ECE 6450 Introduction to Microelectronics Technology

Exam 1

September 13, 2008

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Print your name clearly: Solutions

Note: Solutions are on the "Draft" test. Your "final" exam already has corrections made

Instructions: Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 sheet of notes (1 page front and back) as well as a calculator. There are 100 total points. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I can not read it, it will be considered to be a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I did not observe any ethical violations during this exam:

I observed an ethical violation during this exam:

Problem 1. (25 points total in 5 5 point parts):
True/False and Multiple Choice and short answer/calculation:

a.) Based on the period table (see attached table) which of the following are true (one or more answers possible)?

B P
Ga As
In P

1.) BAs will have a larger bandgap than GaAs
2.) InSb will have a smaller bandgap than InP
3.) $Al_{0.2}Ga_{0.8}Sb$ is not a real semiconductor since its indexes add up to 2.
4.) All of the above
5.) None of the above
6.) I wish I had gone to Clemson instead of Ga Tech.

b.) Which of the following defects can enhance diffusion of a dopant (may have more than one answer....or not)?

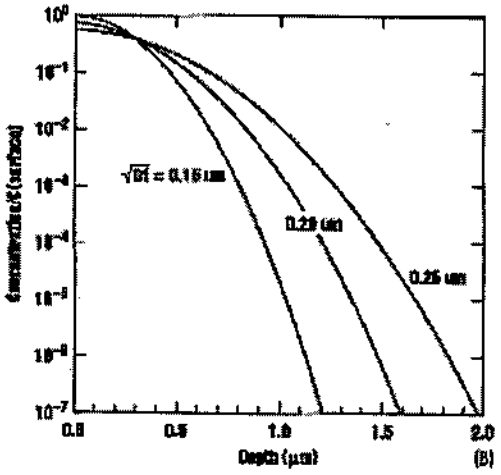
1.) Vacancies
2.) Interstitials
3.) Dislocations
4.) Stacking faults
5.) Precipitates
6.) Grain Boundaries

all

c.) Given the diffusion profiles obtained below for the same temperature in ~~both~~ cases, which of the following are true (may have more than one answers...or not)?

1.) This is a pre-deposition diffusion.
2.) This is a drive in diffusion.
3.) The diffusion coefficient is constant.
4.) For the 0.15 um characteristic diffusion length case, it was performed ~~at a lower temperature~~ than the 0.25 um case.
5.) The diffusion coefficient is lower at high concentrations.

for a shorter time



d.) The present (<65 nm node) Intel process completely replaces SiO_2 with HfO_2.
True or False (circle the correct answer)

Uses SiO_2, $Si_x Hf_{1-x} O_2$

5pts

1 continued – part e.) The equivalent oxide thickness (EOT) is the thickness of a SiO_2 needed to result in the same capacitance as SiO_2. Using thicker "high k" (higher dielectric constant than SiO_2) dielectrics can result in decreased leakage current compared to thinner SiO_2. Leakage current (in the tunnel current limited case) is proportional to:

$e^{\{(-\text{thickness})(\text{thickness})\}}$ (in words this is current is proportional to the exponential of the thickness squared). → add a^2 term where $a = 1nm$

It is desired to change a 1 nm thick SiO_2 dielectric process into a process based on a $Hf_xSi_{1-x}O_2$ dielectric that has a relative dielectric constant (k_r or ε_r) of 7.0 instead of SiO_2's value of 3.9. What reduction in leakage current (ratio of currents only NOT exact values of current) is expected?

$$C = \frac{\epsilon_{r_{ox}} \epsilon_0 A}{t_{ox}} = \frac{\epsilon_{r_{HF}} \epsilon_0 A}{t_{HF}}$$

$$\Rightarrow \frac{3.9}{1nm} = \frac{7}{t_{HF}}$$

$$t_{HF} = 1.79nm$$

$$\frac{I_{SiO_2} \propto e^{-(1/1)^2}}{I_{HF} \propto e^{-(1.79/1)^2}} = e^{\left(-1 + 1.79^2\right)}$$

$$= e^{2.22}$$

$$= 9.22$$

Current reduces by a factor of 9.22

(or 0.108)

Give more detail

Problem 2. (15 points total):

GaAs devices often use a Gold-Germanium alloy for ohmic contacts. This "alloyed contact step" must be performed at low temperature to prevent As out diffusion and other problems. A. (5 points) What is the melting points of gold (Au) and Germanium (Ge)? B. (10 points) explain how and at what lowest possible temperature the solid connection is made. ***For full credit, keep your description to 3 sentences or less and feel free to draw on the phase diagram to furthure explain your answer.***

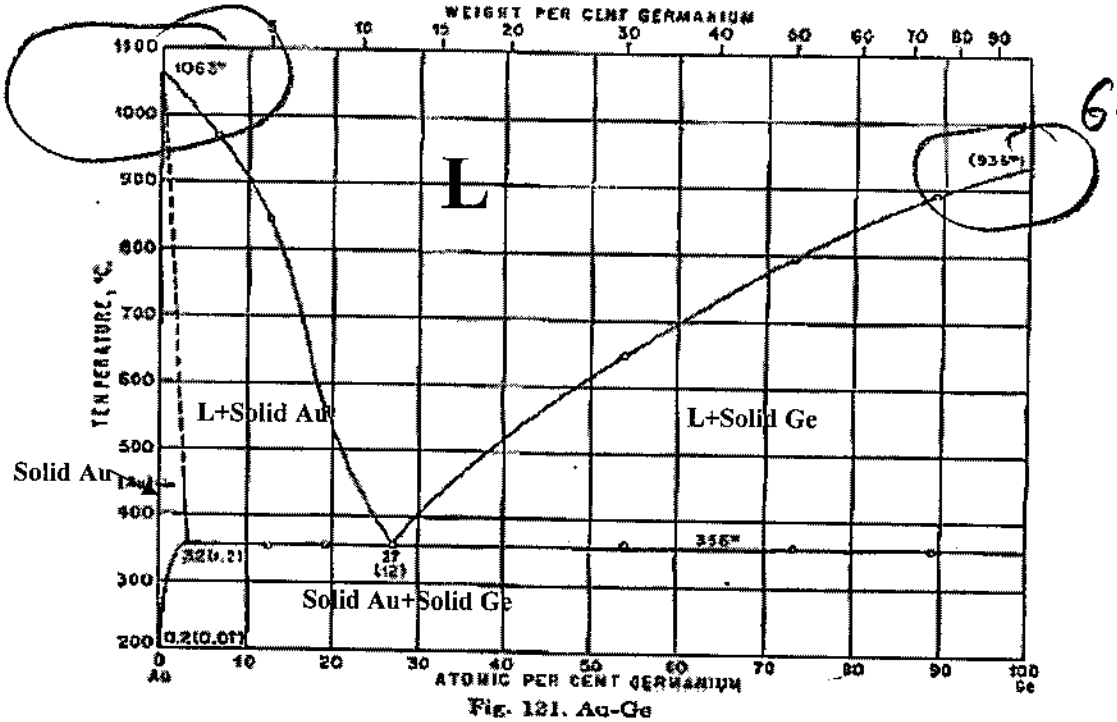


Fig. 121. Au-Ge

Hansen & Anderko, Constitution of Binary Alloys, 1958. p. 206

A) $Ge_{melts} = 936°C$, $Au_{melts} = 1063°C$

Eutectic = 356°C + has 27% Ge

B) Use weight % equivalent to 27 atomic percent Ge + Heat to greater than 356°C. Cool and @ 356°C the mix will solidify into a solid contact.

Problem 3. (30 points total):

Arsenic (As) is first deposited in a p-type silicon wafer uniformly boron doped at $1x10^{15}$ cm^{-3} (bulk concentration) wafer using Arsine (AsH_3) at 1000 degrees C where the solubility of As in Silicon is $1x10^{21}$ cm^{-3}. Assuming a neutral vacancy controlled diffusion with D_o=0.066 cm^2/sec and E_a=3.44 eV, (a-10 points) what is the time required to achieve a dose of $1x10^{16}$ atoms/cm^2? (b-10 points) If the wafer is then capped and the arsenic is then driven into the wafer at 1100 degrees C, how much time is required to achieve a junction depth of 0.1 um?

C_s = Silicon is $1x10^{21}$ cm^{-3}

change to $1x10^{14}$

Note: erfc(x)=1-erf(x), erf(0)=0, erf(∞)=1

add Profile + justification

a)

$$D = D_i = 0.066\, e^{-3.44/k(1273)}$$

$$= 1.59e-15\ cm^2/sec\ @\ 1000^\circ C \quad (1)$$

$$= 0.066\, e^{-3.44/k(1373)}$$

$$= 1.56e-14\ cm^2/sec\ @\ 1100^\circ C \quad (2)$$

$C_s = 1x10^{21}$

$$Q_T = 1x10^{14}\ atoms/cm^2 = \frac{2}{\sqrt{\pi}}(1x10^{21})\sqrt{1.59e-15\ t}$$

t = 4.93 sec

b) Drive-in:

$$X_j = (0.1x10^{-4}\ cm) = \sqrt{4Dt\ln\left(\frac{Q_T}{C_B\sqrt{\pi}\sqrt{Dt}}\right)}$$

$$1e-5 = \sqrt{6.577e-14\,(t)\ln(7.23x10^{-9}\sqrt{t})}$$

t	Right side
1	9e-7
10	2.7e-6
100	8e-6
1000	2.4e-5
500	1.7e-5
250	1.2e-5
175	1.06e-5
150	9.9e-6
153 sec	1e-5

Problem 4. (30 points total):

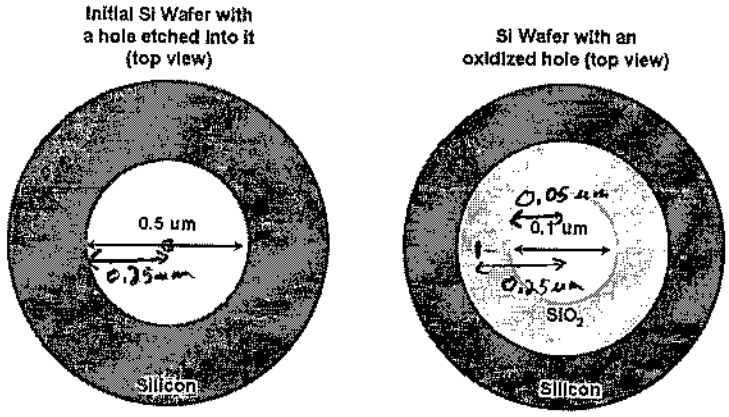
Problem Statement:
A silicon wafer has a cylindrical hole etched into it that is 0.5 um diameter. Your university's / company's cheap equipment cannot make holes smaller than this size. Because you took Dr. Doolittle's class, you remember that oxides can "add volume" to a wafer thus you can "close up the diameter of the hole" making the oxidized hole diameter smaller than the original hole.

(a. 10 points) What time is required to make a hole of 0.1 um diameter using a "low quality" oxide grown at 1200 degrees C?

wet

(b. 10 points) If the hole is further shrank by a 1200 degree C "high quality" oxide to a diameter of 0.05 um, how much time is required?

dry



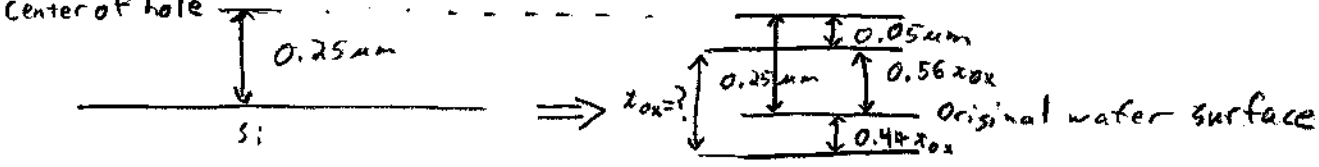
(c. 10 points) Is the new semiconductor/oxide interface (just the interface not the oxide bulk) "high quality" or "low quality" based on electrical characteristics? Justify your answer in 3 sentences or less.

Assumptions:
Assume lateral oxidation occurs at the same rate as the planar oxidations we discussed in class (I.E. consider only the 1 dimensional case), the wet oxide parameters are valid for all regions, regardless of initial conditions, and the porosity and density of wet and dry oxides are the same. To answer this question you must know which oxide, wet or dry is of higher quality.

At 1200 degrees C:
A=0.04 μm, B=0.045 μm^2/hr and τ=0.027 hr for dry oxides
A=0.05 μm, B=0.72 μm^2/hr and τ=0.0 hr for wet oxides.

Dry = High quality
wet = Low quality

a)



$$\Rightarrow 0.56\, x_{ox} = 0.25\,\mu m - 0.05\,\mu m$$

$$x_{ox} = 0.357\ \mu m$$

wet ⇒ lo

$$x_{ox}^2 + 0.05(x_{ox}) = 0.72(t + 0.0)$$

$$t = 0.202\ hrs$$

You may show your work here

b) Dry

Already existing oxide:

$$\tau_{dry} = \frac{x_{ox}^2 + A x_{ox}}{B} = \frac{(0.357)^2 + 0.04(0.357)}{0.045}$$ (Dry)

$$\tau_{dry} = 3.15 \text{ hrs}$$

Note: Some may prefer to add 3.15 + 0.027 (2 for ϕ initial thickness). I accepted either answer.

$$0.56\, x_{ox} = 0.25\,\mu m - 0.025\,\mu m$$

$$x_{ox} = 0.401\,\mu m$$

$$(0.401)^2 + 0.04(0.401) = 0.045(t + 3.15)$$

$$t = 0.79 \text{ hrs}$$

or

$$t = 0.77 \text{ hrs}$$

c) The new interface is "high quality" since additional Si was consumed in the 2nd step. Note: The bulk of the oxide would still be "low quality" but may have been densified during the dry oxidation.

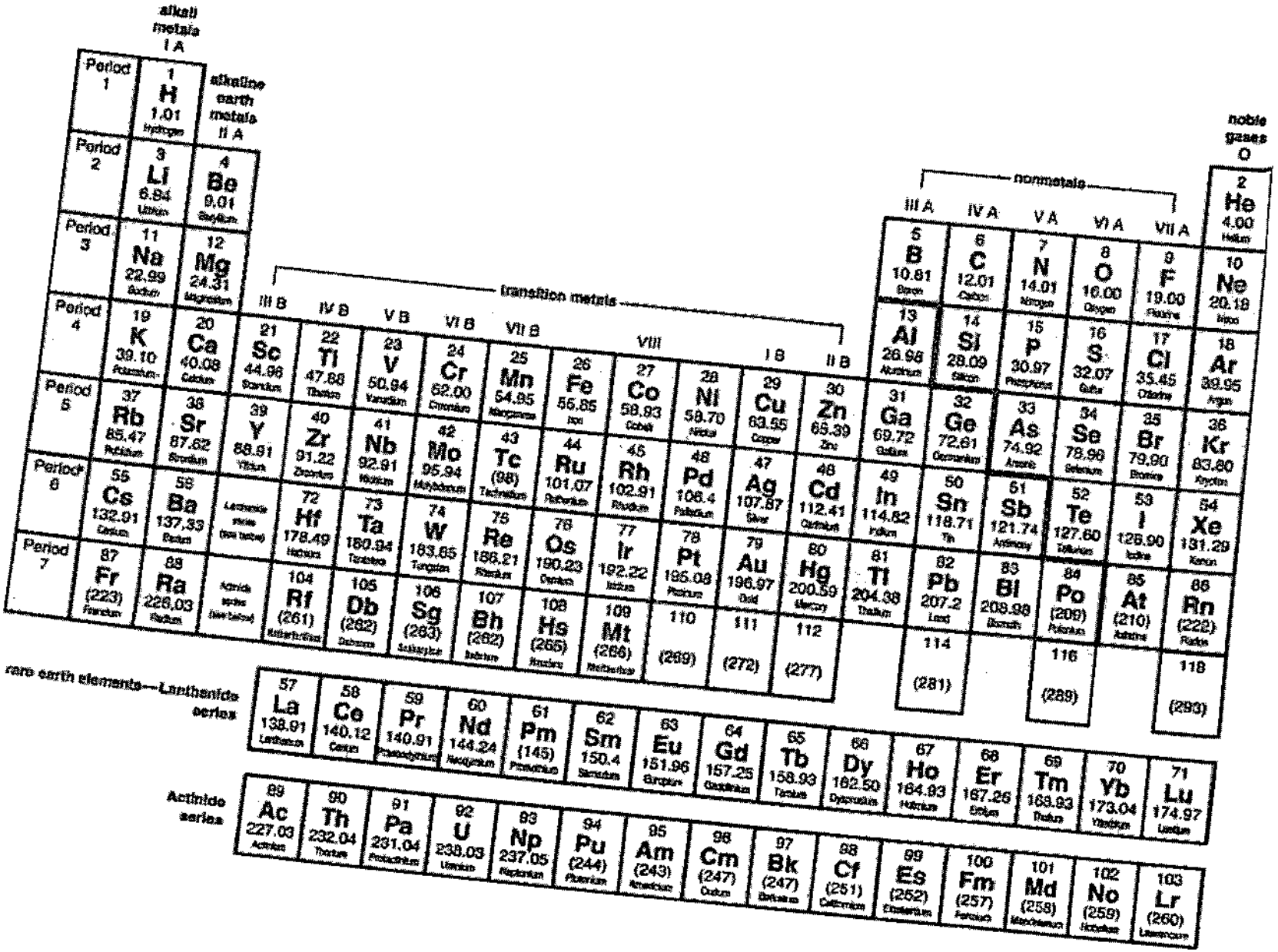
Table A.1 Error Function erf z^a

z	erf(z)	z	erf(z)	z	erf(z)	z	erf(z)
0.00	0.000 000	0.50	0.520 500	1.00	0.842 701	1.50	0.966 105
0.01	0.011 283	0.51	0.529 244	1.01	0.846 810	1.51	0.967 277
0.02	0.022 565	0.52	0.537 899	1.02	0.850 838	1.52	0.968 413
0.03	0.033 841	0.53	0.546 464	1.03	0.854 784	1.53	0.969 516
0.04	0.045 111	0.54	0.554 939	1.04	0.858 650	1.54	0.970 586
0.05	0.056 372	0.55	0.563 323	1.05	0.862 436	1.55	0.971 623
0.06	0.067 622	0.56	0.571 616	1.06	0.866 144	1.56	0.972 628
0.07	0.078 858	0.57	0.579 816	1.07	0.869 773	1.57	0.973 603
0.08	0.090 078	0.58	0.587 923	1.08	0.873 326	1.58	0.974 547
0.09	0.101 281	0.59	0.595 936	1.09	0.876 803	1.59	0.975 462
0.10	0.112 463	0.60	0.603 856	1.10	0.880 205	1.60	0.976 348
0.11	0.123 623	0.61	0.611 681	1.11	0.883 533	1.61	0.977 207
0.12	0.134 758	0.62	0.619 411	1.12	0.886 788	1.62	0.978 038
0.13	0.145 867	0.63	0.627 046	1.13	0.889 971	1.63	0.978 843
0.14	0.156 947	0.64	0.634 586	1.14	0.893 082	1.64	0.979 622
0.15	0.167 996	0.65	0.642 029	1.15	0.896 124	1.65	0.980 376
0.16	0.179 012	0.66	0.649 377	1.16	0.899 096	1.66	0.981 105
0.17	0.189 992	0.67	0.656 628	1.17	0.902 000	1.67	0.981 810
0.18	0.200 936	0.68	0.663 782	1.18	0.904 837	1.68	0.982 493
0.19	0.211 840	0.69	0.670 840	1.19	0.907 608	1.69	0.983 153
0.20	0.222 703	0.70	0.677 801	1.20	0.910 314	1.70	0.983 790
0.21	0.233 522	0.71	0.684 666	1.21	0.912 956	1.71	0.984 407
0.22	0.244 296	0.72	0.691 433	1.22	0.915 534	1.72	0.985 003
0.23	0.255 023	0.73	0.698 104	1.23	0.918 050	1.73	0.985 578
0.24	0.265 700	0.74	0.704 678	1.24	0.920 505	1.74	0.986 135
0.25	0.276 326	0.75	0.711 156	1.25	0.922 900	1.75	0.986 672
0.26	0.286 900	0.76	0.717 537	1.26	0.925 236	1.76	0.987 190
0.27	0.297 418	0.77	0.723 822	1.27	0.927 514	1.77	0.987 691
0.28	0.307 880	0.78	0.730 010	1.28	0.929 734	1.78	0.988 174
0.29	0.318 283	0.79	0.736 103	1.29	0.931 899	1.79	0.988 641
0.30	0.328 627	0.80	0.742 101	1.30	0.934 008	1.80	0.989 091
0.31	0.338 908	0.81	0.748 003	1.31	0.936 063	1.81	0.989 525
0.32	0.349 126	0.82	0.753 811	1.32	0.938 065	1.82	0.989 943
0.33	0.359 279	0.83	0.759 524	1.33	0.940 015	1.83	0.990 347
0.34	0.369 365	0.84	0.765 143	1.34	0.941 914	1.84	0.990 736
0.35	0.379 382	0.85	0.770 668	1.35	0.943 762	1.85	0.991 111
0.36	0.389 330	0.86	0.776 100	1.36	0.945 561	1.86	0.991 472
0.37	0.399 206	0.87	0.781 440	1.37	0.947 312	1.87	0.991 821
0.38	0.409 009	0.88	0.786 687	1.38	0.949 016	1.88	0.992 156
0.39	0.418 739	0.89	0.791 843	1.39	0.950 673	1.89	0.992 479
0.40	0.428 392	0.90	0.796 908	1.40	0.952 285	1.90	0.992 790
0.41	0.437 969	0.91	0.801 883	1.41	0.953 852	1.91	0.993 090
0.42	0.447 468	0.92	0.806 768	1.42	0.955 376	1.92	0.993 378
0.43	0.456 887	0.93	0.811 564	1.43	0.956 857	1.93	0.993 656
0.44	0.466 225	0.94	0.816 271	1.44	0.958 297	1.94	0.993 923
0.45	0.475 482	0.95	0.820 891	1.45	0.959 695	1.95	0.994 179
0.46	0.484 655	0.96	0.825 424	1.46	0.961 054	1.96	0.994 426
0.47	0.493 745	0.97	0.829 870	1.47	0.962 373	1.97	0.994 664
0.48	0.502 750	0.98	0.834 232	1.48	0.963 654	1.98	0.994 892
0.49	0.511 668	0.99	0.838 508	1.49	0.964 898	1.99	0.995 111

Erf cont'd

2.00	0.995 322	2.50	0.999 593	3.00	0.999 977 91	3.50	0.999 999 257
2.01	0.995 525	2.51	0.999 614	3.01	0.999 979 26	3.51	0.999 999 309
2.02	0.995 719	2.52	9.999 634	3.02	0.999 980 53	3.52	0.999 999 358
2.03	0.995 906	2.53	0.999 654	3.03	0.999 981 73	3.53	0.999 999 403
2.04	0.996 086	2.54	0.999 672	3.04	0.999 982 86	3.54	0.999 999 445
2.05	0.996 258	2.55	0.999 689	3.05	0.999 983 92	3.55	0.999 999 485
2.06	0.996 423	2.56	0.999 706	3.06	0.999 984 92	3.56	0.999 999 521
2.07	0.996 582	2.57	0.999 722	3.07	0.999 985 86	3.57	0.999 999 555
2.08	0.996 734	2.58	0.999 736	3.08	0.999 986 74	3.58	0.999 999 587
2.09	0.996 880	2.59	0.999 751	3.09	0.999 987 57	3.59	0.999 999 617
2.10	0.997 021	2.60	0.999 764	3.10	0.999 988 35	3.60	0.999 999 644
2.11	0.997 155	2.61	0.999 777	3.11	0.999 989 08	3.61	0.999 999 670
2.12	0.997 284	2.62	0.999 789	3.12	0.999 989 77	3.62	0.999 999 694
2.13	0.997 407	2.63	0.999 800	3.13	0.999 990 42	3.63	0.999 999 716
2.14	0.997 525	2.64	0.999 811	3.14	0.999 991 03	3.64	0.999 999 736
2.15	0.997 639	2.65	0.999 822	3.15	0.999 991 60	3.65	0.999 999 756
2.16	0.997 747	2.66	0.999 831	3.16	0.999 992 14	3.66	0.999 999 773
2.17	0.997 851	2.67	0.999 841	3.17	0.999 992 64	3.67	0.999 999 790
2.18	0.997 951	2.68	0.999 849	3.18	0.999 993 11	3.68	0.999 999 805
2.19	0.998 046	2.69	0.999 858	3.19	0.999 993 56	3.69	0.999 999 820
2.20	0.998 137	2.70	0.999 866	3.20	0.999 993 97	3.70	0.999 999 833
2.21	0.998 224	2.71	0.999 873	3.21	0.999 994 36	3.71	0.999 999 845
2.22	0.998 308	2.72	0.999 880	3.22	0.999 994 73	3.72	0.999 999 857
2.23	0.998 388	2.73	0.999 887	3.23	0.999 995 07	3.73	0.999 999 867
2.24	0.998 464	2.74	0.999 893	3.24	0.999 995 40	3.74	0.999 999 877
2.25	0.998 537	2.75	0.999 899	3.25	0.999 995 70	3.75	0.999 999 886
2.26	0.998 607	2.76	0.999 905	3.26	0.999 995 98	3.76	0.999 999 895
2.27	0.998 674	2.77	0.999 910	3.27	0.999 996 24	3.77	0.999 999 903
2.28	0.998 738	2.78	0.999 916	3.28	0.999 996 49	3.78	0.999 999 910
2.29	0.998 799	2.79	0.999 920	3.29	0.999 996 72	3.79	0.999 999 917
2.30	0.998 857	2.80	0.999 925	3.30	0.999 996 94	3.80	0.999 999 923
2.31	0.998 912	2.81	0.999 929	3.31	0.999 997 15	3.81	0.999 999 929
2.32	0.998 966	2.82	0.999 933	3.32	0.999 997 34	3.82	0.999 999 934
2.33	0.999 016	2.83	0.999 937	3.33	0.999 997 51	3.83	0.999 999 939
2.34	0.999 065	2.84	0.999 941	3.34	0.999 997 68	3.84	0.999 999 944
2.35	0.999 111	2.85	0.999 944	3.35	0.999 997 838	3.85	0.999 999 948
2.36	0.999 155	2.86	0.999 948	3.36	0.999 997 983	3.86	0.999 999 952
2.37	0.999 197	2.87	0.999 951	3.37	0.999 998 120	3.87	0.999 999 956
2.38	0.999 237	2.88	0.999 954	3.38	0.999 998 247	3.88	0.999 999 959
2.39	0.999 275	2.89	0.999 956	3.39	0.999 998 367	3.89	0.999 999 962
2.40	0.999 311	2.90	0.999 959	3.40	0.999 998 478	3.90	0.999 999 965
2.41	0.999 346	2.91	0.999 961	3.41	0.999 998 582	3.91	0.999 999 968
2.42	0.999 379	2.92	0.999 964	3.42	0.999 998 679	3.92	0.999 999 970
2.43	0.999 411	2.93	0.999 966	3.43	0.999 998 770	3.93	0.999 999 973
2.44	0.999 441	2.94	0.999 968	3.44	0.999 998 855	3.94	0.999 999 975
2.45	0.999 469	2.95	0.999 970	3.45	0.999 998 934	3.95	0.999 999 977
2.46	0.999 497	2.96	0.999 972	3.46	0.999 999 008	3.96	0.999 999 979
2.47	0.999 523	2.97	0.999 973	3.47	0.999 999 077	3.97	0.999 999 980
2.48	0.999 547	2.98	0.999 975	3.48	0.999 999 141	3.98	0.999 999 982
2.49	0.999 571	2.99	0.999 976	3.49	0.999 999 201	3.99	0.999 999 983

[a] For a more complete table, see L. J. Comrie, *Chambers Six Figure Mathematical Tables*, Vol. 2, W. & R. Chambers, Edinburgh, 1949.


alkali metals I A
alkaline earth metals II A
transition metals
III B IV B V B VI B VII B VIII I B II B
nonmetals
III A IV A V A VI A VII A
noble gases 0
Period 1
Period 2
Period 3
Period 4
Period 5
Period 6
Period 7
1 H 1.01 Hydrogen
2 He 4.00 Helium
3 Li 6.94 Lithium
4 Be 9.01 Beryllium
5 B 10.81 Boron
6 C 12.01 Carbon
7 N 14.01 Nitrogen
8 O 16.00 Oxygen
9 F 19.00 Fluorine
10 Ne 20.18 Neon
11 Na 22.99 Sodium
12 Mg 24.31 Magnesium
13 Al 26.98 Aluminum
14 Si 28.09 Silicon
15 P 30.97 Phosphorus
16 S 32.07 Sulfur
17 Cl 35.45 Chlorine
18 Ar 39.95 Argon
19 K 39.10 Potassium
20 Ca 40.08 Calcium
21 Sc 44.96 Scandium
22 Ti 47.88 Titanium
23 V 50.94 Vanadium
24 Cr 52.00 Chromium
25 Mn 54.95 Manganese
26 Fe 55.85 Iron
27 Co 58.93 Cobalt
28 Ni 58.70 Nickel
29 Cu 63.55 Copper
30 Zn 65.39 Zinc
31 Ga 69.72 Gallium
32 Ge 72.61 Germanium
33 As 74.92 Arsenic
34 Se 78.96 Selenium
35 Br 79.90 Bromine
36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium
38 Sr 87.62 Strontium
39 Y 88.91 Yttrium
40 Zr 91.22 Zirconium
41 Nb 92.91 Niobium
42 Mo 95.94 Molybdenum
43 Tc (98) Technetium
44 Ru 101.07 Ruthenium
45 Rh 102.91 Rhodium
46 Pd 106.4 Palladium
47 Ag 107.87 Silver
48 Cd 112.41 Cadmium
49 In 114.82 Indium
50 Sn 118.71 Tin
51 Sb 121.74 Antimony
52 Te 127.60 Tellurium
53 I 126.90 Iodine
54 Xe 131.29 Xenon
55 Cs 132.91 Cesium
56 Ba 137.33 Barium
Lanthanide series (see below)
72 Hf 178.49 Hafnium
73 Ta 180.94 Tantalum
74 W 183.85 Tungsten
75 Re 186.21 Rhenium
76 Os 190.23 Osmium
77 Ir 192.22 Iridium
78 Pt 195.08 Platinum
79 Au 196.97 Gold
80 Hg 200.59 Mercury
81 Tl 204.38 Thallium
82 Pb 207.2 Lead
83 Bi 208.98 Bismuth
84 Po (209) Polonium
85 At (210) Astatine
86 Rn (222) Radon
87 Fr (223) Francium
88 Ra 226.03 Radium
Actinide series (see below)
104 Rf (261) Rutherfordium
105 Db (262) Dubnium
106 Sg (263) Seaborgium
107 Bh (262) Bohrium
108 Hs (265) Hassium
109 Mt (266) Meitnerium
110 (269)
111 (272)
112 (277)
114 (281)
116 (289)
118 (293)
rare earth elements—Lanthanide series
57 La 138.91 Lanthanum
58 Ce 140.12 Cerium
59 Pr 140.91 Praseodymium
60 Nd 144.24 Neodymium
61 Pm (145) Promethium
62 Sm 150.4 Samarium
63 Eu 151.96 Europium
64 Gd 157.25 Gadolinium
65 Tb 158.93 Terbium
66 Dy 162.50 Dysprosium
67 Ho 164.93 Holmium
68 Er 167.26 Erbium
69 Tm 168.93 Thulium
70 Yb 173.04 Ytterbium
71 Lu 174.97 Lutetium
Actinide series
89 Ac 227.03 Actinium
90 Th 232.04 Thorium
91 Pa 231.04 Protactinium
92 U 238.03 Uranium
93 Np 237.05 Neptunium
94 Pu (244) Plutonium
95 Am (243) Americium
96 Cm (247) Curium
97 Bk (247) Berkelium
98 Cf (251) Californium
99 Es (252) Einsteinium
100 Fm (257) Fermium
101 Md (258) Mendelevium
102 No (259) Nobelium
103 Lr (260) Lawrencium