin in the range of the table.

In Table 10A the first two columns contain the same information as given in Table 10. 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 μv , which is roughly equivalent to 0.00003°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 Materials² and the Instrument Society of America.³ An illustration of expected accuracy for cryogenic thermocouple materials may be found in an article by Powell *et al.*⁴

¹R. 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 1, pp. 66-67.

²"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.

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

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

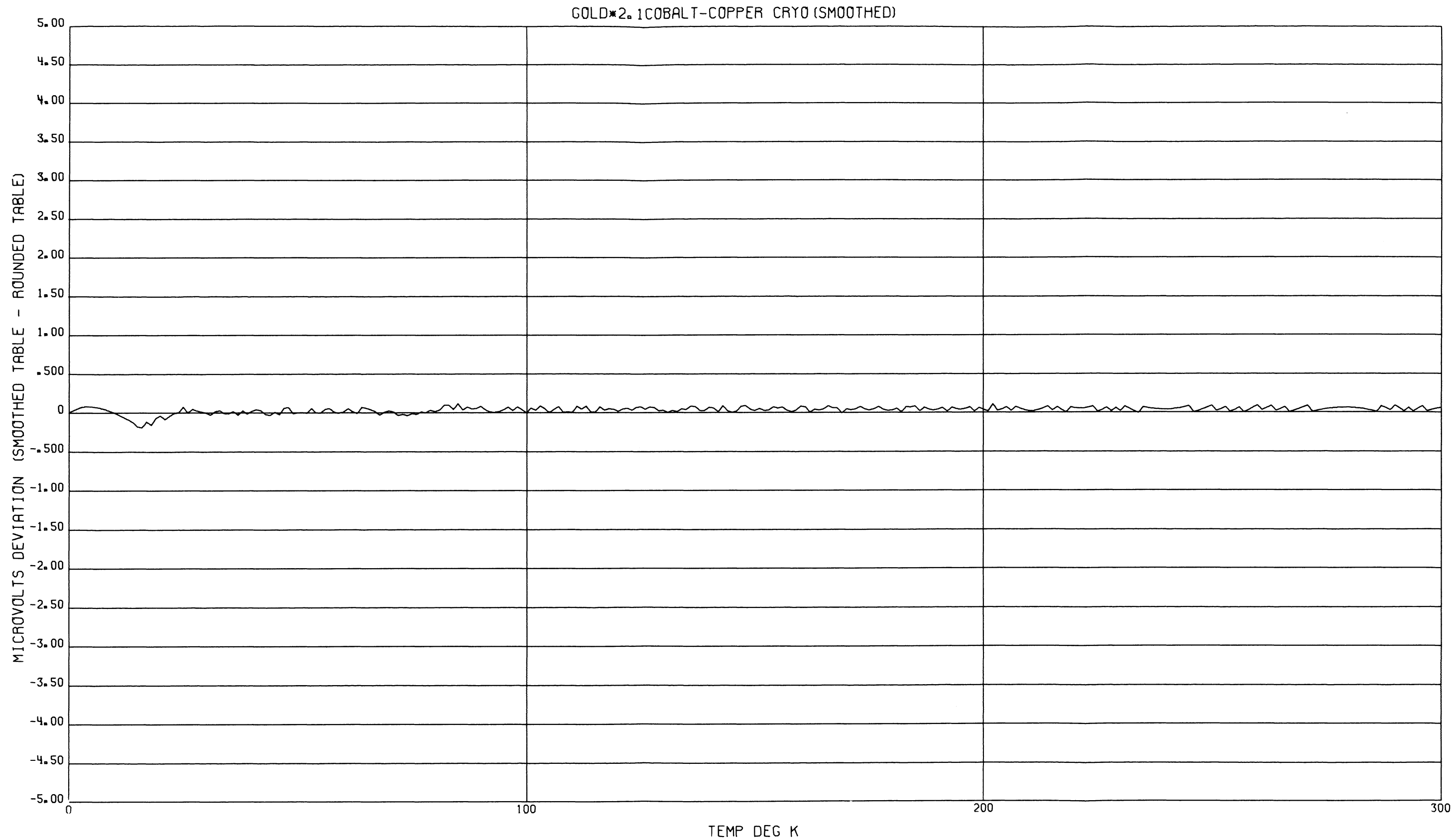


Fig. 1. Deviation of Original Table from Smoothed Table.

GOLD*2.1COBALT-COPPER CRYO(SMOOTHED)
TABLE NO. 10

TEMP=DEG K
VOLTAGE=MILLIVOLT ABSOLUTE

TEMP	0	1	2	3	4	5	6	7	8	9
					MILLIVOLTS					
0	0	.000565	.002152	.004740	.008304	.012823	.018273	.024631	.031875	.039982
10	.046929	.058688	.069239	.080558	.092624	.105415	.118911	.133092	.147940	.163437
20	.179566	.196312	.213661	.231597	.250107	.269178	.288796	.308950	.329626	.350813
30	.372499	.394671	.417318	.440428	.463989	.487991	.512422	.537272	.562529	.588183
40	.614225	.640644	.667431	.694577	.722072	.749908	.778075	.806566	.835372	.864486
50	.893899	.923604	.953593	.983859	1.014396	1.045195	1.076251	1.107557	1.139107	1.170894
60	1.202912	1.235155	1.267617	1.300292	1.333175	1.366260	1.399541	1.433014	1.466672	1.500510
70	1.534525	1.568711	1.603065	1.637581	1.672258	1.707091	1.742078	1.777215	1.812502	1.847936
80	1.883514	1.919235	1.955098	1.991101	2.027242	2.063519	2.099931	2.136476	2.173150	2.209954
90	2.246883	2.283936	2.321111	2.358405	2.395815	2.433340	2.470976	2.508723	2.546577	2.584537
100	2.622600	2.660765	2.699029	2.737391	2.775849	2.814401	2.853045	2.891779	2.930602	2.969512
110	3.008506	3.047585	3.086746	3.125987	3.165307	3.204705	3.244179	3.283728	3.323351	3.363046
120	3.402813	3.442650	3.482555	3.522529	3.562568	3.602673	3.642842	3.683073	3.723366	3.763720
130	3.804132	3.844602	3.885130	3.925712	3.966350	4.007041	4.047785	4.088581	4.129427	4.170323
140	4.211269	4.252262	4.293303	4.334389	4.375522	4.416699	4.457920	4.499184	4.540491	4.581839
150	4.623227	4.664656	4.706123	4.747629	4.789173	4.830754	4.872370	4.914023	4.955710	4.997432
160	5.039187	5.080975	5.122795	5.164647	5.206530	5.248444	5.290387	5.332360	5.374361	5.416391
170	5.458449	5.500533	5.542644	5.584781	5.626944	5.669131	5.711343	5.753580	5.795840	5.838123
180	5.880428	5.922757	5.965106	6.007478	6.049870	6.092283	6.134715	6.177168	6.219639	6.262130
190	6.304638	6.347165	6.389708	6.432269	6.474846	6.517439	6.560048	6.602672	6.645312	6.687965
200	6.730634	6.773316	6.816011	6.858720	6.901442	6.944176	6.986922	7.029680	7.072449	7.115229
210	7.158020	7.200821	7.243633	7.286454	7.329285	7.372125	7.414974	7.457833	7.500700	7.543576
220	7.586461	7.629354	7.672255	7.715164	7.758080	7.801004	7.843935	7.886872	7.929816	7.972766
230	8.015722	8.058684	8.101650	8.144621	8.187597	8.230577	8.273562	8.316551	8.359543	8.402539
240	8.445539	8.488541	8.531548	8.574557	8.617569	8.660584	8.703601	8.746621	8.789643	8.832667
250	8.875692	8.918719	8.961747	9.004776	9.047806	9.090837	9.133868	9.176900	9.219932	9.262963
260	9.305995	9.349027	9.392058	9.435088	9.478118	9.521146	9.564174	9.607200	9.650225	9.693247
270	9.736269	9.779288	9.822305	9.865320	9.908333	9.951344	9.994353	10.037359	10.080363	10.123365
280	10.166365	10.209362	10.252356	10.295348	10.338337	10.381323	10.424305	10.467284	10.510259	10.553229
290	10.596196	10.639157	10.682114	10.725066	10.768012	10.810952	10.853886	10.896814	10.939736	10.982651
300	11.025558									

TABLE 10A

GOLD*2.1 COBALT-COPPER CRYO(SMOOTHED)

TEMP	MV	DIFFERENCE ORDER					
		0 TH	1 ST	2 ND	3 RD	4 TH	5 TH
0	0	0					
1	.000565	565	565	1022			
2	.002152	2152	1587	1001	-21	-4	
3	.004740	4740	2583	976	-25	4	8
4	.008304	8304	3564	955	-21	-3	-7
5	.012823	12823	4519	931	-24	1	4
6	.018273	18273	5450	908	-23	1	0
7	.024631	24631	6358	886	-22	-1	-2
8	.031875	31875	7244	863	-23	0	1
9	.039982	39982	8107	840	-23	-5	-5
10	.048929	48929	8947	812	-28	8	13
11	.058688	58688	9759	792	-20	-4	-12
12	.069239	69239	10551	768	-24	3	7
13	.080558	80558	11319	747	-21	-1	-4
14	.092624	92624	12065	725	-22	2	3
15	.105415	105415	12791	705	-20	0	-2
16	.118911	118911	13495	685	-20	2	2
17	.133092	133092	14181	667	-18	0	-2
18	.147940	147940	14843	649	-18	1	1
19	.163437	163437	15497	632	-17	2	1
20	.179566	179566	16129	617	-15	1	-1
21	.196312	196312	16745	603	-14	-2	-3
22	.213661	213661	17349	587	-16	3	5
23	.231597	231597	17935	574	-13	0	-3
24	.250107	250107	18510	561	-13	-1	-1
25	.269178	269178	19071	547	-14	3	4
26	.288796	288796	19613	536	-11	-3	-6
27	.308950	308950	20154	522	-14	3	6
28	.329626	329626	20675	511	-11	-1	-4
29	.350813	350813	21187	499	-12	-1	0
30	.372499	372499	21685	486	-13	2	3
31	.394671	394671	22172	475	-11	-1	-3
32	.417318	417318	22647	463	-12	0	1
33	.440428	440428	23110	451	-12	2	2
34	.463989	463989	23561	441	-10	-2	-4
35	.487991	487991	24002	429	-12	2	4
36	.512422	512422	24431	419	-10	-2	-4
			24850		-12		4

37	.537272	537272	25257	407	=10	2	=1
38	.562529	562529	23654	397	=9	1	-3
39	.588183	588183	25042	388	=11	-2	4
40	.614225	614225	26419	377	=9	2	-2
41	.640644	640644	25787	368	=9	0	-1
42	.667431	667431	27145	359	=10	-1	3
43	.694577	694577	27495	349	=8	2	-4
44	.722072	722072	27835	341	=10	-2	5
45	.749908	749908	28167	331	=7	3	-5
46	.778075	778075	28491	324	=9	-2	4
47	.806566	806566	28805	315	=7	2	-4
48	.835372	835372	29114	308	=9	-2	4
49	.864486	864486	29413	299	=7	2	-3
50	.893899	893899	29705	292	=8	-1	2
51	.923604	923604	29989	284	=7	1	0
52	.953593	953593	30265	277	=6	1	-4
53	.983859	983859	30537	271	=9	-3	7
54	1.014396	1014396	30799	262	=5	4	-6
55	1.045195	1045195	31055	257	=7	-2	3
56	1.076251	1076251	31305	250	=6	1	-2
57	1.107557	1107557	31550	244	=7	-1	2
58	1.139107	1139107	31787	237	=6	1	=1
59	1.170894	1170894	32019	231	=6	0	0
60	1.202912	1202912	32243	225	=6	0	0
61	1.235155	1235155	32462	219	=6	0	1
62	1.267617	1267617	32675	213	=5	1	=2
63	1.300292	1300292	32883	208	=6	-1	1
64	1.333175	1333175	33085	202	=6	0	2
65	1.366260	1366260	33281	196	=4	2	=5
66	1.399541	1399541	33473	192	=7	-3	5
67	1.433014	1433014	33659	185	=5	2	0
68	1.466672	1466672	33839	180	=3	2	=5
69	1.500510	1500510	34015	177	=6	-3	6
70	1.534525	1534525	34185	171	=3	3	=6
71	1.568711	1568711	34354	168	=5	-3	8
72	1.603065	1603065	34515	162	=1	5	=9
73	1.637581	1637581	34677	161	=5	-4	7
74	1.672258	1672258	34833	156	=2	3	=5
75	1.707091	1707091	34987	154	=4	-2	6
76	1.742078	1742078	35137	150	0	4	=7
77	1.777215	1777215	35287	150	=3	-3	3

78	1.812502	1812502		147		0	
79	1.847936	1847936	35434	144	-3	2	2
80	1.883514	1883514	35573	143	-1	0	-2
81	1.919235	1919235	35721	142	-1	-1	-1
82	1.955098	1955098	35863	140	-2	0	1
83	1.991101	1991101	36003	138	-2	0	0
84	2.027242	2027242	36141	136	-2	1	1
85	2.063519	2063519	36277	135	-1	-1	-2
86	2.099931	2099931	36412	133	-2	-2	-1
87	2.136476	2136476	36545	129	-4	5	7
88	2.173150	2173150	36674	130	1	-6	-11
89	2.209954	2209954	36804	125	-5	4	10
90	2.246883	2246883	36929	124	-1	-1	-5
91	2.283936	2283936	37053	122	-2	-1	0
92	2.321111	2321111	37175	119	-3	0	1
93	2.358405	2358405	37294	116	-3	2	2
94	2.395815	2395815	37410	115	-1	-3	-5
95	2.433340	2433340	37525	111	-4	4	7
96	2.470976	2470976	37635	111	0	-4	-8
97	2.508723	2508723	37747	107	-4	3	7
98	2.546577	2546577	37854	106	-1	-2	-5
99	2.584537	2584537	37960	103	-3	2	4
100	2.622600	2622600	38063	102	-1	-2	-4
101	2.660765	2660765	38165	99	-3	2	4
102	2.699029	2699029	38264	98	-1	-1	-3
103	2.737391	2737391	38362	96	-2	0	1
104	2.775849	2775849	38459	94	-2	0	0
105	2.814401	2814401	38552	92	-2	0	0
106	2.853045	2853045	38644	90	-2	1	1
107	2.891779	2891779	38734	89	-1	-1	-2
108	2.930602	2930602	38823	87	-2	-1	0
109	2.969512	2969512	38910	84	-3	4	5
110	3.008506	3008506	38994	85	1	-4	-8
111	3.047585	3047585	39079	82	-3	1	5
112	3.086746	3086746	39161	80	-2	1	0
113	3.125987	3125987	39241	79	-1	1	-1
114	3.165307	3165307	39320	78	-1	0	-1
115	3.204705	3204705	39399	76	-2	1	2
116	3.244179	3244179	39474	75	-1	0	-1
117	3.283728	3283728	39549	74	-1	1	-1
118	3.323351	3323351	39623	72	-2	2	3
119	3.363046	3363046	39695	72	0	-2	-4
			39767		-2		2

120	3.402813	3402813		70		0	
121	3.442650	3442650	39837	68	-2	3	3
122	3.482555	3482555	39905	69	1	-5	-8
123	3.522529	3522529	39974	65	-4	5	10
124	3.562568	3562568	40039	66	1	-3	-8
125	3.602673	3602673	40105	64	-2	0	3
126	3.642842	3642842	40169	62	-2	2	2
127	3.683073	3683073	40231	62	0	-1	-3
128	3.723366	3723366	40293	61	-1	-2	-1
129	3.763720	3763720	40354	58	-3	3	5
130	3.804132	3804132	40412	58	0	0	-3
131	3.844602	3844602	40470	58	0	-4	-4
132	3.885130	3885130	40529	54	-4	5	10
133	3.925712	3925712	40582	56	2	-5	-11
134	3.966350	3966350	40639	53	-3	3	8
135	4.007041	4007041	40691	53	0	-1	-4
136	4.047785	4047785	40744	52	-1	-1	0
137	4.088581	4088581	40795	50	-2	2	3
138	4.129427	4129427	40845	50	0	0	-2
139	4.170323	4170323	40895	50	0	-3	-3
140	4.211269	4211269	40945	47	-3	4	7
141	4.252262	4252262	40993	48	1	-4	-8
142	4.293303	4293303	41041	45	-3	5	9
143	4.334389	4334389	41085	47	2	-5	-10
144	4.375522	4375522	41133	44	-3	3	8
145	4.416699	4416699	41177	44	0	-1	-4
146	4.457920	4457920	41221	43	-1	1	2
147	4.499184	4499184	41264	43	0	-2	-3
148	4.540491	4540491	41307	41	-2	1	3
149	4.581839	4581839	41348	40	-1	2	1
150	4.623227	4623227	41389	41	1	-4	-6
151	4.664656	4664656	41429	38	-3	4	8
152	4.706123	4706123	41467	39	1	-2	-6
153	4.747629	4747629	41505	38	-1	0	2
154	4.789173	4789173	41544	37	-1	-1	-1
155	4.830754	4830754	41581	35	-2	4	5
156	4.872370	4872370	41616	37	2	-5	-9
157	4.914023	4914023	41653	34	-3	4	9
158	4.955710	4955710	41687	35	1	-3	-7
159	4.997432	4997432	41722	33	-2	2	5
160	5.039187	5039187	41755	33	0	-1	-3
			41788		-1		2

161	5.080975	5080975		32		1	
162	5.122795	5122795	41820	32	0	-1	-2
163	5.164647	5164647	41852	31	-1	1	2
164	5.206530	5206530	41883	31	0		-3
165	5.248444	5248444	41914	29	-2		5
166	5.290387	5290387	41943	30	1	-3	-6
167	5.332360	5332360	41973	28	-2	3	6
168	5.374361	5374361	42001	29	1	-2	-5
169	5.416391	5416391	42030	28	-1	-1	1
170	5.458449	5458449	42059	26	-2		4
171	5.500533	5500533	42084	27	1	-2	-5
172	5.542644	5542644	42111	26	-1	1	3
173	5.584781	5584781	42137	26	0	-2	-3
174	5.626944	5626944	42163	24	-2	3	5
175	5.669131	5669131	42187	25	1	-1	-4
176	5.711343	5711343	42212	25	0	-2	-1
177	5.753580	5753580	42237	23	-2	2	4
178	5.795840	5795840	42260	23	0	-1	-3
179	5.838123	5838123	42283	22	-1	3	4
180	5.880428	5880428	42305	24	2		-9
181	5.922757	5922757	42329	20	-4	7	13
182	5.965106	5965106	42349	23	3	-6	-13
183	6.007478	6007478	42372	20	-3	4	10
184	6.049870	6049870	42392	21	1	-3	-7
185	6.092283	6092283	42413	19	-2	4	7
186	6.134715	6134715	42432	21	2		-9
187	6.177168	6177168	42453	18	-3	5	10
188	6.219639	6219639	42471	20	2	-5	-10
189	6.262130	6262130	42491	17	-3	5	10
190	6.304638	6304638	42509	19	2	-5	-10
191	6.347165	6347165	42527	16	-3	5	10
192	6.389708	6389708	42543	18	2	-4	-9
193	6.432269	6432269	42561	16	-2	2	6
194	6.474846	6474846	42577	16	0		-2
195	6.517439	6517439	42593	16	0	-1	-1
196	6.560048	6560048	42609	15	-1	2	3
197	6.602672	6602672	42624	16	1	-4	-6
198	6.645312	6645312	42640	13	-3	5	10
199	6.687965	6687965	42653	16	3	-6	-12
200	6.730634	6730634	42669	13	-3	3	9
201	6.773316	6773316	42682	13	0	1	-2
			42695		1		-3

202	6.816011	6816011		14		-2	
203	6.858720	6858720	42709	13	-1	0	2
204	6.901442	6901442	42722	12	-1	1	1
205	6.944176	6944176	42734	12	0	0	-1
206	6.986922	6986922	42746	12	0	-1	-1
207	7.029680	7029680	42758	11	-1	1	2
208	7.072449	7072449	42769	11	0	0	-1
209	7.115229	7115229	42780	11	0	-1	-1
210	7.158020	7158020	42791	10	-1	2	3
211	7.200821	7200821	42801	11	1	-3	-5
212	7.243633	7243633	42812	9	-2	3	6
213	7.286454	7286454	42821	10	1	-2	-5
214	7.329285	7329285	42831	9	-1	1	3
215	7.372125	7372125	42840	9	0	1	0
216	7.414974	7414974	42849	10	1	-3	-4
217	7.457833	7457833	42859	8	-2	3	6
218	7.500700	7500700	42867	9	1	-1	-4
219	7.543576	7543576	42876	9	0	-1	0
220	7.586461	7586461	42885	8	-1	1	2
221	7.629354	7629354	42893	8	0	0	-1
222	7.672255	7672255	42901	8	0	-1	-1
223	7.715164	7715164	42909	7	-1	2	3
224	7.758080	7758080	42916	8	1	-2	-4
225	7.801004	7801004	42924	7	-1	0	2
226	7.843935	7843935	42931	6	-1	2	2
227	7.886872	7886872	42937	7	1	-2	-4
228	7.929816	7929816	42944	6	-1	1	3
229	7.972766	7972766	42950	6	0	0	-1
230	8.015722	8015722	42955	6	0	-2	-2
231	8.058684	8058684	42962	4	-2	3	5
232	8.101650	8101650	42966	5	1	-1	-4
233	8.144621	8144621	42971	5	0	-1	0
234	8.187597	8187597	42976	4	-1	2	3
235	8.230577	8230577	42980	5	1	-2	-4
236	8.273562	8273562	42985	4	-1	0	2
237	8.316551	8316551	42989	3	-1	2	2
238	8.359543	8359543	42992	4	1	-1	-3
239	8.402539	8402539	42996	4	0	-2	-1
240	8.445539	8445539	43000	2	-2	5	7
241	8.488541	8488541	43002	5	3	-6	-11
242	8.531548	8531548	43007	2	-3	4	10
243	8.574557	8574557	43009	3	1	-1	-5
			43012		0		0

244	8.617569	8617559		3		-1		
245	8.660584	8660584	43015	2	-1		2	3
246	8.703601	8703601	43017	3	1			-4
247	8.746621	8746621	43020	2	-1		-2	3
248	8.789643	8789643	43022	2	0		1	-2
249	8.832667	8832667	43024	1	-1			3
250	8.875692	8875692	43025	2	1		2	-4
251	8.918719	8918719	43027	1	-1			3
252	8.961747	8961747	43028	1	0		1	-1
253	9.004776	9004776	43029	1	0		0	0
254	9.047806	9047806	43030	1	0		0	-1
255	9.090837	9090837	43031	0	-1		-1	3
256	9.133868	9133868	43031	1	1		2	-4
257	9.176900	9176900	43032	1	-1		-2	2
258	9.219932	9219932	43032	0	-1		0	3
259	9.262963	9262963	43031	-1	-1		3	3
260	9.305995	9305995	43031	1	2			-6
261	9.349027	9349027	43032	1	-1		-3	3
262	9.392058	9392058	43032	0	-1		0	1
263	9.435088	9435088	43031	-1	0		1	0
264	9.478118	9478118	43030	-1	1		1	-4
265	9.521146	9521146	43030	0	-2		-3	7
266	9.564174	9564174	43028	-2	-2		4	-8
267	9.607200	9607200	43028	0	2		-4	7
268	9.650225	9650225	43025	-1	-1		3	-6
269	9.693247	9693247	43025	-1	1		-3	8
270	9.736269	9736269	43022	-3	-2		5	
271	9.779288	9779288	43022	0	3			-11
272	9.822305	9822305	43019	-3	-3		-6	10
273	9.865320	9865320	43017	-3	-3		4	-5
274	9.908333	9908333	43017	-2	1		-1	1
275	9.951344	9951344	43015	-2	0		0	0
276	9.994353	9994353	43013	-2	0		0	0
277	10.037359	10037359	43011	-2	0		0	-1
278	10.080363	10080363	43009	-2	-1		-1	3
279	10.123365	10123365	43005	-3	1		2	-3
280	10.166365	10166365	43004	-2	1		-1	-3
281	10.209362	10209362	43004	-2	0		0	1
282	10.252356	10252356	43002	-2	0		0	-1
283	10.295348	10295348	43000	-2	0		-1	-1
284	10.338337	10338337	42997	-3	-1		1	2
285	10.381323	10381323	42994	-3	0		1	0
			42992	-3	1		1	-3
			42989	-2	-1		-2	3
			42985	-3	0		1	-2
			42982	-3	-1		-1	3
				-4	1		2	-4

286	10.424305	10424305	42979	-3		*2	
287	10.467284	10467284	42975	-4	-1	0	2
288	10.510259	10510259	42970	-5	-1	3	3
289	10.553229	10553229	42967	-3	2	-5	-8
290	10.596196	10596196	42961	-6	-3	5	10
291	10.639157	10639157	42957	-4	2	-3	-8
292	10.682114	10682114	42952	-5	*1	0	3
293	10.725066	10725066	42945	-6	-1	1	1
294	10.768012	10768012	42940	-6	0	0	-1
295	10.810952	10810952	42934	-6	0	0	0
296	10.853886	10853886	42929	-6	0	0	0
297	10.896814	10896814	42922	-6	0	-1	-1
298	10.939736	10939736	42915	-7	-1	0	1
299	10.982651	10982651	42907	-8	-1		
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