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OMNIFORM I:

A GENERAL PURPOSE MACHINE PROGRAM FOR THE CALCULATION OF TABLES OF FUNCTIONS GIVEN EXPLICITLY IN TERMS OF ONE VARIABLE

JOSEPH HILSENRATH AND GERALD M. GALLER

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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OMNIFORM I: A General Purpose Machine Program for the Calculation of Tables of Functions Given Explicitly in Terms of One Variable.

Joseph Hilsenrath and Gerald M. Galler*

A general purpose computer program, designed for use by non-programmers requiring computation of tables of functions written explicitly in terms of one variable, is described. The program features include: 22 types of elementary and special functions; provision for taking of functions of functions, table read-in, flexible print-out; and standardized input to a variety of problems. The use of the program is illustrated with a number of sample problems.

1. INTRODUCTION

In spite of the successful application of digital computers to important problems in virtually every subdivision of modern science, they are not yet being employed widely and effectively to assist in the routine day-to-day computations of a busy laboratory. They have not yet replaced the multicolumned work sheet which is such an indispensable part of both experimental and theoretical research.

A brief catalogue of these routine numerical calculations would include: interpolation, differencing, smoothing, curve fitting, differentiation, integration, and table look-up for elementary and special functions. These mathematical operations obviously have general applicability. Their day-to-day use in any individual situation is, however, quite specialized - too specialized, it would seem, to justify the preparation of a multitude of computer programs tailor-made for each

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application. Access to digital computers has been made easier for both the experienced programmer and the novice by the development recently of a variety of systems, compilers and languages. These aids have encouraged many scientists to learn to program their own problems. In spite of the expanding corps of "scientist-programmers," there is now and will continue to be a need for "painless" access to digital computers by scientists who are not programmers.

A solution to the mechanization of a sizable number of ad hoc calculations now being performed by hand or being avoided altogether, seems to lie in the development of general purpose programs for the various digital computers. Such programs could involve either a number of interpretive general purpose codes in which a large number of different computations are included, or an operating system containing a large number of individual programs with highly simplified input. In any case, such programs should be complete packages permanently assembled with input and output, rather than subroutines. In this way, they would be user-oriented rather than programmer-oriented.

OMNIFORM I is one of a series of such programs under development at the National Bureau of Standards. It was initially intended for thermodynamic calculations. As the planning of the program progressed, indications of its wider applicability became apparent and it was expanded accordingly.

The motivation of the program and its user-oriented specifications arose from the need of a general purpose program by one of us (a non-programmer). The final OMNIFORM I Program, as described herein, was made possible largely through a successful communication of these specifications to the second author (an experienced programmer).

2. OMNIFORM I

2.1 General Characteristics

OMNIFORM I is a completely assembled interpretive program for the IBM 704 - 7090 which permits direct use of the machine by scientists or engineers without knowledge of programming. Instructions, given in decimal form, control the flow of calculations in a manner highly analogous to the logic which prevails in carrying out computations on a desk calculator. More precisely, OMNIFORM I simulates desk computing in that it replaces the desk calculator, mathematical tables, and the multi-column work sheet but not the logic which the scientist employs in such operations.

The name of the program has the following significance. It is one in a series of omnibus programs, hence the OMNI. It is specifically restricted to substituting constants and a single variable into an algebraic formula given explicitly in terms of one variable, hence FORM and I. It should be noted that the formula or function must be written explicitly in terms of the independent variable. It may, however, be given in terms of more than one variable if the other variables can be treated parametrically. The function may involve any of the elementary functions and many of the frequently used special functions. The function must however be explicit.

The function types built into the program are identified and called for by numbers. For example the substitution of a set of values in a power series is accomplished by placing a number 1. in the appropriate column of the instruction sheet. This provides a power series of the form $f_1^n = \sum_{j=1}^{n} a_j X^{b_j}$. A number n then tells the machine how many terms to generate, and n numbers pairs (a_j and b_j)* provide the required coefficients and exponents.

The versatility of the program, over and above the wide range of functions available in it, results from the fact that in any of the functions f_α^n (X) (defined in Table 1), the variable X may be replaced easily by any function of X either previously computed or read into the memory as a table of functional values. Thus the program can readily compute functions of functions, such as: loglogx, e^{e^x}, $[f_1(x)]^{f_2(x)}$, $\sqrt[3]{a + \sqrt{b + \sqrt{c}}}$, continued fractions, ln $(e^{f(x)} + a)$, ln sin (1 + bx) to name a few. Since the order of operations is completely open, any explicit formula involving sums of products of sums of functions can be handled - - a feature which is the basis of OMNIFORM I's extensive applicability.

The program was assembled using the FORTRAN programming system with subprograms from the FORTRAN Library of routines. In addition, specialized subprograms were developed to provide a complete program giving flexibility in input, computing, and output capabilities. These programs are a permanent part of OMNIFORM and hence provide a self-contained computing deck suitable for immediate use. The deck, comprising about 500 binary punched cards, can be read by the computer in less than 2 minutes, after which the computer is ready to interpret the cards containing input data which direct it to the individual problem.

OMNIFORM I is primarily a table generator. It can produce a table

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* a_j, b_j are real numbers but not necessarily integers.

of up to 50 columns (50 different functions) for each of 200 arguments. Among the tables which have been computed on OMNIFORM I thus far are: ideal gas thermodynamic functions for neon and for electrons, anharmonic corrections for diatomic molecules, vapor pressure of solid nitrogen, virial coefficients for nitrogen gas, negative exponentials corresponding to certain atomic energy levels, polynomial substitution, table conversion to other units; table editing (column switching etc.), and various ad hoc mathematical tables for selected arguments.

2.2 Mathematical Foundation

a. The Operator Equation

The generality of OMNIFORM I rests upon two factors: a Function Generator which provides 22 functions $f_\alpha^n(X)$ as defined in Table 1 (the symbol f_α^n indicates a function of type α having n terms) and an Operator Equation

$$F_k(X_i) = G_k(X_i) + f_\alpha^n \left[\Phi_t(X_i)\right] \Omega \, H_c(X_i) \; *$$

which causes these functions to operate on the values $H_c(X_i)$ stored in in column c; and to store that result by addition to the values $G_k(X_i)$ stored in column k.

The integers k, α, n, t, Ω, c constitute the first six numbers in each line of instruction in the Operator Equation. (See Table 3.) These numbers serve to select the function type and the number of terms in each function, to indicate certain operations upon functions, and to specify

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* Ω is a symbol for the operations +, −, x, ÷ , and the X_i are the arguments for which the calculations are performed. Whenever instructions are given for a line of calculations, these are performed for the entire set of arguments (a column of X_i or some function of them).

storage locations. For each line of instruction, the six numbers (defined below) are followed by a variable number of constants - - a_j, b_j; or a_j, b_j, c_j, d_j, - - as required by the particular function type selected and the number of terms in it.

b. Definitions of the Subscripts

k assigns the result of any line of computation to the k^{th} column in the memory by addition, $1 \leq k \leq 50$.

α selects the function type, $1 \leq \alpha \leq 22$.

n is the number of terms in the α^{th} function, $1 \leq n \leq 200$.

t is a transformation switch which is interpreted as follows: on the first pass through the function generator, if

$t = 0$, $\Phi_t(X_i) = X_i$;

$t = 1., 2., \ldots, 19.$, $\Phi_t(X_i) = \beta_t X_i^{\gamma_t} + \delta_t$.

On a subsequent pass through the function generator,*

$\Phi_t(X_i) = F_t(X_i)$, a function previously computed and stored in column t.

Ω is an operator indicated by an integer. Thus:

$\Omega = 1$, adds $f_\alpha^n \left[\Phi_t(X_i)\right]$ to $H_c(X_i)$;

$\Omega = 2$, subtracts $f_\alpha^n \left[\Phi_t(X_i)\right]$ from $H_c(X_i)$;

$\Omega = 3$, multiplies $f_\alpha^n \left[\Phi_t(X_i)\right]$ by $H_c(X_i)$;

$\Omega = 4$, divides $H_c(X_i)$ by $f_\alpha^n \left[\Phi_t(X_i)\right]$.

c is the index of the functional value upon which $f_\alpha^n \left[\Phi_t(X_i)\right]$

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* A pass through the Generator consists of a series of computations initiated by a BCD 1GEN0aa instruction. The repetition of the BCD 1GEN0aa instruction initiates the second pass through the function generator.

operates, $1 \leq c \leq 50$.

If $\Omega = 0$ the function computed does not operate on any other function. A value must nevertheless be supplied for c, since the machine expects six integers.

c. Arguments, Transformations, and Arithmetic Characterisitcs

Instructions for the arguments (the independent variable X) can be supplied in either of two forms: as discrete numbers $X_1, X_2, X_3, \ldots, X_{200}$, or in the incremented mode $X_1, \Delta_1, X_2, \Delta_2, \ldots, X_f$. In the latter mode the Δ's represent uniform intervals of tabulation between the point X_1, X_2, etc. This is analagous to the notation employed in mathematical tables where 1.(1.)100.(10.)1000. indicates that values are tabulated in unit steps from 1 to 100 and in steps of 10 between 100 and 1000.

Provision has been made to read in as many as 19 triplets of constants β_t, γ_t, δ_t which provide a like number of transformations

$$\Phi_t(X) = \beta_t X^{\gamma_t} + \delta_t$$

prior to substitution in the Function Generator. Thus the variable X may be replaced at will by $(1 + 1/X)$, $(4.7\,X^{1.93} + 17.8)$, $(X^2 - 1)$, etc. This provision simplifies the instructions and the flow of the calculations in complicated problems.

The above remarks concerning the role of the integer t apply when the Function Generator is entered for the first time - - when either X_i or $(\beta_t X_i^{\gamma_t} + \delta_t)$ is used as the variable in the function. On subsequent passes through the Function Generator, the integer t no longer denotes a transformation but instead denotes the column number of the

Table 1. Function Generator

$$f_1^n = \sum_{j=1}^{n} a_j X^{b_j}$$

$$f_2^n = \sum_{j=1}^{n} a_j X^{b_j} \log X$$

$$f_3^n = \sum_{j=1}^{n} a_j X^{b_j} \ln X$$

$$f_4^n = \sum_{j=1}^{n} a_j X^{b_j} \exp \left[c_j X^{d_j}\right]$$

$$f_5^n = \sum_{j=1}^{n} (a_j/b_j) X^{c_j} \left[\sin X\right]^{d_j}$$

$$f_6^n = \sum_{j=1}^{n} a_j X^{b_j} \left[\sin c_j X\right]^{d_j}$$

$$f_7^n = \sum_{j=1}^{n} (a_j/b_j) X^{c_j} \left[\cos X\right]^{d_j}$$

$$f_8^n = \sum_{j=1}^{n} a_j X^{b_j} \left[\cos c_j X\right]^{d_j}$$

$$f_9^n = \sum_{j=1}^{n} (a_j/b_j) X^{c_j} \left[\tan X\right]^{d_j}$$

$$f_{10}^n = \sum_{j=1}^{n} a_j X^{b_j} \left[\tan c_j X\right]^{d_j}$$

$$f_{11}^n = \sum_{j=1}^{n} a_j \left[\sinh X\right]^{b_j}$$

$$f_{12}^n = \sum_{j=1}^{n} a_j \left[\cosh X\right]^{b_j}$$

$$f_{13}^n = \sum_{j=1}^{n} a_j \left[\tanh X\right]^{b_j}$$

$$f_{14}^n = \sum_{j=1}^{n} a_j \pi/2 + b_j \text{ arc sin } X$$

$$f_{15}^n = \sum_{j=1}^{n} a_j \pi/2 + b_j \text{ arc tan } X$$

$$f_{16}^n = \sum_{j=1}^{n} a_j T_{n_j}(X) \quad \text{(Chebyshev Polynomial)}$$

$$f_{17}^n = \sum_{j=1}^{n} a_j U_{n_j}(X) \quad \text{(Chebyshev Polynomial)}$$

$$f_{18}^n = \sum_{j=1}^{n} a_j P_{n_j}(X) \quad \text{(Legendre Polynomial)}$$

$$f_{19}^n = \sum_{j=1}^{n} a_j L_{n_j}(X) \quad \text{(Laguerre Polynomial)}$$

$$f_{20}^n = \sum_{j=1}^{n} a_j H_{n_j}(X) \quad \text{(Hermite Polynomial)}$$

$$f_{21}^n = \sum_{j=1}^{n} a_j \Gamma(b_j) \left[\Gamma(c_j X)\right]^{d_j}$$

$$f_{22}^n = \sum_{j=1}^{n} a_j \operatorname{erf}(X)$$

functional values which replace X_i in the Operator Equation. Here t can range from 1 to 50 since space is provided for as many as 50 columns of functions in the memory.

Each function which is computed is forced, by Ω, to operate on another function before it is stored in a designated column. In fact, the only way in which two columns of numbers can be added or multiplied is if one of them either originates in or is made to pass through the Operator Equation. Thus, if we desire the product $A \cdot B$ of two functions previously computed, it is necessary to pass one of them through the Operator Equation via an identity transformation $f_1^1 = 1 \cdot A^1$.

It should be noted that OMNIFORM I is programmed in such a way that when the result of a line of computation is assigned to a column, k, it adds the result to the values already stored. For example: if A, B, and C denote functions stored in the first three columns of the memory, and we compute CsinB, assigning the result to column 1 yields $A + C \sin B$. If, however, only CsinB is desired, it must be stored in a blank column. At the beginning of each problem all columns are blank.

By adding rather than replacing in the storage operation, it is possible to achieve an additional operation. Thus, in one line it is possible to compute one of the following:

$$A + f(B) + C \quad \text{or} \quad A - f(B) + C$$

$$A \pm C \cdot f(B) \quad \text{or} \quad A \pm C/f(B)$$

Provision has been made in OMNIFORM I to read in tables of functional values $\theta_k(X_i)$. The number of functions thus read in may be as large as 50 provided enough room is left for further storage for necessary functions generated. An important requirement is that the array must be rectangular (the same number of entries for each function) and it must be in one - to - one correspondence with the specified arguments. Once read in, these functions may be operated on in the same manner as if they were computed in the generator.

2.3 Input

The input to OMNIFORM I consists of three major parts: a preliminary input, one or two control matrices, and print out instructions. The input is via cards which, except for a few mnemonic instructions contain data in decimal form.

a. Preliminary Input

The preliminary input consists of five distinct parts, three of which are mandatory and two optional. The program first reads a title card and prints the title. It then reads a second card containing three numbers N , M , S . These are written as integers (without decimal points) and are separated by commas. The numbers N , M , S provide instructions for the preparation of the arguments and the table read-in as indicated below.

The third card (or cards) contains N numbers which are either a table of arguments, or parameters from which the arguments may be generated in accordance with the instructions given on the previous card. These are interpreted as follows:

If S = 1 then N values of X will be read in. i.e. $X_1, \ldots X_N$

If S = 0 then N parameters of the form:

$X_1, \Delta_1, X_2, \Delta_2, X_3, \ldots, X_f$ are read in and the corresponding arguments are generated.

As indicated in Section 2.2, OMNIFORM allows a number of transformations of the variable (X) to be made prior to entering the function generator. If the transformation instruction t = 1., the first set β_1, γ_1, δ_1, is used; for t = 2., the set β_2, γ_2, δ_2, is used; for t = 3., the set β_3, γ_3, δ_3, etc. The transformation constants, if any, constitute the fourth set of preliminary input, and are omitted if not required. A TRA 2,4 instruction must follow the above input.

Columns of functional values $\theta_k(X_i)$, k = 1, . . ., M, may be read in at this level of the program. These constitute the fifth set of input data. The control for this read-in is vested in the integer M of the second card. It is interpreted as follows: if M = 0 then θ input is bypassed, if M > 0 then M columns of θ's are read in row by row as follows:

$$\theta_1(X_1),\ \theta_2(X_1),\ \theta_3(X_1),\ .\ .\ .,\ \theta_M(X_1)$$

$$\theta_1(X_2),\ \theta_2(X_2),\ \theta_3(X_2),\ .\ .\ .,\ \theta_M(X_2)$$

$$\theta_1(X_3)\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .$$

These data are stored in the first M columns in the machine and contain a number of rows corresponding to the arguments X_i - a maximum of 200 values. The format for the input is illustrated through typical examples. These are given in Tables 4 et. seq.

b. Control Matrices

After the preliminary input, a single mnemonic instruction 1 GENOaa, instructs the machine to generate a a functions, in accordance with the a a lines of instruction immediately following. Here a a denotes a two digit integer. The lines of instructions may be of variable length.

Each line starts out with the six integers k, α, n, t, Ω, c which were defined earlier. These integers are followed by either 2n, or 4n, numbers depending on the functions selected. The control matrix specifies the calculations in terms of the variable X_i or its transforms $\beta_t X_i^{\gamma_t} + \delta_t$. It is followed by a TRA 2,4.

In order to compute functions of functions, it is necessary to enter the Function Generator a second time. This is accomplished by another BCD 1GENOaa instruction followed by appropriate lines of calculations. In the second pass through the generator, the transformation integer t denotes which column replaces the variable in the Operator Equation. It should be noted that in the trigonometric functions f_5^n through f_{10}^n the transformation applies only to the X in sin X, cos X, or tan X, and not to the factor in front of the trigonometric function. Thus in one line of instruction, it is possible to compute either

$$\sum_j^n (a_j/b_j) X_i^{c_j} \left[\sin\left(\beta_t X_i^{\gamma_t} + \delta_t\right)\right] \quad \text{or} \quad \sum_j^n (a_j/b_j) X_i^{c_j} \sin\left[F(X_i)\right]^{d_j}.$$

c. Output Instructions

The remaining two branches are the temporary and final output branches. These may be entered after computations have been completed in a pass through the Generator branch. The temporary output branch must be entered at least once during the entire computation. It is entered via the instruction BCD 1ØUTγOn*. The word BCD 1ØUT selects

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* In preparing instructions for the key punch operators the symbol Ø is used for the letter "O" to distinguish it from the number zero, which is written simply 0.

Table 2. Typical OMNIFORM Printout in Fixed Decimal

OMNIFORM I TEST OF ELEMENTARY FUNCTIONS MAY 1961

X	LOGX	LNX	SINHX	COSHX	TANH
0.1000	-1.000000	-2.302585	0.100167	1.005004	0.099668
0.2000	-0.698970	-1.609438	0.201336	1.020067	0.197375
0.3000	-0.522879	-1.203973	0.304520	1.045338	0.291313
0.4000	-0.397940	-0.916291	0.410752	1.081072	0.379949
0.5000	-0.301030	-0.693147	0.521095	1.127626	0.462117
0.6000	-0.221849	-0.510826	0.636654	1.185465	0.537050
0.7000	-0.154902	-0.356675	0.758584	1.255169	0.604368
0.8000	-0.096910	-0.223144	0.888106	1.337435	0.664037
0.9000	-0.045758	-0.105361	1.026517	1.433086	0.716298
1.0000	-0.000000	-0.000000	1.175201	1.543081	0.761594
1.1000	0.041393	0.095310	1.335647	1.668518	0.800499
1.2000	0.079181	0.182322	1.509461	1.810655	0.833655
1.3000	0.113943	0.262364	1.698382	1.970914	0.861723
1.4000	0.146128	0.336472	1.904301	2.150898	0.885352
1.5000	0.176091	0.405465	2.129279	2.352409	0.905148
1.6000	0.204120	0.470004	2.375568	2.577464	0.921669
1.7000	0.230449	0.530628	2.645632	2.828315	0.935409
1.8000	0.255272	0.587787	2.942174	3.107473	0.946806
1.9000	0.278754	0.641854	3.268162	3.417731	0.956237
2.0000	0.301030	0.693147	3.626860	3.762195	0.964028
2.1000	0.322219	0.741937	4.021856	4.144312	0.970452
2.2000	0.342423	0.788457	4.457105	4.567908	0.975743
2.3000	0.361728	0.832909	4.936961	5.037220	0.980096
2.4000	0.380211	0.875469	5.466228	5.556946	0.983675
2.5000	0.397940	0.916291	6.050203	6.132288	0.986614
2.6000	0.414973	0.955511	6.694731	6.769004	0.989027
2.7000	0.431364	0.993252	7.406262	7.473467	0.991007
2.8000	0.447158	1.029619	8.191917	8.252726	0.992632
2.9000	0.462398	1.064711	9.059559	9.114583	0.993963
3.0000	0.477121	1.098612	10.017873	10.067659	0.995055
3.1000	0.491362	1.131402	11.076448	11.121498	0.995949
3.2000	0.505150	1.163151	12.245881	12.286643	0.996682
3.3000	0.518514	1.193922	13.537874	13.574757	0.997283
3.4000	0.531479	1.223775	14.965359	14.998733	0.997775
3.5000	0.544068	1.252763	16.542623	16.572820	0.998178
3.6000	0.556302	1.280934	18.285451	18.312774	0.998508
3.7000	0.568202	1.308333	20.211285	20.236008	0.998778
3.8000	0.579784	1.335001	22.339401	22.361771	0.999000
3.9000	0.591065	1.360976	24.691096	24.711338	0.999181
4.0000	0.602060	1.386294	27.289909	27.308224	0.999329
4.1000	0.612784	1.410987	30.161847	30.178420	0.999451
4.2000	0.623249	1.435084	33.335655	33.350651	0.999550
4.3000	0.633468	1.458615	36.843099	36.856667	0.999632
4.4000	0.643453	1.481604	40.719278	40.731554	0.999699
4.5000	0.653212	1.504077	45.002992	45.014098	0.999753
4.6000	0.662758	1.526056	49.737105	49.747157	0.999798
4.7000	0.672098	1.547562	54.969005	54.978100	0.999835
4.8000	0.681241	1.568616	60.751055	60.759287	0.999865
4.9000	0.690196	1.589235	67.141121	67.148569	0.999889
5.0000	0.698970	1.609438	74.203163	74.209900	0.999909

Note Above X = 2. the values for sinh X and cosh X are not correct to six decimals though they are correct to within one unit in the sixth significant digit.

the temporary output branch and is used to save all or part of the results computed up to the time this branch is entered. The γ stands for either an F for floating point or a D for fixed point and n refers to the number of columns of printout desired per "page" ($1 \leq n \leq 7$). Table 2 shows a typical fixed point printout and Table 3 shows a floating point printout format. If the total number of designated columns is not an even multiple of n, the last page of the printout for that group will contain the remaining n' columns ($n' < n$).

Following the "ØUT" instruction is the column selector card. This is a data card containing integers, separated by commas, representing the indices of and order in which the columns are to be printed. This enables the user not only to rearrange the computed functions, but to print only selected ones and to repeat columns if desired.

If all of the computed functions are desired in the printout, in the order in which they are computed, the column selector card merely contains the single integer, zero (written as DEC 0).

For example, suppose a user computes 14 functions (k = 1, 2, 3, . . ., 14) but only wants eleven of them printed. Furthermore, he would like to rearrange the columns in a more suitable order for a two page printout in the floating point mode, with six columns on one page and the remaining five on the second. The instructions would be as follows:

```
BCD 1ØUTF06
DEC 5, 4, 1, 6, 7, 8, 13, 10, 11,  2, 14
```

Note that columns 3, 9, and 12 are not requested. Furthermore, column 5 will be printed first, column 4 second, column 1 third, etc.

Table 3. Typical OMNIFORM I Printout in the Floating Point

TEMP.	H	C	S	F
740.0000	0.405223E 04*	0.108942E 02	0.801557E 01	0.251957E 01
750.0000	0.416139E 04	0.109386E 02	0.816209E 01	0.259351E 01
760.0000	0.427099E 04	0.109818E 02	0.830726E 01	0.266742E 01
770.0000	0.438101E 04	0.110241E 02	0.845108E 01	0.274129E 01
780.0000	0.449146E 04	0.110653E 02	0.859359E 01	0.281510E 01
790.0000	0.460231E 04	0.111056E 02	0.873481E 01	0.288884E 01
800.0000	0.471356E 04	0.111450E 02	0.887474E 01	0.296249E 01
810.0000	0.482520E 04	0.111835E 02	0.901343E 01	0.303605E 01
820.0000	0.493722E 04	0.112212E 02	0.915088E 01	0.310950E 01
830.0000	0.504961E 04	0.112581E 02	0.928711E 01	0.318283E 01
840.0000	0.516237E 04	0.112942E 02	0.942215E 01	0.325602E 01
850.0000	0.527548E 04	0.113296E 02	0.955602E 01	0.332908E 01
860.0000	0.538895E 04	0.113643E 02	0.968873E 01	0.340199E 01
870.0000	0.550276E 04	0.113983E 02	0.982030E 01	0.347474E 01
880.0000	0.561691E 04	0.114317E 02	0.995076E 01	0.354733E 01
890.0000	0.573138E 04	0.114645E 02	0.100801E 02	0.361974E 01
900.0000	0.584619E 04	0.114966E 02	0.102084E 02	0.369198E 01
910.0000	0.596131E 04	0.115282E 02	0.103356E 02	0.376404E 01
920.0000	0.607674E 04	0.115593E 02	0.104617E 02	0.383591E 01
930.0000	0.619248E 04	0.115898E 02	0.105869E 02	0.390758E 01
940.0000	0.630852E 04	0.116198E 02	0.107110E 02	0.397906E 01
950.0000	0.642487E 04	0.116493E 02	0.108341E 02	0.405033E 01
960.0000	0.654150E 04	0.116784E 02	0.109562E 02	0.412139E 01
970.0000	0.665843E 04	0.117070E 02	0.110774E 02	0.419225E 01
980.0000	0.677563E 04	0.117351E 02	0.111976E 02	0.426289E 01
990.0000	0.689312E 04	0.117629E 02	0.113169E 02	0.433331E 01
1000.0000	0.701088E 04	0.117902E 02	0.114352E 02	0.440351E 01
1010.0000	0.712891E 04	0.118172E 02	0.115527E 02	0.447349E 01
1020.0000	0.724721E 04	0.118437E 02	0.116692E 02	0.454324E 01
1030.0000	0.736578E 04	0.118699E 02	0.117849E 02	0.461277E 01
1040.0000	0.748460E 04	0.118958E 02	0.118997E 02	0.468207E 01
1050.0000	0.760369E 04	0.119213E 02	0.120137E 02	0.475114E 01
1060.0000	0.772302E 04	0.119465E 02	0.121268E 02	0.481998E 01
1070.0000	0.784261E 04	0.119714E 02	0.122391E 02	0.488859E 01
1080.0000	0.796244E 04	0.119960E 02	0.123505E 02	0.495695E 01
1090.0000	0.808251E 04	0.120202E 02	0.124612E 02	0.502509E 01
1100.0000	0.820283E 04	0.120442E 02	0.125711E 02	0.509299E 01
1110.0000	0.832339E 04	0.120679E 02	0.126802E 02	0.516065E 01
1120.0000	0.844418E 04	0.120914E 02	0.127885E 02	0.522807E 01
1130.0000	0.856521E 04	0.121146E 02	0.128961E 02	0.529526E 01
1140.0000	0.868647E 04	0.121375E 02	0.130029E 02	0.536221E 01
1150.0000	0.880795E 04	0.121602E 02	0.131091E 02	0.542892E 01
1160.0000	0.892966E 04	0.121827E 02	0.132144E 02	0.549539E 01
1170.0000	0.905160E 04	0.122049E 02	0.133191E 02	0.556162E 01
1180.0000	0.917375E 04	0.122270E 02	0.134231E 02	0.562762E 01
1190.0000	0.929612E 04	0.122488E 02	0.135263E 02	0.569338E 01
1200.0000	0.941872E 04	0.122704E 02	0.136289E 02	0.575889E 01

* 0.405223E 04 = $0.405223 \cdot 10^4 = 4052.23$

Columns 5, 4, 1, 6, 7, and 8 would be printed on the first page with columns 13, 10, 11, 2, and 14 on the second page.

If the user had decided to print all 14 columns in the order in which they were computed, he would merely follow the "ØUT" instruction by a DEC 0.

It should be noted at this point that "page" as referred to above means a physical page only when there are 50 or less arguments. Since OMNIFORM I has provisions for 200 arguments, it will take up to four pages of 704-7090 printout to complete a "page".

The final output branch can be entered only once during any one complete run. That is, the final output branch indicates to the machine that the user is finished with his computation and is now ready to have the results processed and printed. This branch is entered via a BCD 1END000 instruction. Its primary function is to process all information which was placed in temporary storage on the magnetic tape by one or more "ØUT" statements.

Following the "END" instruction are headings for the columns of information to be printed. There must be one heading instruction for every "page" of printout. Headings begin at the extreme left side of the form and may be from one to six characters in length. Each column heading is separated by a comma. The only two characters restricted from use in headings are the comma and blank. A heading must also be provided for the argument.

To continue with the example previously used, the "END" instruction would be followed by X, COL5, COL4, COL1, COL6, COL7, COL8, COL13, COL10, COL11, COL2, COL14 or other headings suitable to the particular problem.

Since the program expects a heading instruction for each "page", a blank card will give a "page" without headings. It is clear that the order and distribution of headings must coincide with the instructions in the several ØUT statements. OMNIFORM is so written that when all of the results on tape have been printed, the machine is ready for another OMNIFORM run.

2.4 Print Format

As indicated above, the printout of OMNIFORM can be arranged for a variable number (1-7) of columns of entries plus one column of arguments. The present version provides six decimals in the fixed decimal mode and six significant figures in the floating point mode. In either case, however, the results are good to at most seven significant figures. The results are printed 50 rows to the page in 5 blocks of 10 numbers each with a single space separation between blocks (See Tables 2 and 3).

Since the printout is selective and can be rearranged at will, it is possible to repeat columns on succeeding pages for ease of interpolation or for other reasons. The program automatically prints the argument as the first column and repeats it on succeeding "pages". It is also possible to repeat the argument on the right side of the page. In order to accomplish this, it is necessary to generate the arguments in the Function Generator by asking for an identity calculation ($1 \cdot X^1$) and storing it in a blank column.

It will be observed that the printout in Table 2 is suitable for direct publication. Had some of the functions been of such size as to require a floating point mode, they could be arranged to appear on a second "page" by repeating the ØUT instruction with appropriate information. Thus, if in addition to the functions shown in Table 2, there were two other functions in the memory which required floating point, the print instructions would be as follows:

```
BCD 1ØUTD04
DEC 0
TRA 2,4
BCD 1ØUTF02
DEC 5,4
TRA 2,4
```

Figures 1 and 2 show the front and back respectively of a form which has been found useful in preparing the input instructions. The form is especially useful for beginners to insure proper order and form of the instructions. Later one may be able to dispense with its use and prepare data on a form as is shown in Table 4, or indeed, in a blank piece of paper.

Table 4. Sample Input for OMNIFORM I

```
PROBLEM
LOC         | OP  |   ADDRESS, TAG, DECREMENT                       COMMENTS
1         6 | 7 | 8   10 | 11 | 12

1^ØMNIFØRM^I^IDEAL^GAS^THERMØDYNAMIC^FUNCTIONS^FOR^H+
       DEC  3,0,0
       DEC  50.,50.,5000.
       TRA  2,4
       BCD  1GEN004
       DEC  1,3,1,0,0,1,2.5,0.
       DEC  2,1,1,0,1,1,-3.65354,0.
       DEC  3.,1,1,0,0,3.,2.5,0.
       DEC  4,1,1,0,1,1,-1.15354,0.
       TRA  2,4
       BCD  1ØUTD04
       DEC  2,3,4,3
       TRA  2,4
       BCD  1END000
TEMP.,F-E/RT,H-E/RT,S/R,C/R
```

```
1 OMNIFORM I IDEAL GAS THERMODYNAMIC FUNCTION FOR H+
      DEC 3,0,0
      DEC 50.,50.,5000.
      TRA 2,4
      BCD 1GEN004
      DEC 1.,3.,1.,0.,0.,1.,2.5,0.
      DEC 2.,1.,1.,0.,1.,1.,-3.65354,0.
      DEC 3.,1.,1.,0.,0.,3.,2.5,0.
      DEC 4.,1.,1.,0.,1.,1.,-1.15354,0.
      TRA 2,4
      BCD 1OUTD04
      DEC 2,3,4,3
      TRA 2,4
      BCD 1END000
TEMP.,F-E/RT,H-E/RT,S/R,C/R
```

3. PROPERTIES OF THE FUNCTION GENERATOR

3.1 Elementary Functions

The properties and limitations, if any, of the functions available in OMNIFORM I are discussed briefly in this section. Limitations result either from the mathematical properties of the functions or from the particular sub-routines which are used for their evaluation. Space does not permit a full discussion of the sub-routines used in OMNIFORM I. However, a brief review of the computational logic and the capabilities or limitations of the major sub-routines is important to insure proper use of the program and to establish confidence in the results.

OMNIFORM I is designed to substitute real numbers in a real function given explicitly in terms of a real independent variable. Thus operations leading to imaginary or complex numbers are ruled out as is also any iterative operation.

In functions of type 1 and indeed in many of the others, a provision is made for terms in arbitrary powers of the variable. No problem exists when the exponents b_j are integers, since the functions are then defined for all real values of X. Since OMNIFORM I performs calculations on real numbers only, care must be taken not to require X^{b_j} for negative values of the variable when b_j is nonintegral.

The program is written to examine the argument for its sign. When the argument is positive, X^b is evaluated through a logarithmic routine by evaluating the antilog of blogX. When the argument is found to be negative, only integral exponents are allowed, and results are obtained by successive multiplications. To avoid a program stop when a negative number is raised to a nonintegral exponent inadvertently, the program truncates the exponent for negative arguments, thereby ignoring anything to the right of the decimal point. Thus $(-2)^2$ is +4 and $(-2)^{2.3}$ is taken as +4. While the latter answer is obviously wrong, the user should be aware of such occurrences, and should arrange for a listing out of intermediate results if there is a chance that certain arguments or functions might give complex or imaginary values.

The logarithmic functions are obviously defined for positive non-zero numbers. When a logarithm of a negative number is called for, the result is automatically set equal to zero. Here again the user must exercise caution.

In the trigonometric functions, the angle X is considered to be given in radians. If evaluation is desired for angles in degrees, it is possible to use the transformation feature in functions 5, 7, and 9, or by setting the coefficient $c_j = 57.29577$ in functions 6, 8 and 10. In all of the trigonometric functions, the transformation provision applies only to the variable inside the bracket and not to the factor X^{c_j} or X^{b_j} in front. The program gives the proper sign to the functions. Obviously the tangent function is undefined for angles of $-\pi/2$ and $+\pi/2$.

The inverse trigonometric functions provide the principal values - - in the case of the arc sin from 0 to $\pm\pi/2$, and from $-\pi/2$ to $+\pi/2$ for the arc tangent. It will be observed that by putting $a_j = 0$ in functions 14 and 15 gives arc sin and arc tan, respectively. If, however, $a_j = 1$ and $b_j = -1$, these functions yield arc cos and arc cot, respectively, since arc cos $\theta = \pi/2$ - arc cos θ and arc cot $\theta = \pi/2$ - arc tan θ.

3.2 Special Functions

Among the special functions incorporated in OMNIFORM I are:

the Chebyshev polynomials[1]

$$T_n(x) = \cos (n \cos^{-1} x)$$
$$U_n(x) = [T'_{n+1}(x)]/n + 1, \quad \text{(for } -1 \leq x \leq 1 \text{ and } n = 0, 1, 2, 3, \ldots)$$

the Legendre polynomials[2]

$$P_n(x) = \frac{1}{2^n \, n!} \frac{d^n}{dx^n} [x^2 - 1]^n,$$

the Laguerre polynomials[3]

$$L_n(x) = e^x \frac{d^n}{dx^n} [x^n e^{-x}],$$

the Hermite polynomials[4]

$$H_n(x) = (-1)^n e^{x^2} \frac{d^n}{dx^n} (e^{-x^2}).$$

The above listed special functions are computed from initial values and the recursion formulas given in Table 5. The subroutines for the calculation of these functions were written especially for OMNIFORM I and have been described in the Communications of the Association for Computing Machinery.[5]

---

1. Anonymous. "Tables of Chebyshev Polynomials Sn(x) and Cn(x)", National Bureau of Standards, Applied Mathematics Series 9. Government Printing Office, Washington, D. C. (1952).

2. Kopal, Z. "Numerical Analysis", p. 368, John Wiley and Sons, New York (1955).

3. ibid, p. 370.

4. ibid, p. 371.

5. Gerald M. Galler, Communications ACM, 3, 353 (1960).

Table 5. Initial Values and Recursion Formulas

for Certain Special Functions

Symbol	n = 0	n = 1	n = 2	n = 3	Recursion Formula
$T_n(x)$	1	x	$2x^2-1$	$4x^3-3x$	$T_{n+1}(x) = 2xT_n(x)-T_{n-1}(x)$
$U_n(x)$	1	$2x$	$4x^2-1$	$8x^3-4x$	$U_{n+1}(x) = 2xU_n(x)-U_{n-1}(x)$
$P_n(x)$	1	x	$\frac{3}{2}x^2-\frac{1}{2}$	$\frac{5}{2}x^3-\frac{3}{2}x$	$P_{n+1}(x) = xP_n(x)+\frac{n}{n+1}[xP_n(x) -P_{n-1}(x)]$
$H_n(x)$	1	$2x$	$4x^2-2$	$8x^3-12x$	$H_{n+1}(x) = 2xH_n(x)-2nH_{n-1}(x)$
$L_n(x)$	1	$-x+1$	x^2-4x+2	$-x^3+9x^2-18x+6$	$L_{n+1}(x) = (1+2n-x)L_n(x) -n^2L_{n-1}(x)$

Other special functions include:

the error function

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt,$$

and the gamma function

$$\Gamma(n) = \int_0^\infty x^{n-1} e^{-x} dx \text{ (for } n > 0).$$

It should be observed that for positive integers

$$\Gamma(n) = (n - 1)!$$

and that this function can, therefore, be used to generate factorials of positive integers. It should be noted that the gamma function is infinite for negative integers.

3.3 Column Sums

The program automatically sums each column in the memory and prints this sum automatically as an additional line of output. The column sums are not shown in the sample outputs since they appeared on the following page when more than 50 lines are printed.

4. ACKNOWLEDGMENTS

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Problem | OMNIFORM I | Sponsor | Date

1–6	7	8–10	11	12 … 72
1ΔØMNIFØRMΔ1Δ				
		DEC		, ,
		DEC		
		DEC		
		DEC		
		DEC		
		TRA		2, 4
				Insert data from page
		TRA		2, 4
		BCD		1GENO. .
				k , a , n , t , Ω , c ,
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		, , , , , ,
		DEC		
		DEC		
		TRA		2, 4
		BCD		1ØUT O .
		DEC		
		TRA		2, 4
		BCD		1ENDOOO

Figure 1. OMNIFORM I Input Form (Front)

O M N I F O R M I

1 6	7	8 10	11	12 72
		BCD		1GENO . .
		DEC		
		DEC		
		DEC		
		DEC		
		DEC		
		DEC		
		DEC		
		DEC		
		DEC		
		DEC		

OMNIFORM I: FUNCTION GENERATOR

$$f_1^n = \sum_{j=1}^{n} a_j X^{b_j}$$

$$f_2^n = \sum_{j=1}^{n} a_j X^{b_j} \log X$$

$$f_3^n = \sum_{j=1}^{n} a_j X^{b_j} \ln x$$

$$f_4^n = \sum_{j=1}^{n} a_j X^{b_j} \exp \left[c_j X^{d_j} \right]$$

$$f_5^n = \sum_{j=1}^{n} (a_j/b_j) X^{c_j} \left[\sin X \right]^{d_j}$$

$$f_6^n = \sum_{j=1}^{n} a_j X^{b_j} \left[\sin c_j X \right]^{d_j}$$

$$f_7^n = \sum_{j=1}^{n} (a_j/b_j) X^{c_j} \left[\cos X \right]^{d_j}$$

$$f_8^n = \sum_{j=1}^{n} a_j X^{b_j} \left[\cos c_j X \right]^{d_j}$$

$$f_9^n = \sum_{j=1}^{n} (a_j/b_j) X^{c_j} \left[\tan X \right]^{d_j}$$

$$f_{10}^n = \sum_{j=1}^{n} a_j X^{b_j} \left[\tan c_j X \right]^{d_i}$$

$$f_{11}^n = \sum_{j=1}^{n} a_j \left[\sinh X \right]^{b_j}$$

$$f_{12}^n = \sum_{j=1}^{n} a_j \left[\cosh X \right]^{b_j}$$

$$f_{13}^n = \sum_{j=1}^{n} a_j \left[\tanh X \right]^{b_j}$$

$$f_{14}^n = \sum_{j=1}^{n} a_j \pi/2 + b_j \text{ arc sin } X$$

$$f_{15}^n = \sum_{j=1}^{n} a_j \pi/2 + b_j \text{ arc tan } X$$

$$f_{16}^n = \sum_{j=1}^{n} a_j T_{n_j}(X) \quad \text{Chebyshev}$$

$$f_{17}^n = \sum_{j=1}^{n} a_j U_{nj}(X) \quad \text{Chebyshev}$$

$$f_{18}^n = \sum_{j=1}^{n} a_j P_{n_j}(X) \quad \text{Legendre}$$

$$f_{19}^n = \sum_{j=1}^{n} a_j L_{n_j}(X) \quad \text{Laguerre}$$

$$f_{20}^n = \sum_{j=1}^{n} a_j H_{n_j}(X) \quad \text{Hermite}$$

$$f_{21}^n = \sum_{j=1}^{n} a_j \Gamma(b_j) \left[\Gamma(c_j X) \right]^{d_j} \quad \text{Gamma}$$

$$f_{22}^n = \sum_{j=1}^{n} a_j \operatorname{erf}(X) \quad \text{Error}$$

OMNIFORM I

Operator Equation

$$F_k(X_i) = G_k(X_i) + f_\alpha^n \left[\Phi_t(X_i) \right] \Omega \, H_c(X_i)$$

USCOMM-NBS-DC

Figure 2 OMNIFORM I Input Form (Back)

Problem 1. Prepare a table of values V = 1226.877/0.001316PF for values of F supplied in a one column table corresponding to 33 values of pressure P (given in millimeters of mercury), which are taken as the arguments.

```
1 OMNIFORM 1 SPECIFIC VOL. SB 26
a.   DEC 33,1,1
b. { DEC 50.75,66.5,74.4,79.2,91.8,98.2,101.8
     DEC 109.8,114.55,117.9,125.05,132.75,144.2
     DEC 153.3,162.7,172.2,175.8,185.,190.7,207.
     DEC 230.4,244.05,257.1,275.3,305.15,330.5
     DEC 350.4,399.25,421.35,455.1,474.05,498.55,522.3
     TRA 2,4
c. { DEC 1.008
     DEC 1.011
     DEC 1.012
     DEC 1.013
     DEC 1.015
     DEC 1.017
     DEC 1.017
     DEC 1.019
     DEC 1.02
     DEC 1.02
     DEC 1.022
     DEC 1.023
     DEC 1.027
     DEC 1.028
     DEC 1.032
     DEC 1.034
     DEC 1.037
     DEC 1.04
     DEC 1.043
     DEC 1.049
c (cont.) { DEC 1.064
     DEC 1.074
     DEC 1.086
     DEC 1.104
     DEC 1.146
     DEC 1.18
     DEC 1.223
     DEC 1.356
     DEC 1.431
     DEC 1.54
     DEC 1.619
     DEC 1.718
     DEC 1.832
     BCD 1GEN002
d -> DEC 2.,1.,1.,0.,0.,2.,.001316,1.
e -> DEC 3.,1.,1.,0.,0.,3.,1226.877,0.
     TRA 2,4
f -> BCD 1GEN002
g -> DEC 4.,1.,1.,1.,3.,2.,1.,1.
h -> DEC 5.,1.,1.,4.,4.,3.,1.,1.
     TRA 2,4
i -> BCD 1OUTD03
j -> DEC 1,2,5
     TRA 2,4
k -> BCD 1END000
P*MM*,F,P*ATM*,V
```

Remarks

Card a. indicates that there are 33 numbers in the argument instructions following, that a one column table will be read in, and that the 33 numbers are to be taken as written for the arguments.

Cards b. list the arguments for which the calculations are to be made.

Cards c. comprise the table of F values read in corresponding to the 33 pressures P which comprise the arguments.

Card d. computes 0.001316P which converts the pressures to atmospheres.

Card e. simply sets up a constant, 1226.877 in column 3.

Card f. instructs the machine to reenter the function generator. Now the transformation parameter (the fourth number in each line of instruction) denotes the column which replaces the variable.

Card g. multiplies column 1 by column 2 and stores in column 4 (PF).

Card h. divides column 4 into column 3 and stores in column 5 (1226.877/PF).

Card i. asks for a dumps out of 3 columns in fixed decimal form.

Card j. asks for columns 1, 2, and 5 to be printed.

Card k. indicates the end of the computation at which point the machine is ready for the headings and the final printout.

Card l. provides the column headings for the results.

Note that four headings are supplied, the first being for the argument column.

Problem 1 (Results)

OMNIFORM 1 SPECIFIC VOL. SB 26

P*MM*	F	P*ATM*	V
50.7500	1.008000	0.066787	18224.204102
66.5000	1.011000	0.087514	13866.676392
74.4000	1.012000	0.097910	12382.025879
79.2000	1.013000	0.104227	11620.118164
91.8000	1.015000	0.120809	10005.446289
98.2000	1.017000	0.129231	9334.965942
101.8000	1.017000	0.133969	9004.849121
109.8000	1.019000	0.144497	8332.372681
114.5500	1.020000	0.150748	7979.027344
117.9000	1.020000	0.155156	7752.312012
125.0500	1.022000	0.164566	7294.752808
132.7500	1.023000	0.174699	6864.912537
144.2000	1.027000	0.189767	6295.198914
153.3000	1.028000	0.201743	5915.751282
162.7000	1.032000	0.214113	5552.364075
172.2000	1.034000	0.226615	5235.902100
175.8000	1.037000	0.231353	5113.844910
185.0000	1.040000	0.243460	4845.517029
190.7000	1.043000	0.250961	4687.164551
207.0000	1.049000	0.272412	4293.380127
230.4000	1.064000	0.303206	3802.954102
244.0500	1.074000	0.321170	3556.821716
257.1000	1.086000	0.338344	3338.975555
275.3000	1.104000	0.362295	3067.396057
305.1500	1.146000	0.401577	2665.920471
330.5000	1.180000	0.434938	2390.516327
350.4000	1.223000	0.461126	2175.477570
399.2500	1.356000	0.525413	1722.029541
421.3500	1.431000	0.554497	1546.188858
455.1000	1.540000	0.598911	1330.202194
474.0500	1.619000	0.623850	1214.714447
498.5500	1.718000	0.656092	1088.462128
522.3000	1.832000	0.687347	974.315727

Problem 2. Prepare a table of the form

$$n \quad \frac{1}{\sqrt{n}} \quad \frac{1}{\sqrt{n(n-1)}} \quad \frac{.6745}{\sqrt{(n-1)}} \quad \frac{.6745}{\sqrt{n(n-1)}} \quad \frac{.8453}{n\sqrt{n-1}} \quad \frac{.8453}{\sqrt{n(n-1)}}$$

for integral values of X = 1(1)100.

Omniform Instructions

```
1 OMNIFORM I FACTORS FOR PROBABLE ERROR CALC.
    a.  DEC 3,0,0
    b.  DEC 1.,1.,100.
    c.  DEC 1.,1.,-1.
        TRA 2,4
        BCD 1GEN007
        DEC 1.,1.,1.,0.,0.,1.,1.,-0.5
        DEC 2.,1.,1.,1.,0.,2.,0.6745,-0.5
  d.    DEC 3.,1.,1.,1.,3.,1.,1.,-0.5
        DEC 4.,1.,1.,0.,3.,2.,1.,-0.5
        DEC 5.,1.,1.,1.,0.,5.,0.8453,-0.5
        DEC 6.,1.,1.,0.,3.,5.,1.,-1.
        DEC 7.,1.,1.,0.,3.,5.,1.,-0.5
        TRA 2,4
        BCD 1OUTD06
        DEC 1,3,2,4,6,7
        TRA 2,4
        BCD 1END000
X,1,2,3,4,5,6
```

Remarks

a. This line indicates that there are 3 numbers on the following card defining the arguments; that zero columns are being read in; and that the arguments are given in the incremented mode.

b. This line sets up the arguments 1 to 100 in steps of unity.

c. This line sets up the transformation (n-1).

d. Line 1 computes $1/\sqrt{n}$.

Line 2 computes $.6745/\sqrt{(n-1)}$.

Line 3 computes $1/\sqrt{(n-1)}$ and multiplies it by $1/\sqrt{n}$ yielding $\frac{1}{\sqrt{n}\sqrt{n-1}}$.

Line 4 computes $1/\sqrt{n}$ and multiplies it by $.6745/\sqrt{(n-1)}$

Line 5 computes $.8453/\sqrt{(n-1)}$

Line 6 computes $1/n$ and multiplies it by $.8453/\sqrt{(n-1)}$

Line 7 computes $1/\sqrt{n}$ and multiplies it by $.8453/\sqrt{(n-1)}$

Problem 2 (Results)

OMNIFORM I FACTORS FOR PROBABLE ERROR CALC.

X	1	2	3	4	5	6
* 1.0000	1.00000034217727.00000090529856.00000090529856.00000013454243.00000013454244.000000					
2.0000	0.707107	0.707107	0.674500	0.476944	0.422650	0.597717
3.0000	0.577350	0.408248	0.476944	0.275363	0.199239	0.345092
4.0000	0.500000	0.288675	0.389423	0.194711	0.122009	0.244017
5.0000	0.447214	0.223607	0.337250	0.150823	0.084530	0.189015
6.0000	0.408248	0.182574	0.301646	0.123146	0.063005	0.154330
7.0000	0.377964	0.154303	0.275363	0.104078	0.049299	0.130433
8.0000	0.353553	0.133631	0.254937	0.090134	0.039937	0.112958
9.0000	0.333333	0.117851	0.238472	0.079491	0.033207	0.099620
10.0000	0.316228	0.105409	0.224833	0.071099	0.028177	0.089102
11.0000	0.301511	0.095346	0.213296	0.064311	0.024301	0.080596
12.0000	0.288675	0.087039	0.203369	0.058708	0.021239	0.073574
13.0000	0.277350	0.080064	0.194711	0.054003	0.018771	0.067678
14.0000	0.267261	0.074125	0.187073	0.049997	0.016746	0.062658
15.0000	0.258199	0.069007	0.180268	0.046545	0.015061	0.058331
16.0000	0.250000	0.064550	0.174155	0.043539	0.013641	0.054564
17.0000	0.242536	0.060634	0.168625	0.040898	0.012431	0.051254
18.0000	0.235702	0.057166	0.163590	0.038559	0.011390	0.048323
19.0000	0.229416	0.054074	0.158981	0.036473	0.010486	0.045709
20.0000	0.223607	0.051299	0.154741	0.034601	0.009696	0.043363
21.0000	0.218218	0.048795	0.150823	0.032912	0.009001	0.041246
22.0000	0.213201	0.046524	0.147188	0.031381	0.008385	0.039327
23.0000	0.208514	0.044455	0.143804	0.029985	0.007836	0.037578
24.0000	0.204124	0.042563	0.140643	0.028709	0.007344	0.035978
25.0000	0.200000	0.040825	0.137682	0.027536	0.006902	0.034509
26.0000	0.196116	0.039223	0.134900	0.026456	0.006502	0.033155
27.0000	0.192450	0.037743	0.132280	0.025457	0.006140	0.031904
28.0000	0.188982	0.036370	0.129808	0.024531	0.005810	0.030743
29.0000	0.185695	0.035093	0.127469	0.023670	0.005509	0.029664
30.0000	0.182574	0.033903	0.125252	0.022868	0.005232	0.028658
31.0000	0.179605	0.032791	0.123146	0.022118	0.004978	0.027718
32.0000	0.176777	0.031750	0.121144	0.021415	0.004744	0.026838
33.0000	0.174078	0.030773	0.119236	0.020756	0.004528	0.026012
34.0000	0.171499	0.029854	0.117415	0.020137	0.004328	0.025236
35.0000	0.169031	0.028989	0.115676	0.019553	0.004142	0.024504
36.0000	0.166667	0.028172	0.114011	0.019002	0.003969	0.023814
37.0000	0.164399	0.027400	0.112417	0.018481	0.003808	0.023161
38.0000	0.162221	0.026669	0.110887	0.017988	0.003657	0.022543
39.0000	0.160128	0.025976	0.109418	0.017521	0.003516	0.021958
40.0000	0.158114	0.025318	0.108006	0.017077	0.003384	0.021402
41.0000	0.156174	0.024693	0.106648	0.016656	0.003260	0.020873
42.0000	0.154303	0.024098	0.105339	0.016254	0.003143	0.020370
43.0000	0.152499	0.023531	0.104078	0.015872	0.003033	0.019891
44.0000	0.150756	0.022990	0.102860	0.015507	0.002930	0.019433
45.0000	0.149071	0.022473	0.101685	0.015158	0.002832	0.018997
46.0000	0.147442	0.021979	0.100549	0.014825	0.002739	0.018579
47.0000	0.145865	0.021507	0.099450	0.014506	0.002652	0.018180
48.0000	0.144338	0.021054	0.098386	0.014201	0.002569	0.017797
49.0000	0.142857	0.020620	0.097356	0.013908	0.002490	0.017430
50.0000	0.141421	0.020203	0.096357	0.013627	0.002415	0.017078

* This line is the result of trying to divide by zero.

Problem 3. Prepare a table of the form

$$X \quad X^2 \quad \sqrt{X} \quad \sqrt{10X} \quad X^3 \quad \sqrt[3]{X} \quad \sqrt[3]{10X} \quad \sqrt[3]{100X}$$

for integral values of X = 1(1)200.

Omniform Instructions

```
1 OMNIFORM I SQUARES,CUBES,AND ROOTS
       DEC 3,0,0
    a. DEC 1.,1.,200.
    b. DEC 10.,1.,0.,100.,1.,0.
       TRA 2,4
       BCD 1GEN008
       DEC 1.,1.,1.,0.,0.,1.,1.,1.
       DEC 2.,1.,1.,0.,3.,1.,1.,1.
       DEC 3.,1.,1.,0.,3.,2.,1.,1.
       DEC 4.,1.,1.,0.,0.,4.,1.,0.5
  c.   DEC 5.,1.,1.,1.,0.,5.,1.,0.5
       DEC 6.,1.,1.,0.,0.,6.,1.,0.3333333
       DEC 7.,1.,1.,1.,0.,7.,1.,0.3333333
       DEC 8.,1.,1.,2.,0.,8.,1.,0.3333333
       TRA 2,4
    d. BCD 1OUTF07
       DEC 2,4,5,3,6,7,8
       TRA 2,4
       BCD 1END000
N,2,1/2,1/2,3,1/3,1/3,1/3
```

Remarks

a. This line sets up the arguments 1. to 200. in unit steps.

b. This line provides for two transformations 10X and 100X.

c. Line 1 simply computes f(X) = X and stores it in column 1.

Line 2 also computes f(X) = X but multiplies it by the value in column 1 (yielding X^2) and stores it in column 2.

Line 3 similarly computes X^3 and stores it in column 3.

Line 4 computes $\sqrt{X}$ and stores it in column 4.

Line 5 computes $\sqrt{10X}$ and stores it in column 5.

Line 6 computes $\sqrt[3]{X}$ and stores it in column 6.

Line 7 computes $\sqrt[3]{10X}$ and stores it in column 7.

Line 8 computes $\sqrt[3]{100X}$ and stores it in column 8.

d. This line asks for a floating point print out, seven columns to the page.

Problem 3 (Results)

OMNIFORM I SQUARES,CUBES,AND ROOTS

N	2	1/2	1/2	3	1/3	1/3	1/3
1.0000	0.100000E 01	0.100000E 01	0.316228E 01	0.100000E 01	0.100000E 01	0.215443E 01	0.464159E 01
2.0000	0.400000E 01	0.141421E 01	0.447214E 01	0.800000E 01	0.125992E 01	0.271442E 01	0.584803E 01
3.0000	0.900000E 01	0.173205E 01	0.547723E 01	0.270000E 02	0.144225E 01	0.310723E 01	0.669433E 01
4.0000	0.160000E 02	0.200000E 01	0.632456E 01	0.640000E 02	0.158740E 01	0.341995E 01	0.736806E 01
5.0000	0.250000E 02	0.223607E 01	0.707107E 01	0.125000E 03	0.170998E 01	0.368403E 01	0.793700E 01
6.0000	0.360000E 02	0.244949E 01	0.774597E 01	0.216000E 03	0.181712E 01	0.391487E 01	0.843432E 01
7.0000	0.490000E 02	0.264575E 01	0.836660E 01	0.343000E 03	0.191293E 01	0.412128E 01	0.887904E 01
8.0000	0.640000E 02	0.282843E 01	0.894427E 01	0.512000E 03	0.200000E 01	0.430887E 01	0.928317E 01
9.0000	0.810000E 02	0.300000E 01	0.948683E 01	0.729000E 03	0.208008E 01	0.448140E 01	0.965489E 01
10.0000	1.000000E 02	0.316228E 01	1.000000E 01	1.000000E 03	0.215443E 01	0.464159E 01	1.000000E 01
11.0000	0.121000E 03	0.331662E 01	0.104881E 02	0.133100E 04	0.222398E 01	0.479142E 01	0.103228E 02
12.0000	0.144000E 03	0.346410E 01	0.109545E 02	0.172800E 04	0.228943E 01	0.493242E 01	0.106266E 02
13.0000	0.169000E 03	0.360555E 01	0.114018E 02	0.219700E 04	0.235133E 01	0.506580E 01	0.109139E 02
14.0000	0.196000E 03	0.374166E 01	0.118322E 02	0.274400E 04	0.241014E 01	0.519249E 01	0.111869E 02
15.0000	0.225000E 03	0.387298E 01	0.122474E 02	0.337500E 04	0.246621E 01	0.531329E 01	0.114471E 02
16.0000	0.256000E 03	0.400000E 01	0.126491E 02	0.409600E 04	0.251984E 01	0.542883E 01	0.116961E 02
17.0000	0.289000E 03	0.412311E 01	0.130384E 02	0.491300E 04	0.257128E 01	0.553966E 01	0.119348E 02
18.0000	0.324000E 03	0.424264E 01	0.134164E 02	0.583200E 04	0.262074E 01	0.564621E 01	0.121644E 02
19.0000	0.361000E 03	0.435890E 01	0.137840E 02	0.685900E 04	0.266840E 01	0.574890E 01	0.123856E 02
20.0000	0.400000E 03	0.447214E 01	0.141421E 02	0.800000E 04	0.271442E 01	0.584803E 01	0.125992E 02
21.0000	0.441000E 03	0.458258E 01	0.144914E 02	0.926100E 04	0.275892E 01	0.594392E 01	0.128058E 02
22.0000	0.484000E 03	0.469042E 01	0.148324E 02	0.106480E 05	0.280204E 01	0.603681E 01	0.130059E 02
23.0000	0.529000E 03	0.479583E 01	0.151657E 02	0.121670E 05	0.284387E 01	0.612692E 01	0.132001E 02
24.0000	0.576000E 03	0.489898E 01	0.154919E 02	0.138240E 05	0.288450E 01	0.621446E 01	0.133887E 02
25.0000	0.625000E 03	0.500000E 01	0.158114E 02	0.156250E 05	0.292402E 01	0.629960E 01	0.135721E 02
26.0000	0.676000E 03	0.509902E 01	0.161245E 02	0.175760E 05	0.296250E 01	0.638250E 01	0.137507E 02
27.0000	0.729000E 03	0.519615E 01	0.164317E 02	0.196830E 05	0.300000E 01	0.646330E 01	0.139248E 02
28.0000	0.784000E 03	0.529150E 01	0.167332E 02	0.219520E 05	0.303659E 01	0.654213E 01	0.140946E 02
29.0000	0.841000E 03	0.538516E 01	0.170294E 02	0.243890E 05	0.307232E 01	0.661910E 01	0.142604E 02
30.0000	0.900000E 03	0.547723E 01	0.173205E 02	0.270000E 05	0.310723E 01	0.669433E 01	0.144225E 02
31.0000	0.961000E 03	0.556776E 01	0.176068E 02	0.297910E 05	0.314138E 01	0.676790E 01	0.145810E 02
32.0000	0.102400E 04	0.565685E 01	0.178885E 02	0.327680E 05	0.317480E 01	0.683990E 01	0.147361E 02
33.0000	0.108900E 04	0.574456E 01	0.181659E 02	0.359370E 05	0.320753E 01	0.691042E 01	0.148880E 02
34.0000	0.115600E 04	0.583095E 01	0.184391E 02	0.393040E 05	0.323961E 01	0.697953E 01	0.150369E 02
35.0000	0.122500E 04	0.591608E 01	0.187083E 02	0.428750E 05	0.327107E 01	0.704730E 01	0.151829E 02
36.0000	0.129600E 04	0.600000E 01	0.189737E 02	0.466560E 05	0.330193E 01	0.711378E 01	0.153262E 02
37.0000	0.136900E 04	0.608276E 01	0.192354E 02	0.506530E 05	0.333222E 01	0.717905E 01	0.154668E 02
38.0000	0.144400E 04	0.616441E 01	0.194936E 02	0.548720E 05	0.336197E 01	0.724315E 01	0.156049E 02
39.0000	0.152100E 04	0.624500E 01	0.197484E 02	0.593190E 05	0.339121E 01	0.730614E 01	0.157406E 02
40.0000	0.160000E 04	0.632456E 01	0.200000E 02	0.640000E 05	0.341995E 01	0.736806E 01	0.158740E 02
41.0000	0.168100E 04	0.640312E 01	0.202485E 02	0.689210E 05	0.344822E 01	0.742896E 01	0.160052E 02
42.0000	0.176400E 04	0.648074E 01	0.204939E 02	0.740880E 05	0.347603E 01	0.748887E 01	0.161343E 02
43.0000	0.184900E 04	0.655744E 01	0.207364E 02	0.795070E 05	0.350340E 01	0.754784E 01	0.162613E 02
44.0000	0.193600E 04	0.663325E 01	0.209762E 02	0.851840E 05	0.353035E 01	0.760590E 01	0.163864E 02
45.0000	0.202500E 04	0.670820E 01	0.212132E 02	0.911250E 05	0.355689E 01	0.766309E 01	0.165096E 02
46.0000	0.211600E 04	0.678233E 01	0.214476E 02	0.973360E 05	0.358305E 01	0.771944E 01	0.166310E 02
47.0000	0.220900E 04	0.685565E 01	0.216795E 02	0.103823E 06	0.360883E 01	0.777498E 01	0.167507E 02
48.0000	0.230400E 04	0.692820E 01	0.219089E 02	0.110592E 06	0.363424E 01	0.782973E 01	0.168686E 02
49.0000	0.240100E 04	0.700000E 01	0.221359E 02	0.117649E 06	0.365931E 01	0.788373E 01	0.169850E 02
50.0000	0.250000E 04	0.707107E 01	0.223607E 02	0.125000E 06	0.368403E 01	0.793700E 01	0.170998E 02

Problem 4. Compute the function

$$\frac{N + (.001)k}{1.98726}$$

for N = 0.01(.01)1.0; k = 0, 1, 2, . . . 9, and print results in cols 1 through 10.

Omniform Instructions

```
1 OMNIFORM I CONVERSION TABLE FOR N/1.98726
        DEC 3,0,0
   a.   DEC 0.01,0.01,1.0
   b. { DEC 1.,1.,.001,1.,1.,.002,1.,1.,.003,1.,1.,.004,1.,1.,.005
        DEC 1.,1.,.006,1.,1.,.007,1.,1.,.008,1.,1.,.009
        TRA 2,4
        BCD 1GEN010
      { DEC 1.,1.,1.,0.,0.,1.,0.50320542,1.
        DEC 2.,1.,1.,1.,0.,1.,0.50320542,1.
        DEC 3.,1.,1.,2.,0.,1.,0.50320542,1.
   c.   DEC 4.,1.,1.,3.,0.,1.,0.50320542,1.
        DEC 5.,1.,1.,4.,0.,1.,0.50320542,1.
        DEC 6.,1.,1.,5.,0.,1.,0.50320542,1.
        DEC 7.,1.,1.,6.,0.,1.,0.50320542,1.
        DEC 8.,1.,1.,7.,0.,1.,0.50320542,1.
        DEC 9.,1.,1.,8.,0.,1.,0.50320542,1.
        DEC 10.,1.,1.,9.,0.,1.,0.50320542,1.
        TRA 2,4
        BCD 1OUTD05.
   d. → DEC 0
        TRA 2,4
        BCD 1END000
e. { N,0,.001,.002,.003,.004
     N,.005,.006,.007,.008,.009
```

Remarks

a. This line sets up the argument from .01 in intervals of .01 to 1.0

b. These lines set up the transformations N + .001, N + .002, . . N + .009.

c. Lines 1 through 10 compute N/1.98726 = .50320542N for the values of N indicated in line a, and for each of the 9 transformations specified in b.

d. This line asks for a printout of the columns in the order in which they were computed.

e. These are the column headings for the 2 pages of printout.

It will be noted on the reverse that the conversion table has been computed for 1,000 values of N and arranged in a rectangular array as is usual in logarithmic tables.

Problem 4 (Results)

OMNIFORM I CONVERSION TABLE FOR N/1.98726

N	0	.001	.002	.003	.004
0.0100	0.005032	0.005535	0.006038	0.006542	0.007045
0.0200	0.010064	0.010567	0.011071	0.011574	0.012077
0.0300	0.015096	0.015599	0.016103	0.016606	0.017109
0.0400	0.020128	0.020631	0.021135	0.021638	0.022141
0.0500	0.025160	0.025663	0.026167	0.026670	0.027173
0.0600	0.030192	0.030696	0.031199	0.031702	0.032205
0.0700	0.035224	0.035728	0.036231	0.036734	0.037237
0.0800	0.040256	0.040760	0.041263	0.041766	0.042269
0.0900	0.045288	0.045792	0.046295	0.046798	0.047301
0.1000	0.050321	0.050824	0.051327	0.051830	0.052333
0.1100	0.055353	0.055856	0.056359	0.056862	0.057365
0.1200	0.060385	0.060888	0.061391	0.061894	0.062397
0.1300	0.065417	0.065920	0.066423	0.066926	0.067430
0.1400	0.070449	0.070952	0.071455	0.071958	0.072462
0.1500	0.075481	0.075984	0.076487	0.076990	0.077494
0.1600	0.080513	0.081016	0.081519	0.082022	0.082526
0.1700	0.085545	0.086048	0.086551	0.087055	0.087558
0.1800	0.090577	0.091080	0.091583	0.092087	0.092590
0.1900	0.095609	0.096112	0.096615	0.097119	0.097622
0.2000	0.100641	0.101144	0.101647	0.102151	0.102654
0.2100	0.105673	0.106176	0.106680	0.107183	0.107686
0.2200	0.110705	0.111208	0.111712	0.112215	0.112718
0.2300	0.115737	0.116240	0.116744	0.117247	0.117750
0.2400	0.120769	0.121273	0.121776	0.122279	0.122782
0.2500	0.125801	0.126305	0.126808	0.127311	0.127814
0.2600	0.130833	0.131337	0.131840	0.132343	0.132846
0.2700	[illegible]135865	0.136369	0.136872	0.137375	0.13787[illegible]
[illegible]	[illegible]	[illegible]	0.14[illegible]	0.14[illegible]	0.1[illegible]

N	.005	.006	.007	.008	.009
0.0100	0.007548	0.008051	0.008554	0.009058	0.009561
0.0200	0.012580	0.013083	0.013587	0.014090	0.014593
0.0300	0.017612	0.018115	0.018619	0.019122	0.019625
0.0400	0.022644	0.023147	0.023651	0.024154	0.024657
0.0500	0.027676	0.028179	0.028683	0.029186	0.029689
0.0600	0.032708	0.033212	0.033715	0.034218	0.034721
0.0700	0.037740	0.038244	0.038747	0.039250	0.039753
0.0800	0.042772	0.043276	0.043779	0.044282	0.044785
0.0900	0.047805	0.048308	0.048811	0.049314	0.049817
0.1000	0.052837	0.053340	0.053843	0.054346	0.054849
0.1100	0.057869	0.058372	0.058875	0.059378	0.059881
0.1200	0.062901	0.063404	0.063907	0.064410	0.064913
0.1300	0.067933	0.068436	0.068939	0.069442	0.069946
0.1400	0.072965	0.073468	0.073971	0.074474	0.074978
0.1500	0.077997	0.078500	0.079003	0.079506	0.080010
0.1600	0.083029	0.083532	0.084035	0.084539	0.085042
0.1700	0.088061	0.088564	0.089067	0.089571	0.090074
0.1800	0.093093	0.093596	0.094099	0.094603	0.095106
0.1900	0.098125	0.098628	0.099131	0.099635	0.100138
0.2000	0.103157	0.103660	0.104164	0.104667	0.105170
0.2100		0.108692	0		
0.2200		113724			

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulalation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. Microwave Circuit Standards. Electronic Calibration Center.

NBS