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Tables of Genera of Groups of Linear Fractional Transformations*

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The genera of the groups $\Gamma_0(n)$, $\Gamma^*(n)$ together with certain associated number-theoretic functions are given for $1 \leq n \leq 1000$.

The 2×2 modular group Γ and its subgroups are of fundamental importance in the theory of automorphic functions (in particular the elliptic modular functions) and in the theory of Riemann surfaces. Let G be such a subgroup. Then the substitutions

$$\tau' = \frac{a\tau + b}{c\tau + d} \tag{1}$$

of G map the upper τ half-plane onto itself, and the points of this half-plane are partitioned into equivalence classes modulo G. A set of points consisting of one point from each equivalence class is termed a *fundamental set*, and if G is of finite index in Γ there is a simple way of selecting a standard fundamental set R, which is fully described in Ford's book [1] [1] or in Gunning's book [3]. The set R is commonly called a *fundamental region*. After appropriate identifications of sides and vertices are made R becomes a surface whose genus g plays a central role in the study of G.

Among the subgroups of finite index in Γ the congruence subgroups have been studied most extensively and among the congruence subgroups the (nonnormal) subgroups $\Gamma_0(n)$ are of primary importance. These are defined for every natural number n as the totality of substitutions (1) where a, b, c, d are rational integers, $ad-bc=1$, and $c\equiv 0 \pmod{n}$.

If the substitution

$$\tau' = -\frac{1}{n\tau}$$

is adjoined to $\Gamma_0(n)$ the larger group so obtained (in general not a subgroup of Γ) is donoted by $\Gamma^*(n)$. Formulas for the genera $g_0(n)$, $g^*(n)$ of $\Gamma_0(n)$, $\Gamma^*(n)$, respectively, have been given by F. Klein [6], E. Hecke [4,5], and R. Fricke [2]. Denote the number of solutions of the congruence

$$x^2 - x + 1 \equiv 0 \pmod{n},\ 0 \leq x \leq n-1 \tag{2}$$

by $\nu_1(n)$, and the number of solutions of the congruence

$$x^2 + 1 \equiv 0 \pmod{n},\ 0 \leq x \leq n-1 \tag{3}$$

by $\nu_2(n)$. Set

$$\mu(n) = n \prod_{q \mid n} \left(1 + \frac{1}{q}\right),$$

$$\sigma_0(n) = \sum_{d \mid n} \varphi\left(d, \frac{n}{d}\right) = \prod_{q^e \| n} \left(q^{\left[\frac{e}{2}\right]} + q^{\left[\frac{e-1}{2}\right]}\right),$$

where $\left(d, \frac{n}{d}\right)$ denotes the greatest common divisor of d and $\frac{n}{d}$, and φ is the Euler function. Then $\nu_1(n)$ is the number of inequivalent elliptic vertices of period 3 of the fundamental region R_n of $\Gamma_0(n)$, $\nu_2(n)$ the number of inequivalent elliptic vertices of period 2 of R_n, $\mu(n)$ the index of $\Gamma_0(n)$ in Γ, and $\sigma_0(n)$ the number of inequivalent parabolic vertices of R_n. The genus $g_0(n)$ of $\Gamma_0(n)$ is then

$$g_0(n) = 1 + \frac{\mu(n)}{12} - \frac{\nu_1(n)}{3} - \frac{\nu_2(n)}{4} - \frac{\sigma_0(n)}{2}.$$

Furthermore let $h(-4n)$ denote the number of classes of primitive positive binary quadratic forms of discriminant $-4n$, and set

$$\delta_n = \begin{cases} 2 & n \equiv 7 \pmod 8 \\ \frac{4}{3} & n \equiv 3 \pmod 8,\ n > 3 \\ 1 & \text{otherwise.} \end{cases}$$

Then the genus $g^*(n)$ of $\Gamma^*(n)$ is given by

$$g^*(n) = \frac{1}{2} g_0(n) + \frac{1}{2} - \frac{1}{4} \delta_n h(-4n).$$

In this article we give the actual numerical values of $g_0(n)$, $g^*(n)$ for $1 \leq n \leq 1000$ together with the values of the associated functions $\nu_1(n)$, $\nu_2(n)$, $\mu(n)$, $\sigma_0(n)$, $h(-4n)$. These were computed on the IBM 7090 of the NBS in a negligible amount of time. The resulting tables are of considerable interest however and should prove useful in many number-

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[1] Figures in brackets indicate the literature references at the end of this paper.

theoretic investigations, as well as in the study of the groups $\Gamma_0(n)$, $\Gamma^*(n)$.

We say some words about the computation of the tables. The functions $\nu_1(n)$, $\nu_2(n)$ were computed directly as the number of solutions of the congruences (2), (3) respectively. It is easy to give closed expressions for $\nu_1(n)$, $\nu_2(n)$ however. These are

$$\nu_1(n)=\begin{cases}0 & 2|n \text{ or } 9|n\\ \prod\limits_{q|n}\left(1+\left(\frac{-3}{q}\right)\right) & \text{otherwise,}\end{cases} \tag{4}$$

$$\nu_2(n)=\begin{cases}0 & 4|n\\ \prod\limits_{q|n}\left(1+\left(\frac{-4}{q}\right)\right) & \text{otherwise.}\end{cases} \tag{5}$$

We see that (4) and (5) imply that for $n>3$, $\nu_1(n)$ and $\nu_2(n)$ can take only 0 or powers of 2 as values. This provides an excellent check on the computation of $\nu_1(n)$, $\nu_2(n)$.

The function $\mu(n)$ is a multiplicative arithmetic function of n with easily computed values at the prime powers. In addition, if q is a prime $\mu(n)$ satisfies

$$\mu(nq)=\begin{cases}q\mu(n) & q|n\\ (q+1)\mu(n) & \text{otherwise.}\end{cases} \tag{6}$$

Relationship (6) provides an efficient and easily applied check on the computation of $\mu(n)$. Similar remarks apply to the function $\sigma_0(n)$.

The class number $h(-4n)$ was computed as the number of solutions of the system

$$\begin{cases}b^2-4ac=-4n\\ (a,b,c)=1\\ -a<b\leq a<c \text{ or } 0\leq b\leq a=c.\end{cases} \tag{7}$$

A check on the computation was provided by determining the parity of $h(-4n)$. It is not difficult to show from (7) that

$$h(-4n)\equiv U(n)+V(n) \pmod 2, \tag{8}$$

where

$$U(n)=\sum_{\substack{d|n\\ \left(d,\frac{n}{d}\right)=1\\ d^2<n}}1 \tag{9}$$

$$V(n)=\sum_{\substack{d|n\\ \left(d,\frac{d+\frac{n}{d}}{2}\right)=1\\ d^2\leq n\\ d+\frac{n}{d}\equiv 2 \pmod 4}}1. \tag{10}$$

From (9) and (10) it follows for example that for $n>1$, $n\equiv 1 \pmod 4$ $h(-4n)$ is even. For $n\equiv 3 \pmod 4$ $h(-4n)$ is even if n is not a prime power and odd if n is a prime power. Another excellent check arises from the fact that for $n\equiv 3 \pmod 8$, $n>3$, $h(-4n)$ is divisible by 3.

A different type of check is available from the relationship

$$h(-4fm^2)=h(-4f)\,m\prod_{p|m}\left\{1-\frac{1}{p}\left(\frac{-4f}{p}\right)\right\},$$

where $f>1$, $f\equiv 1, 2 \pmod 4$ and square-free.

The computation of $g_0(n)$ was checked by computing 12 $g_0(n)$ and verifying the divisibility of 12 $g_0(n)$ by 12. The computation of $g^*(n)$ was checked by the fact that always, $g^*(n)\leq \frac{1}{2}g(n)$. In addition, R. Fricke gives in [2] the first 50 or so values of $g_0(n)$, $g^*(n)$ and these agree with the values given here.

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
1	1	1	1	1	1	0	0
2	0	1	3	2	1	0	0
3	1	0	4	2	1	0	0
4	0	0	6	3	1	0	0
5	0	2	6	2	2	0	0
6	0	0	12	4	2	0	0
7	2	0	8	2	1	0	0
8	0	0	12	4	2	0	0
9	0	0	12	4	2	0	0
10	0	2	18	4	2	0	0
11	0	0	12	2	3	1	0
12	0	0	24	6	2	0	0
13	2	2	14	2	2	0	0
14	0	0	24	4	4	1	0
15	0	0	24	4	2	1	0
16	0	0	24	6	2	0	0
17	0	2	18	2	4	1	0
18	0	0	36	8	2	0	0
19	2	0	20	2	3	1	0
20	0	0	36	6	4	1	0
21	2	0	32	4	4	1	0
22	0	0	36	4	2	2	1
23	0	0	24	2	3	2	0
24	0	0	48	8	4	1	0
25	0	2	30	6	2	0	0
26	0	2	42	4	6	2	0
27	0	0	36	6	3	1	0
28	0	0	48	6	2	2	1
29	0	2	30	2	6	2	0
30	0	0	72	8	4	3	1
31	2	0	32	2	3	2	0
32	0	0	48	8	4	1	0
33	0	0	48	4	4	3	1
34	0	2	54	4	4	3	1
35	0	0	48	4	6	3	0
36	0	0	72	12	4	1	0
37	2	2	38	2	2	2	1
38	0	0	60	4	6	4	1
39	2	0	56	4	4	3	0
40	0	0	72	8	4	3	1
41	0	2	42	2	8	3	0
42	0	0	96	8	4	5	2
43	2	0	44	2	3	3	1
44	0	0	72	6	6	4	1
45	0	0	72	8	4	3	1
46	0	0	72	4	4	5	2
47	0	0	48	2	5	4	0
48	0	0	96	12	4	3	1
49	2	0	56	8	4	1	0
50	0	2	90	12	6	2	0
51	0	0	72	4	6	5	1
52	0	0	84	6	4	5	2
53	0	2	54	2	6	4	1
54	0	0	108	12	6	4	1
55	0	0	72	4	4	5	1

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
56	0	0	96	8	8	5	1
57	2	0	80	4	4	5	2
58	0	2	90	4	2	6	3
59	0	0	60	2	9	5	0
60	0	0	144	12	4	7	3
61	2	2	62	2	6	4	1
62	0	0	96	4	8	7	2
63	0	0	96	8	4	5	1
64	0	0	96	12	4	3	1
65	0	4	84	4	8	5	1
66	0	0	144	8	8	9	3
67	2	0	68	2	3	5	2
68	0	0	108	6	8	7	2
69	0	0	96	4	8	7	2
70	0	0	144	8	4	9	4
71	0	0	72	2	7	6	0
72	0	0	144	16	4	5	2
73	2	2	74	2	4	5	2
74	0	2	114	4	10	8	2
75	0	0	120	12	6	5	1
76	0	0	120	6	6	8	3
77	0	0	96	4	8	7	2
78	0	0	168	8	4	11	5
79	2	0	80	2	5	6	1
80	0	0	144	12	8	7	2
81	0	0	108	12	6	4	1
82	0	2	126	4	4	9	4
83	0	0	84	2	9	7	1
84	0	0	192	12	8	11	4
85	0	4	108	4	4	7	3
86	0	0	132	4	10	10	3
87	0	0	120	4	6	9	2
88	0	0	144	8	4	9	4
89	0	2	90	2	12	7	1
90	0	0	216	16	8	11	4
91	4	0	112	4	6	7	2
92	0	0	144	6	6	10	4
93	2	0	128	4	4	9	4
94	0	0	144	4	8	11	4
95	0	0	120	4	8	9	1
96	0	0	192	16	8	9	3
97	2	2	98	2	4	7	3
98	0	0	168	16	8	7	2
99	0	0	144	8	6	9	3
100	0	0	180	18	4	7	3
101	0	2	102	2	14	8	1
102	0	0	216	8	4	15	7
103	2	0	104	2	5	8	2
104	0	0	168	8	12	11	3
105	0	0	192	8	8	13	5
106	0	2	162	4	6	12	5
107	0	0	108	2	9	9	2
108	0	0	216	18	6	10	4
109	2	2	110	2	6	8	3
110	0	0	216	8	12	15	5
111	2	0	152	4	8	11	2
112	0	0	192	12	4	11	5
113	0	2	114	2	8	9	3
114	0	0	240	8	8	17	7
115	0	0	144	4	6	11	4
116	0	0	180	6	12	13	4
117	0	0	168	8	8	11	4
118	0	0	180	4	6	14	6
119	0	0	144	4	10	11	1
120	0	0	288	16	8	17	7
121	0	0	132	12	6	6	2
122	0	2	186	4	10	14	5
123	0	0	168	4	6	13	5
124	0	0	192	6	6	14	6
125	0	2	150	10	10	8	2
126	0	0	288	16	8	17	7
127	2	0	128	2	5	10	3
128	0	0	192	16	8	9	3
129	2	0	176	4	12	13	4
130	0	4	252	8	4	17	8
131	0	0	132	2	15	11	1
132	0	0	288	12	8	19	8
133	4	0	160	4	4	11	5
134	0	0	204	4	14	16	5
135	0	0	216	12	6	13	4

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
136	0	0	216	8	8	15	6
137	0	2	138	2	8	11	4
138	0	0	288	8	8	21	9
139	2	0	140	2	9	11	3
140	0	0	288	12	12	19	7
141	0	0	192	4	8	15	6
142	0	0	216	4	4	17	8
143	0	0	168	4	10	13	2
144	0	0	288	24	8	13	5
145	0	4	180	4	8	13	5
146	0	2	222	4	16	17	5
147	2	0	224	16	6	11	4
148	0	0	228	6	4	17	8
149	0	2	150	2	14	12	3
150	0	0	360	24	8	19	8
151	2	0	152	2	7	12	3
152	0	0	240	8	12	17	6
153	0	0	216	8	8	15	6
154	0	0	288	8	8	21	9
155	0	0	192	4	12	15	4
156	0	0	336	12	8	23	10
157	2	2	158	2	6	12	5
158	0	0	240	4	8	19	8
159	0	0	216	4	10	17	4
160	0	0	288	16	8	17	7
161	0	0	192	4	16	15	4
162	0	0	324	24	6	16	7
163	2	0	164	2	3	13	6
164	0	0	252	6	16	19	6
165	0	0	288	8	8	21	9
166	0	0	252	4	10	20	8
167	0	0	168	2	11	14	2
168	0	0	384	16	8	25	11
169	2	2	182	14	6	8	3
170	0	4	324	8	12	23	9
171	0	0	240	8	12	17	5
172	0	0	264	6	6	20	9
173	0	2	174	2	14	14	4
174	0	0	360	8	12	27	11
175	0	0	240	12	6	15	5
176	0	0	288	12	12	19	7
177	0	0	240	4	4	19	9
178	0	2	270	4	8	21	9
179	0	0	180	2	15	15	3
180	0	0	432	24	8	25	11
181	2	2	182	2	10	14	5
182	0	0	336	8	12	25	10
183	2	0	248	4	8	19	6
184	0	0	288	8	8	21	9
185	0	4	228	4	16	17	5
186	0	0	384	8	12	29	12
187	0	0	216	4	6	17	7
188	0	0	288	6	10	22	9
189	0	0	288	12	12	19	7
190	0	0	360	8	4	27	13
191	0	0	192	2	13	16	2
192	0	0	384	24	8	21	9
193	2	2	194	2	4	15	7
194	0	2	294	4	20	23	7
195	0	0	336	8	12	25	9
196	0	0	336	24	8	17	7
197	0	2	198	2	10	16	6
198	0	0	432	16	8	29	13
199	2	0	200	2	9	16	4
200	0	0	360	24	12	19	7
201	2	0	272	4	12	21	8
202	0	2	306	4	6	24	11
203	0	0	240	4	12	19	6
204	0	0	432	12	12	31	13
205	0	4	252	4	8	19	8
206	0	0	312	4	20	25	8
207	0	0	288	8	6	21	8
208	0	0	336	12	8	23	10
209	0	0	240	4	20	19	5
210	0	0	576	16	8	41	19
211	2	0	212	2	9	17	6
212	0	0	324	6	12	25	10
213	0	0	288	4	8	23	10
214	0	0	324	4	6	26	12
215	0	0	264	4	14	21	4

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
216	0	0	432	24	12	25	10
217	4	0	256	4	8	19	8
218	0	2	330	4	10	26	11
219	2	0	296	4	12	23	8
220	0	0	432	12	8	31	14
221	0	4	252	4	16	19	6
222	0	0	456	8	12	35	15
223	2	0	224	2	7	18	6
224	0	0	384	16	16	25	9
225	0	0	360	24	8	19	8
226	0	2	342	4	8	27	12
227	0	0	228	2	15	19	5
228	0	0	480	12	8	35	16
229	2	2	230	2	10	18	7
230	0	0	432	8	20	33	12
231	0	0	384	8	12	29	9
232	0	0	360	8	4	27	13
233	0	2	234	2	12	19	7
234	0	0	504	16	12	35	15
235	0	0	288	4	6	23	10
236	0	0	360	6	18	28	10
237	2	0	320	4	12	25	10
238	0	0	432	8	8	33	15
239	0	0	240	2	15	20	3
240	0	0	576	24	8	37	17
241	2	2	242	2	12	19	7
242	0	0	396	24	10	22	9
243	0	0	324	18	9	19	7
244	0	0	372	6	12	29	12
245	0	0	336	16	12	21	8
246	0	0	504	8	12	39	17
247	4	0	280	4	6	21	8
248	0	0	384	8	16	29	11
249	0	0	336	4	12	27	11
250	0	2	450	20	10	28	12
251	0	0	252	2	21	21	4
252	0	0	576	24	8	37	17
253	0	0	288	4	4	23	11
254	0	0	384	4	16	31	12
255	0	0	432	8	12	33	11
256	0	0	384	24	8	21	9
257	0	2	258	2	16	21	7
258	0	0	528	8	8	41	19
259	4	0	304	4	12	23	8
260	0	0	504	12	16	37	15
261	0	0	360	8	12	27	11
262	0	0	396	4	6	32	15
263	0	0	264	2	13	22	5
264	0	0	576	16	16	41	17
265	0	4	324	4	8	25	11
266	0	0	480	8	20	37	14
267	0	0	360	4	6	29	13
268	0	0	408	6	6	32	15
269	0	2	270	2	22	22	6
270	0	0	648	24	12	43	19
271	2	0	272	2	11	22	6
272	0	0	432	12	16	31	12
273	4	0	448	8	8	33	15
274	0	2	414	4	12	33	14
275	0	0	360	12	12	25	9
276	0	0	576	12	16	43	18
277	2	2	278	2	6	22	10
278	0	0	420	4	14	34	14
279	0	0	384	8	12	29	9
280	0	0	576	16	8	41	19
281	0	2	282	2	20	23	7
282	0	0	576	8	8	45	21
283	2	0	284	2	9	23	9
284	0	0	432	6	14	34	14
285	0	0	480	8	16	37	15
286	0	0	504	8	12	39	17
287	0	0	336	4	14	27	7
288	0	0	576	32	8	33	15
289	0	2	306	18	8	17	7
290	0	4	540	8	20	41	16
291	2	0	392	4	12	31	12
292	0	0	444	6	8	35	16
293	0	2	294	2	18	24	8
294	0	0	672	32	12	41	18
295	0	0	360	4	8	29	11
296	0	0	456	8	20	35	13
297	0	0	432	12	12	31	13
298	0	2	450	4	6	36	17
299	0	0	336	4	24	27	6
300	0	0	720	36	12	43	19

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
301	4	0	352	4	8	27	12
302	0	0	456	4	12	37	16
303	0	0	408	4	10	33	12
304	0	0	480	12	12	35	15
305	0	4	372	4	16	29	11
306	0	0	648	16	16	47	20
307	2	0	308	2	9	25	10
308	0	0	576	12	16	43	18
309	2	0	416	4	12	33	14
310	0	0	576	8	8	45	21
311	0	0	312	2	19	26	4
312	0	0	672	16	8	49	23
313	2	2	314	2	8	25	11
314	0	2	474	4	26	38	13
315	0	0	576	16	12	41	17
316	0	0	480	6	10	38	17
317	0	2	318	2	10	26	11
318	0	0	648	8	12	51	23
319	0	0	360	4	10	29	10
320	0	0	576	24	16	37	15
321	0	0	432	4	20	35	13
322	0	0	576	8	8	45	21
323	0	0	360	4	12	29	11
324	0	0	648	36	12	37	16
325	0	4	420	12	12	29	12
326	0	0	492	4	22	40	15
327	2	0	440	4	12	35	12
328	0	0	504	8	8	39	18
329	0	0	384	4	24	31	10
330	0	0	864	16	8	65	31
331	2	0	332	2	9	27	11
332	0	0	504	6	18	40	16
333	0	0	456	8	8	35	16
334	0	0	504	4	12	41	18
335	0	0	408	4	18	33	8
336	0	0	768	24	16	53	23
337	2	2	338	2	8	27	12
338	0	2	546	28	14	32	13
339	0	0	456	4	18	37	13
340	0	0	648	12	8	49	23
341	0	0	384	4	28	31	9
342	0	0	720	16	12	53	24
343	2	0	392	14	7	26	10
344	0	0	528	8	20	41	16
345	0	0	576	8	8	45	21
346	0	2	522	4	10	42	19
347	0	0	348	2	15	29	10
348	0	0	720	12	12	55	25
349	2	2	350	2	14	28	11
350	0	0	720	24	16	49	21
351	0	0	504	12	12	37	13
352	0	0	576	16	8	41	19
353	0	2	354	2	16	29	11
354	0	0	720	8	16	57	25
355	0	0	432	4	12	35	14
356	0	0	540	6	24	43	16
357	0	0	576	8	8	45	21
358	0	0	540	4	6	44	21
359	0	0	360	2	19	30	6
360	0	0	864	32	16	57	25
361	2	0	380	20	10	22	9
362	0	2	546	4	18	44	18
363	0	0	528	24	12	33	13
364	0	0	672	12	12	51	23
365	0	4	444	4	20	35	13
366	0	0	744	8	12	59	27
367	2	0	368	2	9	30	11
368	0	0	576	12	12	43	19
369	0	0	504	8	16	39	16
370	0	4	684	8	12	53	24
371	0	0	432	4	24	35	10
372	0	0	768	12	8	59	28
373	2	2	374	2	10	30	13
374	0	0	648	8	28	51	19
375	0	0	600	20	10	41	16
376	0	0	576	8	16	45	19
377	0	4	420	4	16	33	13
378	0	0	864	24	12	61	28
379	2	0	380	2	9	31	13
380	0	0	720	12	16	55	24
381	2	0	512	4	20	41	16
382	0	0	576	4	8	47	22
383	0	0	384	2	17	32	8
384	0	0	768	32	16	49	21
385	0	0	576	8	8	45	21

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
386	0	2	582	4	20	47	19
387	0	0	528	8	12	41	17
388	0	0	588	6	8	47	22
389	0	2	390	2	22	32	11
390	0	0	1008	16	16	77	35
391	0	0	432	4	14	35	11
392	0	0	672	32	16	41	17
393	0	0	528	4	12	43	19
394	0	2	594	4	10	48	22
395	0	0	480	4	24	39	12
396	0	0	864	24	12	61	28
397	2	2	398	2	6	32	15
398	0	0	600	4	20	49	20
399	4	0	640	8	16	49	17
400	0	0	720	36	8	43	20
401	0	2	402	2	20	33	12
402	0	0	816	8	16	65	29
403	4	0	448	4	6	35	16
404	0	0	612	6	28	49	18
405	0	0	648	24	12	43	19
406	0	0	720	8	16	57	25
407	0	0	456	4	16	37	11
408	0	0	864	16	8	65	31
409	2	2	410	2	16	33	13
410	0	4	756	8	16	59	26
411	0	0	552	4	18	45	17
412	0	0	624	6	10	50	23
413	0	0	480	4	20	39	15
414	0	0	864	16	16	65	29
415	0	0	504	4	10	41	16
416	0	0	672	16	24	49	19
417	2	0	560	4	12	45	20
418	0	0	720	8	8	57	27
419	0	0	420	2	27	35	9
420	0	0	1152	24	16	85	39
421	2	2	422	2	10	34	15
422	0	0	636	4	10	52	24
423	0	0	576	8	10	45	18
424	0	0	648	8	12	51	23
425	0	4	540	12	24	39	14
426	0	0	864	8	24	69	29
427	4	0	496	4	6	39	18
428	0	0	648	6	18	52	22
429	0	0	672	8	16	53	23
430	0	0	792	8	12	63	29
431	0	0	432	2	21	36	8
432	0	0	864	36	12	55	25
433	2	2	434	2	12	35	15
434	0	0	768	8	24	61	25
435	0	0	720	8	12	57	25
436	0	0	660	6	12	53	24
437	0	0	480	4	20	39	15
438	0	0	888	8	8	71	34
439	2	0	440	2	15	36	11
440	0	0	864	16	24	65	27
441	0	0	672	32	16	41	17
442	0	4	756	8	8	59	28
443	0	0	444	2	15	37	14
444	0	0	912	12	16	71	32
445	0	4	540	4	8	43	20
446	0	0	672	4	32	55	20
447	0	0	600	4	14	49	18
448	0	0	768	24	8	53	25
449	0	2	450	2	20	37	14
450	0	0	1080	48	12	67	31
451	0	0	504	4	18	41	15
452	0	0	684	6	16	55	24
453	2	0	608	4	12	49	22
454	0	0	684	4	14	56	25
455	0	0	672	8	20	53	17
456	0	0	960	16	16	73	33
457	2	2	458	2	8	37	17
458	0	2	690	4	26	56	22
459	0	0	648	12	18	49	19
460	0	0	864	12	12	67	31
461	0	2	462	2	30	38	12
462	0	0	1152	16	8	89	43
463	2	0	464	2	7	38	16
464	0	0	720	12	24	55	22
465	0	0	768	8	16	61	27
466	0	2	702	4	8	57	27
467	0	0	468	2	21	39	13
468	0	0	1008	24	16	73	33
469	4	0	544	4	16	43	18
470	0	0	864	8	20	69	30

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
471	2	0	632	4	16	51	18
472	0	0	720	8	12	57	26
473	0	0	528	4	12	43	19
474	0	0	960	8	20	77	34
475	0	0	600	12	12	45	19
476	0	0	864	12	20	67	29
477	0	0	648	8	12	51	23
478	0	0	720	4	8	59	28
479	0	0	480	2	25	40	8
480	0	0	1152	32	16	81	37
481	4	4	532	4	16	41	17
482	0	2	726	4	20	59	25
483	0	0	768	8	12	61	27
484	0	0	792	36	12	49	22
485	0	4	588	4	20	47	19
486	0	0	972	36	18	64	28
487	2	0	488	2	7	40	17
488	0	0	744	8	20	59	25
489	2	0	656	4	20	53	22
490	0	0	1008	32	12	69	32
491	0	0	492	2	27	41	12
492	0	0	1008	12	12	79	37
493	0	4	540	4	12	43	19
494	0	0	840	8	28	67	27
495	0	0	864	16	16	65	25
496	0	0	768	12	12	59	27
497	0	0	576	4	24	47	18
498	0	0	1008	8	8	81	39
499	2	0	500	2	9	41	18
500	0	0	900	30	20	61	26
501	0	0	672	4	16	55	24
502	0	0	756	4	14	62	28
503	0	0	504	2	21	42	11
504	0	0	1152	32	16	81	37
505	0	4	612	4	8	49	23
506	0	0	864	8	28	69	28
507	2	0	728	28	12	47	20
508	0	0	768	6	10	62	29
509	0	2	510	2	30	42	14
510	0	0	1296	16	16	101	47
511	4	0	592	4	14	47	17
512	0	0	768	32	16	49	21
513	0	0	720	12	12	55	25
514	0	2	774	4	16	63	28
515	0	0	624	4	18	51	20
516	0	0	1056	12	24	83	36
517	0	0	576	4	12	47	21
518	0	0	912	8	16	73	33
519	0	0	696	4	18	57	20
520	0	0	1008	16	8	77	37
521	0	2	522	2	32	43	14
522	0	0	1080	16	8	83	40
523	2	0	524	2	15	43	17
524	0	0	792	6	30	64	25
525	0	0	960	24	16	69	31
526	0	0	792	4	12	65	30
527	0	0	576	4	18	47	15
528	0	0	1152	24	16	85	39
529	0	0	552	24	12	35	15
530	0	4	972	8	28	77	32
531	0	0	720	8	18	57	23
532	0	0	960	12	8	75	36
533	0	4	588	4	12	47	21
534	0	0	1080	8	20	87	39
535	0	0	648	4	14	53	20
536	0	0	816	8	28	65	26
537	0	0	720	4	12	59	27
538	0	2	810	4	10	66	31
539	0	0	672	16	24	49	17
540	0	0	1296	36	12	91	43
541	2	2	542	2	10	44	20
542	0	0	816	4	24	67	28
543	2	0	723	4	12	59	24
544	0	0	864	16	16	65	29
545	0	4	660	4	32	53	19
546	0	0	1344	16	24	105	47
547	2	0	548	2	9	45	20
548	0	0	828	6	16	67	30
549	0	0	744	8	24	59	24
550	0	0	1080	24	12	79	37
551	0	0	600	4	26	49	12
552	0	0	1152	16	16	89	41
553	4	0	640	4	8	51	24
554	0	2	834	4	22	68	29
555	0	0	912	8	12	73	33

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n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
556	0	0	840	6	18	68	30
557	0	2	558	2	18	46	19
558	0	0	1152	16	16	89	41
559	4	0	616	4	16	49	17
560	0	0	1152	24	24	85	37
561	0	0	864	8	16	69	31
562	0	2	846	4	8	69	33
563	0	0	564	2	27	47	15
564	0	0	1152	12	16	91	42
565	0	4	684	4	12	55	25
566	0	0	852	4	30	70	28
567	0	0	864	24	12	61	25
568	0	0	864	8	8	69	33
569	0	2	570	2	32	47	16
570	0	0	1440	16	16	113	53
571	2	0	572	2	15	47	19
572	0	0	1008	12	20	79	35
573	0	0	768	4	16	63	28
574	0	0	1008	8	16	81	37
575	0	0	720	12	18	55	19
576	0	0	1152	48	16	73	33
577	2	2	578	2	8	47	22
578	0	2	918	36	16	59	26
579	2	0	776	4	24	63	24
580	0	0	1080	12	16	85	39
581	0	0	672	4	28	55	21
582	0	0	1176	8	16	95	44
583	0	0	648	4	8	53	23
584	0	0	888	8	32	71	28
585	0	0	1008	16	16	77	35
586	0	2	882	4	18	72	32
587	0	0	588	2	21	49	18
588	0	0	1344	48	12	89	42
589	4	0	640	4	16	51	22
590	0	0	1080	8	20	87	39
591	0	0	792	4	22	65	22
592	0	0	912	12	8	71	34
593	0	2	594	2	24	49	19
594	0	0	1296	24	24	97	43
595	0	0	864	8	12	69	31
596	0	0	900	6	28	73	30
597	2	0	800	4	12	65	30
598	0	0	1008	8	8	81	39
599	0	0	600	2	25	50	13
600	0	0	1440	48	16	97	45
601	2	2	602	2	20	49	20
602	0	0	1056	8	24	85	37
603	0	0	816	8	12	65	29
604	0	0	912	6	14	74	34
605	0	0	792	24	24	55	22
606	0	0	1224	8	12	99	47
607	2	0	608	2	13	50	19
608	0	0	960	16	24	73	31
609	0	0	960	8	16	77	35
610	0	4	1116	8	12	89	42
611	0	0	672	4	30	55	18
612	0	0	1296	24	16	97	45
613	2	2	614	2	10	50	23
614	0	0	924	4	34	76	30
615	0	0	1008	8	20	81	31
616	0	0	1152	16	16	89	41
617	0	2	618	2	12	51	23
618	0	0	1248	8	12	101	48
619	2	0	620	2	15	51	21
620	0	0	1152	12	24	91	40
621	0	0	864	12	24	67	28
622	0	0	936	4	12	77	36
623	0	0	720	4	22	59	19
624	0	0	1344	24	16	101	47
625	0	2	750	30	10	48	22
626	0	2	942	4	36	77	30
627	0	0	960	8	12	77	35
628	0	0	948	6	12	77	36
629	0	4	684	4	36	55	19
630	0	0	1728	32	16	129	61
631	2	0	632	2	13	52	20
632	0	0	960	8	16	77	35
633	2	0	848	4	20	69	30
634	0	2	954	4	14	78	36
635	0	0	768	4	30	63	22
636	0	0	1296	12	20	103	47
637	4	0	784	16	12	57	26
638	0	0	1080	8	20	87	39
639	0	0	864	8	14	69	28
640	0	0	1152	32	16	81	37

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
641	0	2	642	2	28	53	20
642	0	0	1296	8	16	105	49
643	2	0	644	2	9	53	24
644	0	0	1152	12	32	91	38
645	0	0	1056	8	16	85	39
646	0	0	1080	8	16	87	40
647	0	0	648	2	23	54	16
648	0	0	1296	48	12	85	40
649	0	0	720	4	20	59	25
650	0	4	1260	24	24	93	41
651	4	0	1024	8	24	81	33
652	0	0	984	6	6	80	39
653	0	2	654	2	14	54	24
654	0	0	1320	8	28	107	47
655	0	0	792	4	12	65	27
656	0	0	1008	12	32	79	32
657	0	0	888	8	16	71	32
658	0	0	1152	8	8	93	45
659	0	0	660	2	33	55	17
660	0	0	1728	24	16	133	63
661	2	2	662	2	18	54	23
662	0	0	996	4	22	82	36
663	0	0	1008	8	16	81	33
664	0	0	1008	8	20	81	36
665	0	0	960	8	24	77	33
666	0	0	1368	16	20	107	49
667	0	0	720	4	12	59	26
668	0	0	1008	6	22	82	36
669	2	0	896	4	12	73	34
670	0	0	1224	8	12	99	47
671	0	0	744	4	30	61	16
672	0	0	1536	32	16	113	53
673	2	2	674	2	12	55	25
674	0	2	1014	4	24	83	36
675	0	0	1080	36	18	73	31
676	0	0	1092	42	12	71	33
677	0	2	678	2	30	56	21
678	0	0	1368	8	20	111	51
679	4	0	784	4	18	63	23
680	0	0	1296	16	24	101	45
681	0	0	912	4	20	75	33
682	0	0	1152	8	12	93	44
683	0	0	684	2	15	57	24
684	0	0	1440	24	24	109	49
685	0	4	828	4	12	67	31
686	0	0	1176	28	28	85	36
687	2	0	920	4	12	75	32
688	0	0	1056	12	12	83	39
689	0	4	756	4	40	61	21
690	0	0	1728	16	16	137	65
691	2	0	692	2	15	57	24
692	0	0	1044	6	28	85	36
693	0	0	1152	16	16	89	41
694	0	0	1044	4	10	86	41
695	0	0	840	4	24	69	23
696	0	0	1440	16	24	113	51
697	0	4	756	4	8	61	29
698	0	2	1050	4	26	86	37
699	0	0	936	4	30	77	29
700	0	0	1440	36	12	103	49
701	0	2	702	2	34	58	21
702	0	0	1512	24	12	115	55
703	4	0	760	4	14	61	24
704	0	0	1152	24	24	85	37
705	0	0	1152	8	24	93	41
706	0	2	1062	4	24	87	38
707	0	0	816	4	18	67	28
708	0	0	1440	12	8	115	56
709	2	2	710	2	10	58	27
710	0	0	1296	8	32	105	45
711	0	0	960	8	20	77	29
712	0	0	1080	8	16	87	40
713	0	0	768	4	24	63	26
714	0	0	1728	16	24	137	63
715	0	0	1008	8	12	81	37
716	0	0	1080	6	30	88	37
717	0	0	960	4	16	79	36
718	0	0	1080	4	12	89	42
719	0	0	720	2	31	60	15
720	0	0	1728	48	16	121	57
721	4	0	832	4	16	67	30
722	0	0	1140	40	18	76	34
723	2	0	968	4	12	79	36
724	0	0	1092	6	20	89	40
725	0	4	900	12	24	69	29

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
726	0	0	1584	48	20	109	50
727	2	0	728	2	13	60	24
728	0	0	1344	16	24	105	47
729	0	0	972	36	18	64	28
730	0	4	1332	8	12	107	51
731	0	0	792	4	36	65	21
732	0	0	1488	12	16	119	56
733	2	2	734	2	14	60	27
734	0	0	1104	4	40	91	36
735	0	0	1344	32	16	97	41
736	0	0	1152	16	16	89	41
737	0	0	816	4	20	67	29
738	0	0	1512	16	16	119	56
739	2	0	740	2	15	61	26
740	0	0	1368	12	32	109	47
741	4	0	1120	8	24	89	39
742	0	0	1296	8	8	105	51
743	0	0	744	2	21	62	21
744	0	0	1536	16	24	121	55
745	0	4	900	4	16	73	33
746	0	2	1122	4	26	92	40
747	0	0	1008	8	18	81	35
748	0	0	1296	12	12	103	49
749	0	0	864	4	32	71	28
750	0	0	1800	40	20	131	61
751	2	0	752	2	15	62	24
752	0	0	1152	12	20	91	41
753	0	0	1008	4	12	83	39
754	0	4	1260	8	20	101	46
755	0	0	912	4	36	75	26
756	0	0	1728	36	24	127	58
757	2	2	758	2	10	62	29
758	0	0	1140	4	22	94	42
759	0	0	1152	8	24	93	35
760	0	0	1440	16	8	113	55
761	0	2	762	2	40	63	22
762	0	0	1536	8	12	125	60
763	4	0	880	4	12	71	32
764	0	0	1152	6	26	94	41
765	0	0	1296	16	16	101	47
766	0	0	1152	4	24	95	42
767	0	0	840	4	22	69	24
768	0	0	1536	48	16	105	49
769	2	2	770	2	20	63	27
770	0	0	1728	16	32	137	61
771	0	0	1032	4	18	85	37
772	0	0	1164	6	8	95	46
773	0	2	774	2	26	64	26
774	0	0	1584	16	20	125	58
775	0	0	960	12	12	75	32
776	0	0	1176	8	40	95	38
777	4	0	1216	8	16	97	45
778	0	2	1170	4	14	96	45
779	0	0	840	4	30	69	25
780	0	0	2016	24	24	157	73
781	0	0	864	4	20	71	31
782	0	0	1296	8	24	105	47
783	0	0	1080	12	18	85	34
784	0	0	1344	48	16	89	41
785	0	4	948	4	16	77	35
786	0	0	1584	8	16	129	61
787	2	0	788	2	15	65	28
788	0	0	1188	6	20	97	44
789	0	0	1056	4	32	87	36
790	0	0	1440	8	16	117	55
791	0	0	912	4	32	75	22
792	0	0	1728	32	16	129	61
793	4	4	868	4	8	69	33
794	0	2	1194	4	42	98	39
795	0	0	1296	8	12	105	49
796	0	0	1200	6	18	98	45
797	0	2	798	2	30	66	26
798	0	0	1920	16	16	153	73
799	0	0	864	4	16	71	28
800	0	0	1440	48	24	97	43
801	0	0	1080	8	24	87	38
802	0	2	1206	4	12	99	47
803	0	0	888	4	30	73	27
804	0	0	1632	12	24	131	60
805	0	0	1152	8	16	93	43
806	0	0	1344	8	28	109	48
807	0	0	1080	4	14	89	38
808	0	0	1224	8	12	99	47
809	0	2	810	2	32	67	26
810	0	0	1944	48	24	139	64

n	$\nu_1(n)$	$\nu_2(n)$	$\mu(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
811	2	0	812	2	21	67	27
812	0	0	1440	12	24	115	52
813	2	0	1088	4	12	89	42
814	0	0	1368	8	12	111	53
815	0	0	984	4	30	81	26
816	0	0	1728	24	24	133	61
817	4	0	880	4	12	71	33
818	0	2	1230	4	28	101	44
819	0	0	1344	16	24	105	45
820	0	0	1512	12	16	121	57
821	0	2	822	2	30	68	27
822	0	0	1656	8	20	135	63
823	2	0	824	2	9	68	30
824	0	0	1248	8	40	101	41
825	0	0	1440	24	24	109	49
826	0	0	1440	8	12	117	56
827	0	0	828	2	21	69	28
828	0	0	1728	24	12	133	64
829	2	2	830	2	22	68	29
830	0	0	1512	8	20	123	57
831	2	0	1112	4	28	91	32
832	0	0	1344	24	16	101	47
833	0	0	1008	16	24	77	33
834	0	0	1680	8	16	137	65
835	0	0	1008	4	18	83	36
836	0	0	1440	12	40	115	48
837	0	0	1152	12	12	91	43
838	0	0	1260	4	14	104	49
839	0	0	840	2	33	70	19
840	0	0	2304	32	16	177	85
841	0	2	870	30	14	58	26
842	0	2	1266	4	26	104	46
843	0	0	1128	4	18	93	41
844	0	0	1272	6	18	104	48
845	0	4	1092	28	28	77	32
846	0	0	1728	16	32	137	61
847	0	0	1056	24	10	77	34
848	0	0	1296	12	24	103	46
849	2	0	1136	4	28	93	40
850	0	4	1620	24	16	123	58
851	0	0	912	4	30	75	28
852	0	0	1728	12	16	139	66
853	2	2	854	2	10	70	33
854	0	0	1488	8	44	121	50
855	0	0	1440	16	16	113	49
856	0	0	1296	8	12	105	50
857	0	2	858	2	32	71	28
858	0	0	2016	16	16	161	77
859	2	0	860	2	21	71	29
860	0	0	1584	12	28	127	57
861	0	0	1344	8	24	109	49
862	0	0	1296	4	8	107	52
863	0	0	864	2	21	72	26
864	0	0	1728	48	24	121	55
865	0	4	1044	4	16	85	39
866	0	2	1302	4	44	107	43
867	0	0	1224	36	18	85	37
868	0	0	1536	12	16	123	58
869	0	0	960	4	32	79	32
870	0	0	2160	16	16	173	83
871	4	0	952	4	22	77	28
872	0	0	1320	8	20	107	49
873	0	0	1176	8	16	95	44
874	0	0	1440	8	20	117	54
875	0	0	1200	20	30	91	36
876	0	0	1776	12	24	143	66
877	2	2	878	2	10	72	34
878	0	0	1320	4	20	109	50
879	0	0	1176	4	22	97	38
880	0	0	1728	24	16	133	63
881	0	2	882	2	40	73	27
882	0	0	2016	64	16	137	65
883	2	0	884	2	9	73	34
884	0	0	1512	12	32	121	53
885	0	0	1440	8	24	117	53
886	0	0	1332	4	18	110	51
887	0	0	888	2	29	74	23
888	0	0	1824	16	24	145	67
889	4	0	1024	4	16	83	38
890	0	4	1620	8	24	131	60
891	0	0	1296	24	18	97	43
892	0	0	1344	6	14	110	52
893	0	0	960	4	28	79	33
894	0	0	1800	8	28	147	67
895	0	0	1080	4	16	89	37

n	$\nu_1(n)$	$\nu_2(n)$	$\mu_0(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
896	0	0	1536	32	32	113	49
897	0	0	1344	8	16	109	51
898	0	2	1350	4	12	111	53
899	0	0	960	4	42	79	26
900	0	0	2160	72	16	145	69
901	0	4	972	4	24	79	34
902	0	0	1512	8	28	123	55
903	4	0	1408	8	16	113	49
904	0	0	1368	8	16	111	52
905	0	4	1092	4	24	89	39
906	0	0	1824	8	28	149	68
907	2	0	908	2	9	75	35
908	0	0	1368	6	30	112	49
909	0	0	1224	8	28	99	43
910	0	0	2016	16	16	161	77
911	0	0	912	2	31	76	23
912	0	0	1920	24	16	149	71
913	0	0	1008	4	12	83	39
914	0	2	1374	4	36	113	48
915	0	0	1488	8	24	121	53
916	0	0	1380	6	20	113	52
917	0	0	1056	4	20	87	39
918	0	0	1944	24	12	151	73
919	2	0	920	2	19	76	29
920	0	0	1728	16	40	137	59
921	2	0	1232	4	20	101	46
922	0	2	1386	4	18	114	53
923	0	0	1008	4	30	83	32
924	0	0	2304	24	24	181	85
925	0	4	1140	12	12	89	42
926	0	0	1392	4	40	115	48
927	0	0	1248	8	20	101	41
928	0	0	1440	16	8	113	55
929	0	2	930	2	36	77	30
930	0	0	2304	16	24	185	87
931	4	0	1120	16	18	85	37
932	0	0	1404	6	24	115	52
933	0	0	1248	4	16	103	48
934	0	0	1404	4	26	116	52
935	0	0	1296	8	28	105	39
936	0	0	2016	32	24	153	71
937	2	2	938	2	20	77	34
938	0	0	1632	8	16	133	63
939	2	0	1256	4	24	103	44
940	0	0	1728	12	12	139	67
941	0	2	942	2	46	78	28
942	0	0	1896	8	12	155	75
943	0	0	1008	4	16	83	34
944	0	0	1440	12	36	115	49
945	0	0	1728	24	24	133	61
946	0	0	1584	8	16	129	61
947	0	0	948	2	15	79	35
948	0	0	1920	12	24	155	72
949	4	4	1036	4	12	83	39
950	0	0	1800	24	36	139	61
951	0	0	1272	4	26	105	40
952	0	0	1728	16	16	137	65
953	0	2	954	2	32	79	32
954	0	0	1944	16	24	155	72
955	0	0	1152	4	12	95	44
956	0	0	1440	6	30	118	52
957	0	0	1440	8	16	117	55
958	0	0	1440	4	16	119	56
959	0	0	1104	4	36	91	28
960	0	0	2304	48	16	169	81

n	$\nu_1(n)$	$\nu_2(n)$	$\mu_0(n)$	$\sigma_0(n)$	$h(-4n)$	$g_0(n)$	$g^*(n)$
961	2	0	992	32	16	67	30
962	0	4	1596	8	28	129	58
963	0	0	1296	8	18	105	47
964	0	0	1452	6	24	119	54
965	0	4	1164	4	44	95	37
966	0	0	2304	16	24	185	87
967	2	0	968	2	11	80	35
968	0	0	1584	48	20	109	50
969	0	0	1440	8	24	117	53
970	0	4	1764	8	12	143	69
971	0	0	972	2	45	81	26
972	0	0	1944	54	18	136	64
973	4	0	1120	4	12	91	43
974	0	0	1464	4	36	121	52
975	0	0	1680	24	16	129	57
976	0	0	1488	12	24	119	54
977	0	2	978	2	20	81	36
978	0	0	1968	8	24	161	75
979	0	0	1080	4	24	89	37
980	0	0	2016	48	24	145	67
981	0	0	1320	8	24	107	48
982	0	0	1476	4	10	122	59
983	0	0	984	2	27	82	28
984	0	0	2016	16	24	161	75
985	0	4	1188	4	24	97	43
986	0	4	1620	8	44	131	55
987	0	0	1536	8	24	125	55
988	0	0	1680	12	12	135	65
989	0	0	1056	4	36	87	35
990	0	0	2592	32	24	201	95
991	2	0	992	2	17	82	33
992	0	0	1536	16	32	121	53
993	2	0	1328	4	12	109	52
994	0	0	1728	8	16	141	67
995	0	0	1200	4	24	99	42
996	0	0	2016	12	24	163	76
997	2	2	998	2	14	82	38
998	0	0	1500	4	26	124	56
999	0	0	1368	12	24	109	43
1000	0	0	1800	40	20	131	61

References

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JOURNAL OF RESEARCH of the National Bureau of Standards—B. Mathematics and Mathematical Physics
Vol. 67B, No. 1, January–March 1963

Publications of the National Bureau of Standards*

Selected Abstracts

Tables of Einstein functions, Vibrational contributions to the thermodynamic functions, J. Hilsenrath and G. G. Ziegler, *NBS Mono. 49, (July 12, 1962) $2.75.*
Tables are presented for the contribution of a harmonic oscillator to the free energy function, enthalpy function, entropy, and heat capacity of gases. Dimensionless values of the Planck-Einstein functions are given as a function of $x=hc\nu/kT$ for $x=0.0010(.0001)$ °K directly as a function of frequency ν, and temperature T, was computed using the values 1.43880 for the second radiation constant hc/k, and 1.98717 for the universal gas constant R. The arguments for the latter table are spaced at 10 wave number intervals from 100 cm^{-1} to 400 cm^{-1}.

Systems of electrical units, F. B. Silsbee, *NBS Mono. 56, (Sept. 20, 1962) 30 cents.*
The various systems of measurement, with their respective sets of units, used in the literature on electricity and magnetism are described in detail. Their historical development is summarized. The manner in which each is derived from either of the two alternative points of view of the experimentalist and the theoretician is compared and contrasted. The desirability of recognizing both points of view in international standardization, particularly when discussing rationalization, is pointed out. The present status of the absolute measurements on which all electrical units are based is reported, and tables are included for the conversion of equations and numerical values from one system to another.

Tchebycheff approximations by exponentials, J. R. Rice, *J. Soc. Ind. Appl. Math.* **10,** *No. 1, 149–161 (Mar. 1962).*
Tchebycheff approximations of the form

$$\sum_{i=1}^{k}\sum_{j=0}^{m_i} p_{ij}x^j b_i^x$$

where $\sum_{i=1}^{k}(m_i+1)\leq n$ are studied. With this approximating function it is shown that a best approximation on [0,1] exists for every continuous function. It is shown that this function is a varisolvent function and the uniqueness and characteristic properties of best approximations follow from known results for varisolvent functions. A theorem relating the best approximation on [0,1] is established for varisolvent functions, and hence for this approximating function. The generalization to an approximating function which is an arbitrary linear combination of exponentials with polynomial coefficients is given.

Real representations of coordinate rotations, U. Fano, *J. Math. Phys.* **1,** *No. 5, 417–423 (Sept.–Oct. 1960).*
Since irreducible tensorial sets that represent observables are of integral degree, their transformations under coordinate rotations have real representations. Real representations, with rows and columns classified by eigenvalues of the commuting operators J_z^2 and $\exp(i\tau J_y)$, are given explicitly, so that complex functions of rotation angles need not be used. The addition of angular momenta is worked out for sets in the real representation such as the sets of real orbital wave functions. Applications to the theory of angular distributions are discussed.

The vapor pressure of 20 °K equilibrium hydrogen, L. C. Weber, Jr., D. E. Diller, H. M. Roder, and R. D. Goodwin, *cryogenics* **3,** *236–238 (June 1962).*
The vapor pressure of 20 °K equilibrium hydrogen has been measured between the normal boiling point and the critical point. The data are represented analytically for purposes of smoothing and interpolation and the results are compared with earlier work.

Studies in non-equilibrium rate processes. V. The relaxation of moments derived from a master equation, K. E. Shuler, K. Anderson, and G. H. Weiss, *J. Math. Phys.* **3,** *No. 3, 550–556 (May–June 1962).*
A study has been made of the relaxation of the moments of probability distributions whose time evolution are governed by a master equation. The necessary and sufficient conditions for the first moment to undergo a simple exponential relaxation have been derived. The necessary and sufficient conditions under which the first k moments satisfy a closed system of linear equations also have been developed. This treatment has also been extended to an investigation of the moments of the distribution determined by the Fokker-Planck equation.

Irreversible processes in liquids and the density matrix: monatomic molecules, R. E. Nettleton, *Phys. Fluids* **5,** *No. 6, 687–700 (June 1962).*
A small subvolume of an infinite, isotropic, monatomic liquid is approximated by a model in which no diffusion is permitted across the boundary, and interaction with the surroundings is represented by a random force potential in the Hamiltonian. The density matrix for this model is expanded in a sum of scalar, vector, and tensor parameters, for which rate equations are derived from the quantum Liouville equation. An interpretation of these rate equations as phenomenological equations in the sense of irreversible thermodynamics leads to a set of conditions which can be used to determine the molecular configuration dependence of the density matrix and the stochastic interaction term in the Hamiltonian. The result provides a generalization, based on quantum statistics, of a previous, purely phenomenological, extension of irreversible thermodynamics to include inertial effects.

Graphs for bivariate normal probabilities, M. Zelen and N. C. Severo, *Ann. Math. Stat.* **31,** *No. 3, 619–624 (Sept. 1960).*
A chart is presented which enables one to quickly calculate the bivariate normal probability integral

$$L(h,k;\rho)=\int_h^\infty dx\int_k^\infty g(x,y;\rho)dy$$

$$\text{where } g(x,y;\rho)=[2\Pi\sqrt{1-\rho^2}]^{-1}\exp\ -\frac{1}{2}\left(\frac{x^2-2\rho xy+y^2}{1-\rho^2}\right)$$

The use of this chart will result in at most an error of 10^{-2}. Examples of application are included.

Oscillatory phenomena, A. H. Kahn (*Proc. Conf. High Magnetic Field, Mass. Inst. Tech., Cambridge, Mass., Nov. 1–4, 1961), Book, High Magnetic Fields, pp. 480–488 (Mass. Inst. Tech. Press, Cambridge, Mass., and John Wiley and Sons, Inc., New York, N.Y., 1962).*
A quantum treatment of electrical conductivity in high magnetic fields will be presented. It will be shown how the transport coefficients and the magnetic susceptibility display variations periodic in the reciprocal of the magnetic field strength. The use of this high field behavior in the determination of electronic band structures will be discussed. The scattering of conduction electrons by impurities is greatly modified by the magnetic field. The effect on conductivity will be discussed.

Games associated with a renewal process, M. M. Siddiqui, *Ann. Math. Stat.* **31,** *697–701 (June 1962).*
Robbins (Annals of Mathematical Statistics, Vol. 32 (1961),

pp. 187–194) considered games associated with a recurrent event, when the trials are being performed at discrete times so that the interval between two events is an integer. His results are extended to the situations where the interval between two events is not necessarily an integer, such as the interval between arrivals of two meteors within the atmosphere.

Criteria for the reality of matrix eigenvalues, M. P. Drazin and E. V. Haynesworth, *Z. Math.* **78,** *449–452 (Mar. 1962).*
This note is concerned with generalizations of the known fact that an nxn matrix with n linearly independent eigenvectors all corresponding to real eigenvalues is similar to a hermitian matrix, and can consequently be transformed into its conjugate transpose by a hermitian similarity. For any positive integer m, an analogous necessary and sufficient is established for a given square complex matrix A to have a set of real eigenvalues (not necessarily all distinct) to which there correspond at least m linearly independent eigenvectors; analogous results about eigenvalues of modulus unity and pure imaginary eigenvalues are also obtained.
The above-mentioned results are applied to establish a theorem on the reality of the eigenvalues of a certain type of matrix, and to give a new proof of a theorem of K. Goldberg; but in fact Goldberg's defining conditions for the class of matrices in question are very dissimilar from ours, so the point of interest is rather the (essential) equivalence of two definitions. Another application leads to theorems about the reality of the roots of an arbitrary complex polynomial $h(\lambda)$, which refine and extend previously known theorems along similar lines.

Group theory and crystal field theory, C. M. Herzfeld and P. H. E. Meijer, *Book, Solid State Physics* **12,** *1–91 (Academic Press, Inc., New York, N.Y., 1961).*
A survey of the principal group theoretical principles and methods used in crystal field theory.

Algorithm and rapid binary division, R. S. Ledley and J. B. Wilson, *IRE Trans. Electronic Computers* **EC–10,** *No. 4, 662–670 (Dec. 1961).*
An algorithm for performing rapid division with binary numbers is described. First a partial algorithm is presented that has the advantage of extreme simplicity, and in a majority of the cases significantly reduces the number of operations required for division. Second, the complete algorithm is given that produces the minimum number of operations for division, which will result on the average in a saving of nearly two thirds the normal division time in digital computers.

A procedure for estimating eigenvalues, N. W. Bazley and D. Fox, *J. Math. Phys.* **3,** *469–471 (May–June 1962).*
A new procedure is given for calculation of lower bounds to the eigenvalues of self-adjoint operators. Calculation of the lower bounds is reduced to the solution of linear algebraic problems.

Structural and internal state variables in the description of scalar rate processes in fluids, R. E. Nettleton, *Phys. Fluids* **4,** *1488 (1961).*
Arguments are presented to show that the internal energy per molecule in a macroscopically small volume element of an infinite liquid should remain constant, in first approximation, during a sudden fluctuation in liquid structure at constant density and temperature. This result is shown to be consistent with a formulation of non-equilibrium thermodynamics in which the departures of structural parameters from their local equilibrium values appear as thermodynamic variables and in which there is no relaxing structural specific heat. However, it is shown that such a relaxing specific heat must appear in the thermodynamic treatment of thermal variables, which give the populations of internal vibrational-rotational states; and a new non-equilibrium thermodynamics of thermal relaxation, extending the earlier work of Meixner to include inertial effects, is formulated in such a way as to be consistent with this fact. The new formulation, which replaces a previous theory now shown to be valid only for structural variables, is based on the Pauli equation, generalized to include second-order time-derivatives. It is shown, on plausible assumptions about the molecular transition probabilities, that one can calculate all the rate constants and relaxation times introduced to describe inertial effects, as well as the thermodynamic forces.

Quantum-mechanical calculation of harmonic oscillator transition probabilities in a one-dimensional impulsive collision, K. E. Shuler and R. W. Zwanzig, *J. Chem. Phys.* **33,** *No. 6, 1778–1784 (Dec. 1960).*
The quantum mechanical vibrational transition probabilities $P_{i\to f}(\epsilon)$ for harmonic oscillators, undergoing impulsive hard sphere collisions along the line of centers with an incident beam of atoms with relative kinetic energy ϵ, have been computed by a machine (IBM–704) solution of the relevant Schrödinger equation. Curves for $P_{i\to f}(\epsilon)$ over a range of ϵ are presented for initial (i) and final (f) vibrational oscillator states i, $f=0$, 1, 2, and 3. It is shown that this model of an inelastic collision gives rise to appreciable vibrational transitions $\nu(i)\to\nu(f)$ with $|\Delta\nu|>1$ (in addition to the $|\Delta\nu|=1$ transitions) in contrast to the Landau-Teller-Herzfeld adiabatic, 1st order perturbation treatment which permits only transitions for which $|\Delta\nu|=1$. The implication of this result is discussed in relation to the dissociation of diatomic molecules and to the adsorption of atoms on solids. Averaged transition probabilities $\overline{P}_{i\to f}(T)$ are computed for an incident beam of particles with a Maxwellian velocity distribution. It is pointed out that such averaged transition probabilities may give a misleading impression of the efficiency of translational-vibrational energy transfer if the $P_{i\to f}(\epsilon)$ show a resonance type of behavior, i.e., a strong order of magnitude dependence of $P_{i\to f}(\epsilon)$ on ϵ over a small interval of ϵ.

Other NBS Publications

J. Research NBS 66A (Phys. and Chem.), No. 6 (Nov.–Dec. 1962), 70 cents.
Heat of formation of nitronium perchlorate. A. A. Gilliland.
Phase equilibrium relations in the binary system bismuth sesquioxide-niobium pentoxide. R. S. Roth and J. L. Waring.
Elastic constants of rutile (TiO_2). J. B. Wachtman, Jr., W. E. Tefft, and D. G. Lam, Jr.
Reaction of hardened portland cement paste with carbon dioxide. C. M. Hunt and L. A. Tomes.
Titanium standards for hydrogen content. J. T. Sterling, F. J. Palumbo, and L. L. Wyman.
Ultraviolet stability of crosslinked polycaprolactam systems. S. D. Bruck.
Spectral-line intensities and gf-values in the first spectrum of copper. C. H. Corliss.
Batch adsorption from solution. W. V. Loebenstein.
Separation of hafnium from zirconium and their determination: Separation by anion-exchange. L. A. Machlan and J. L. Hague.

J. Research NBS 67A (Phys. and Chem.), No. 1 (Jan.–Feb. 1963), 70 cents.
Heat of formation of calcium aluminate monosulfate at 25 °C. H. A. Berman and E. S. Newman.
2,3-Dimethylpentane and 2-methylhexane as a test mixture for evaluating highly efficient fractionating columns. E. C. Kuehner.
Phase equilibrium relations in the Sc_2O_3-Ga_2O_3 system. S. J. Schneider and J. L. Waring.
Analysis of two infrared bands of CH_2D_2. W. B. Olson, H. C. Allen, Jr., and E. K. Plyler.
Precise coulometric titrations of halides. G. Marinenko and J. K. Taylor.
Radial distribution study of vitreous barium borosilicate. G. J. Piermarini and S. Block.
Dynamic compressibility of poly(vinyl acetate) and its relation to free volume. J. E. McKinney and H. V. Belcher.
An investigation of the constitution of the mercury-tin system. D. F. Taylor and C. L. Burns.
Effect of methyl bromide additions on the flame speed of methane. C. Halpern.

J. Research NBS 67C (Eng. and Instr.), No. 1 (Jan.–Mar. 1963), 75 cents.

Method for calibrating a standard volt box. B. L. Dunfee.

Stability of residual thiosulfate in processed microfilm. C. I. Pope.

Equipment for single crystal growth from aqueous solution. J. L. Torgesen, A. T. Horton, and C. P. Saylor.

An automatic multichannel correlator. R. F. Brown, Jr.

Elastic constant—porosity relations for polycrystalline thoria. S. Spinner, F. P. Knudsen, and L. Stone.

An oxygen partial pressure warning instrument. L. Greenspan.

New fast-opening, large-aperture shutter for high-speed photography. E. C. Cassidy and D. H. Tsai.

Equations for the radiofrequency magnetic permeameter. C. A. Hoer and A. L. Rasmussen.

J. Research NBS 67D (Radio Prop.), No. 1 (Jan.–Feb. 1963), 70 cents.

A lunar theory reasserted—a rebuttal. J. V. Evans.

Point-to-point communication on the moon. L. E. Vogler.

HF communication during ionospheric storms. G. E. Hill.

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