ECE 6450 Introduction to Microelectronics Technology

Exam 1

September 27, 2017

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Print your name clearly: Solutions

Instructions:
Read all the problems carefully and thoroughly before you begin working. **DO NOT SEPARATE ANY PAGES OF THIS EXAM.** You are allowed to use 1 sheet of hand written notes (1 page front and back) which you must turn in 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 ON THE PROVIDED SHEETS AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED.** Write legibly. No work should be done on any other paper. If I cannot 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. (20 points total in 4, 5 point parts):
True/False and Multiple Choice and short answer/calculation: Choose the best answer or answers

a.) Based on the periodic table (see attached table) which of the following are true (one or more answers possible)?
   1.) AlAs will have a larger bandgap than InAs
   2.) InAs will have a smaller bandgap than InP
   3.) $Al_{0.4}Ga_{0.6}N$ is a real semiconductor
   opt. 4.) All of the above
   5.) None of the above
   6.) I wish I had gone to Clemson instead of Ga Tech.

b.) Why are defects considered important to understanding semiconductors and semiconductor fabrication?
   1.) Many defects such as vacancies and interstitials enhance or retard the diffusion of atoms
   2.) Defects can trap electrical carriers (electrons or holes) causing detrimental results
   3.) Defects like precipitates set the upper limit of the solubility of desirable impurities like dopants
   4.) Some defects like grain boundaries result in the ability to dope materials to higher levels than possible without the grain boundaries.
   5.) Defects and impurities are things we always want to avoid in semiconductor fabrication

c.) Which of the following are true regarding the use of $Hf_xSi_{1-x}O_2$ for CMOS
   1.) For a given desired capacitance, $Hf_xSi_{1-x}O_2$ can be thicker than SiO_2
   2.) For a given desired capacitance, $Hf_xSi_{1-x}O_2$ can result in lower DC gate leakage current than SiO_2
   3.) For a given desired capacitance, $Hf_xSi_{1-x}O_2$ can result in lower interface state density than SiO_2
   4.) $Hf_xSi_{1-x}O_2$ is now used for "field oxides" (oxides separating the interconnect wiring) because it has a higher dielectric constant than does SiO_2
   5.) $Hf_xSi_{1-x}O_2$ is now used for "gate oxides" (oxides immediately above the channel of a MOSFET) because it has a higher dielectric constant than does SiO_2

d.) True or False (circle the correct answer)
Since oxide trapped charge is always detrimental, there is no known device application that benefits from oxide trapped charge.

Problem 2. (20 points total in two parts):

A.) Describe the kinetics (mechanisms of atomic motion) for the oxidation process. ***For full credit, keep your description to 4 sentences or less and be sure to describe the surface and interface reactions and the transport of chemical species towards and away from the interfaces. If needed, feel free to draw diagrams to furthur explain your answer.***

Any discussion that includes the three flow regimes below was acceptable. It should also include details of how the gas impinges on the stagnant layer, diffuses through that layer, diffuses across the oxide and reacts at or near the SiO2/Si interface.

3 flow regimes occurring during oxidation:

1.) Stagnant Gas Flow: occurs due to finite gas flow in the bulk gas, and zero flow at the wafer surface. The "boundary layer" between the wafer and the free flowing gas acts as a diffusion barrier for incoming gas molecules.

2.) Diffusion through the oxide: Molecular diffusion of O2 or H2O.

3.) Reaction limited flux at the Si/SiO2 interface.

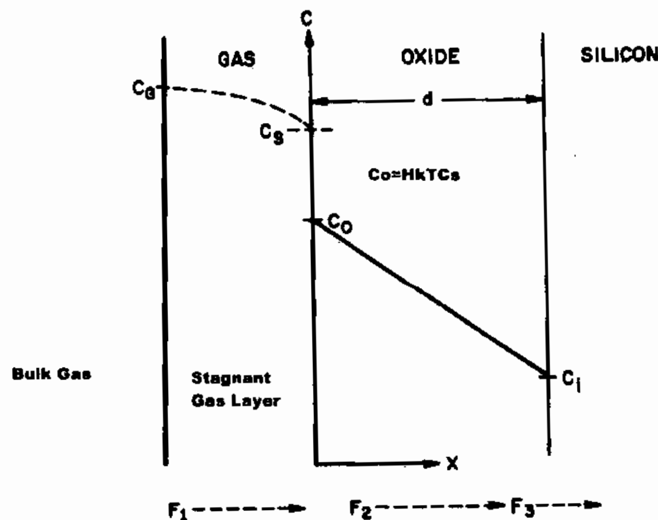


FIGURE 2
Basic model for thermal oxidation of silicon (*After Deal and Grove, Ref. 4.*)

C_G=Concentration in Gas

C_S=Concentration in the stagnant layer/oxide boundary

C_O= Concentration in the oxide at the stagnant layer/oxide boundary

C_i= Concentration in the oxide at the oxide/Si boundary

B.) Describe the physics of the two step diffusion process. ***For full credit, keep your description to <u>4 sentences or less</u> and be sure to include the concepts of solubility, gas kinetics, and which mathematical description is used in each step. If needed, feel free to draw diagrams to furthur explain your answer.***

Any discussion of the TWO STEP DIFFUSION is okay.

The discussion should describe the delivery of an effectively infinite number of dopant elements via a gas flow, the thermal and chemical cracking of the molecules on the surface, and thus, the surface concentration reaching the soluability limit. The source of atoms is turned off and the wafer is oxidized to cap in impurities. The temperature is then increased and the finite impurity concentration is driben deeper into the wafer. The math is goverened by the Smith Integral which in the special cases of If $(D_1t_1)^{0.5}$ << $(D_2t_2)^{0.5}$ results in a gaussian profile while if $(D_1t_1)^{0.5}$ >> $(D_2t_2)^{0.5}$ results in an erfc profile.

$$C(z,t_1,t_2)=\frac{2C(0,t_1)}{\pi}\int_0^U \frac{e^{-\beta(1+U^2)}}{1+U^2}dU \qquad U=\sqrt{\frac{D_1t_t}{D_2t_2}} \qquad \beta=\left[\frac{x}{2\sqrt{D_1t_1+D_2t_2}}\right]^2$$

where the integral is known as the smith integral

Problem 3. (60 points total):

You are about to make your first MOSFET. This question makes a MOSFET in several steps.
Assumptions:
Assume no lateral oxidation nor diffusion occurs (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 1000 degrees C:
A=0.165 μm, B=0.0117 μm²/hr and t=0.15 hr for dry oxides
A=0.226 μm, B=0.287 μm²/hr for wet oxides.

At 1200 degrees C:
A=0.040 μm, B=0.045 μm²/hr and t=0.027 hr for dry oxides
A=0.05 μm, B=0.720 μm²/hr for wet oxides.

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

A.) (10 points) A 150 angstrom gate oxide is to be grown and should be of the highest possible electrical quality. What time at 1000 degrees C is required and where is the initial SiO_2/Si interface located?

Choose Dry Oxide

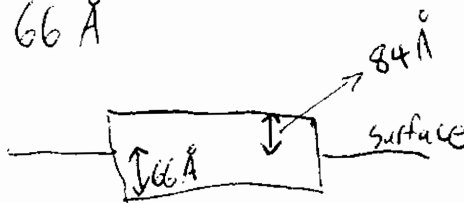
150 Å = 0.015 um

$(0.015)^2 + (0.165)(0.015) = (0.0117)(t + 0.15)$

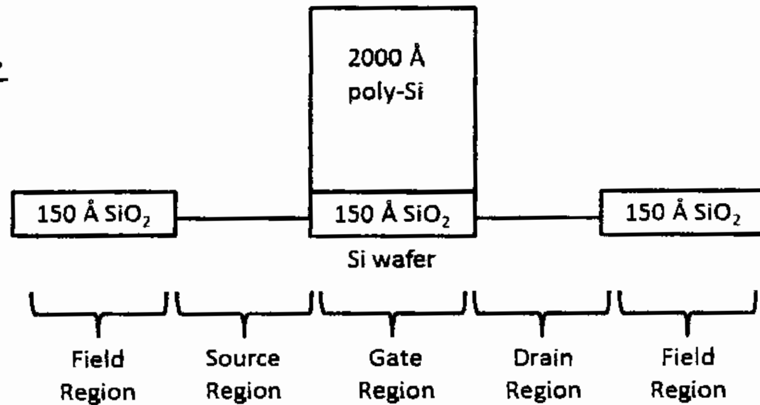
t = 0.0808 hours
or
4.85 minutes
or
4 minutes 51 seconds

thin oxide approximation!
$t_{ox} = \frac{0.165(0.005)}{0.0117} - 0.15$
= 0.0615 hours
3 min 41 sec

$0.44d = 0.44(150\text{ Å})$
$= 66\text{ Å}$



NOTE: For either part B or C you will need to assume a ~~surface concentration~~ Dose of 1×10^{14} cm^{-2}.
A 2000 angstrom thick polysilicon Gate "metal" is deposited and patterned which will act as a subsequent mask for the later diffusions and oxidation steps. Openings in the oxide are also created for the source and drain regions. Thus, the starting configuration for part (B) is as shown in the figure. The silicon wafer is n-type silicon uniformly Phosphorous doped at 1×10^{17} cm^{-3} (bulk concentration).



B.) (20 Points) You are to use Boron (B) using diborane (B_2H_6) at 1200 degrees C to create a source and drain that has the highest possible surface concentration (good for contacts to metals). Pick the appropriate ONE STEP diffusion process to achieve this highest surface concentration. At this temperature, the solubility of B in Silicon is 2×10^{20} cm^{-3}. Assuming a neutral ionized vacancy controlled diffusion and given the diffusion parameters for Boron are $D_o = 0.037$ cm^2/sec and $E_a = 3.46$ eV, and a $D^+_o = 0.41$ cm^2/sec and $E^+_a = 3.46$ eV what is the time required to form a shallow 0.05um junction depth?

$k = 8.63e{-5}$ eV/°K   Predeposition

$$D = 0.037 e^{-(3.46/(k(1200+273.15)))}$$

$$= 5.66e{-14} \text{ cm}^2/\text{sec}$$

$$x_j = 2\sqrt{Dt}\ \text{erfc}^{-1}\left|\frac{C_B}{C_s}\right|$$

$C_B \rightarrow 1 \times 10^{17}$ cm^{-3}

$C_s \rightarrow 2 \times 10^{20}$ cm^{-3}

$x_j \rightarrow 0.05 \times 10^{-4}$ cm

argument = 0.0005

$\text{erfc}^{-1}(0.0005) \cong 2.461$

$$t = 18.23 \text{ seconds}$$

$\text{erfc}(x) = 1 - \text{erf}(x)$
Find argument x in tables that has $0.9995 = (1 - 0.0005)$ as it's result

C.) (20 Points) Your competitor uses the opposite process that you selected in part B. How much time does it take them to diffuse B to obtain the same junction depth at the same temperature?

Drive In

$Q_T \rightarrow$ 1e14 cm^{-2}

$$* \quad (0.05 \times 10^{-4})\,cm = x_j = \sqrt{4Dt \ln\left(\frac{Q_T}{C_B\sqrt{\pi D t}}\right)}$$

$C_B = 10^{17}\ cm^{-3}$

$D = 5.66e{-14}\ cm^2/sec$

Optional: Use previous solution (~18sec) to determine ~ magnitude of the initial guess

t	Right Hand Side of *	
20	5.329e-6 cm	>
10	3.87 e-6 cm	<
15	4.668e-6	<
18	5.077e-6	~>
17	4.94 e-6	~<
17.5	5.01 e-6	~=
17.4	4.998e-6	~=

Any answer between 17 - 18 is okay for the exam

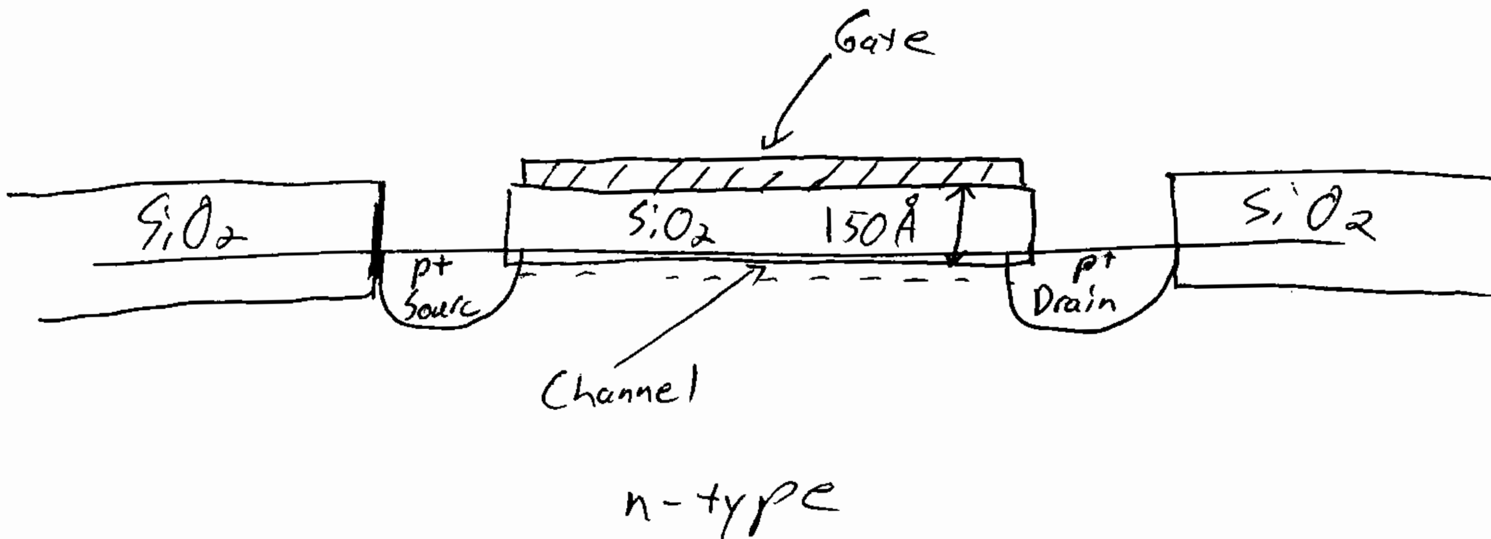
D.) (5 Points) What is the FINAL surface concentration for your competitor's process? Note in practice this strongly affects the resistance of the metal to semiconductor contact.

$$C_s = \frac{Q_T}{\sqrt{\pi D t}}$$

$$= \frac{1e14}{\sqrt{\pi (5.66e-14)(17.4)}}$$

$$= 5.6 \times 10^{19} \, cm^{-3}$$

E.) (5 points) Magically, metal contacts are added (this process is covered in detail later in the class) and the device is operated in the conductive state (i.e. the device is biased to turn it on). Draw the final cross-sectional view (i.e. similar to the above figure) of the resulting structure clearly label the channel region where current is controlled (i.e. where the resistance of the device is modulated and the Gate, source and drain.



Erf Table

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.

Periodic Table of the Elements

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Series															
Lanthanide Series	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinide Series	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Atomic Number
Symbol
Name
Atomic Mass