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A COMPUTERIZED DATA BASE OF THE FUNDAMENTAL CONSTANTS OF NATURE

E. A. Henry and V. E. Hampel

December 3, 1975

MASTER

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Contents

Abstract	1
Introduction	1
Fundamental Constants Data Base	2
Availability	4
Conclusion	4
References	5
Appendix	7

A COMPUTERIZED DATA BASE OF THE FUNDAMENTAL CONSTANTS OF NATURE

Abstract

We have computerized 57 fundamental constants of nature from the up-to-date evaluations of E. R. Cohen and B. N. Taylor. The constants are annotated with regard to symbol, value, uncertainty, and scaling factor. This computerization is part of the scientific data base project of the Information Research Group at Lawrence Livermore Laboratory. The MASTER CONTROL data base management system is used. The computerized

fundamental constants can be requested from the ERDA Computer Program Exchange and Information Center of the Argonne National Laboratory or from the National Technical Information Service of the U.S. Department of Commerce. This is the first of a series of releases on preparation of computerized scientific and technological data banks. The next release is a data bank of conversion factors for different units of measurements.

Introduction

The mandate of the U.S. Energy Research & Development Administration¹ focuses the attention of the scientific community and the public on the energy problems of our nation. These energy issues manifest themselves in fuel shortages, rising prices, concern for the environment, and health problems resulting from human exposure to toxic chemicals and radiation. The scientific and technical community is faced with the challenge of solving these large-

scale, interdisciplinary problems in a relatively short time.

The Lawrence Livermore Laboratory is conducting basic and applied research in vital related programs such as nuclear energy,² controlled thermonuclear fusion,³ solar⁴ and geothermal⁵ energy conversion, national resource assessment,⁶ environmental⁷ and biological⁸ research, and laser-induced fusion.⁹ These complex research programs are probing the frontiers of science and

technology. They depend on interdisciplinary collaboration and powerful computers.

One necessary aspect for the solution of any one of these problems is the use of computers for data acquisition and analysis, modeling, computer-assisted prediction, pattern recognition, and the computerized management of large, diverse data bases. Of these, the one technique probably least familiar to scientists in general is the effective use of computerized scientific and technological data.

The complex interplay of energy and environmentally related research programs often necessitates the use of large sets of diverse numeric data simultaneously, such as basic chemical and physical properties of substances, environmental and biological data, and engineering tabulations. These data bases, however fragmentary and incomplete, are only now becoming available for computerized usage in specialized areas. But as the exchange of information and data and the interac-

tive use of authoritative data bases over computer networks becomes increasingly practical, much larger collections will soon be developed. These large collections will be used in simulation and modeling.

In recognition of the growing importance of computerized data base management, the LLL Computation Department has initiated research into the creation, management, and use of large scientific data bases, with the development of energy-related data bases of particular importance.¹⁰ This research and development is being done by the Information Research Group in cooperation with other programmatic activities at ERDA laboratories.

A valid comparison of calculated results, using these data bases, depends on use of the best identical values of fundamental constants and units of measurement conversion factors.

This report documents the computerization of 57 fundamental constants of nature. A later report will deal with conversion factors for units of measurement.

Fundamental Constants Data Base

To provide one common source for fundamental constants, we have computerized the most recent values published by Cohen and Taylor.^{11,12} The MASTER CONTROL data base manage-

ment system is used.¹³⁻¹⁸ (Details are in the appendix.)

Seven fields are used to describe each fundamental constant:

1. Symbol. The "computerized" standard symbol for each

fundamental constant. Normal computer usage is restricted to the upper case English alphabet. Because the customary symbols of fundamental constants use the upper and lower case English alphabet, Greek alphabet, subscripts and special characters, the symbols have been transliterated into the upper case English alphabet only. For example, Greek letters are replaced by the first three letters of their English name (two letters for μ , π , etc.). (T)*

2. Definition. The written definition of the constant. (T)

3. Value. The significant figures of the numeric value of the fundamental constant. (F)[†]

4. Uncertainty. The uncertainty in the significant figures of the numeric value. (F)

5. Scale. The power-of-ten exponent that provides the

scaling factor for the value and the uncertainty. (I)**

6. Units. The units of measurement for each fundamental constant using the International System of Units (SI).¹⁹ A FORTRAN-like expression, using SI abbreviations, applies. (Use of upper case English letters may lead to confusion between seconds, s, and Siemens, S. In this data base, S is seconds.) (T)

7. Identification number. Arbitrarily assigned to each fundamental constant. (I)

An example of this annotation is shown below.

<u>Field</u>	<u>Entry</u>
1. Symbol	E
2. Definition	Elementary charge
3. Value	1.6021892
4. Uncertainty	0.0000046
5. Scale (exponent)	-19
6. Units	C
7. Identification number	1

* (T), textual description.

[†] (F), floating-point number.

** (I), integer number.

Availability

Users of the Lawrence Livermore Laboratory computer system may obtain the data base and the user interface from the IBM-1360 Photo-store under the directory:

.603750:CONST-75. The data base consists of the data file CONST-75 and the index file CONST-7501. The user interface file is MC-CONST.

Interested users elsewhere may request the data base in card-image, fixed-field form from:

ERDA Computer Program Exchange &
Information Center
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
Tel.: (312) 739-7711

or

U.S. Department of Commerce
National Technical Information
Service (NTIS)
5285 Port Royal Road
Springfield, VA 22151
Tel.: (703) 321-8572

Conclusion

Although the set of fundamental constants is small, we believe that its computerization is a necessary first step in developing a reliable data base library open to the scrutiny of the scientific community. The frequent use of these constants as input to computer models is

facilitated by this data base. The user has at his disposal reliable numeric values. Updates of future evaluations will be computerized as they become available.

This set of 57 fundamental constants of nature will be referred to as "CONSTANTS-1975."

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Appendix

The data base of fundamental constants is managed at the Lawrence Livermore Laboratory by means of the MASTER CONTROL program.²⁰ Included in the appendix are listings of the fundamental constants (Table A-1), the MASTER CONTROL user interface by which the constants can be accessed (Fig. A-1), and printouts of the fundamental constants file available through the ANL Code Center and NTIS (Table A-2).

For users of MASTER CONTROL we give the following explanations with regard to the user interface, MC-CONST:

1. The original bibliographic references are cited at the beginning.
2. The array names and array types are defined by which the fundamental constants

are stored, recognized and managed in user-specified arithmetic and functional relations.

3. The International System of Units (SI) are noted.
4. The preferred columnar print formats, inclusive of headings, are defined for the seven basic arrays and for three derived variables. An EDIT command addressed to the array name will list their contents.
5. For general explanations refer to the MASTER CONTROL User's Manual.

Examples of some possible uses are shown in Figs. A-2 and A-3.

KC/gw

Table A-1. Standard symbols of the fundamental constants and their equivalent data base form.

Standard symbol	Symbol used in data base	Symbol definition
e	E	Elementary charge
h	H	Planck constant
$\hbar$	H-	Planck constant divided by 2π
N_A	NA	Avogadro constant
u	U	Atomic mass unit (10^{-3} kg/mol $\cdot N_A$)
m_e	ME	Electron rest mass
m_p	MP	Proton rest mass
m_p/m_e	MP/ME	Ratio of proton mass to electron mass
m_n	MN	Neutron rest mass
e/m_e	E/ME	Electron-charge-to-mass ratio
Φ_0	PHI0	Magnetic flux quantum
h/e	H/E	Magnetic flux quantum $\left(\frac{1}{c} \cdot \frac{h \cdot c}{2e}\right)$
$2e/h$	2E/H	Josephson frequency-voltage ratio
$h/2m_e$	H/2ME	Quantum of circulation
h/m_e	H/ME	Two times quantum of circulation
F	F	Faraday constant ($N_A \cdot e$)
R_∞	RINF	Rydberg constant
a_0	A0	Bohr radius
r_e	RE	Classical electron radius
σ_e	SIGE	Thomson cross section
$g_e/2$	GE/2	Free electron g-factor, or electron magnetic moment in Bohr magnetons
$g_u/2$	GMO/2	Free muon g-factor, or muon magnetic moment $\left(c \cdot \frac{e \cdot h}{4\pi m_\mu \cdot c}\right)$
μ_B	MUB	Bohr magneton $\left(c \cdot \frac{e \cdot h}{4\pi m_e \cdot c}\right)$
μ_e	MUE	Electron magnetic moment
γ_p^+	GAMPP	Gyromagnetic ratio of protons in H_2O
$\gamma_p^+/2\pi$	GAMPP-	Gyromagnetic ratio of protons in H_2O divided by 2π
γ_p	GAMP	Gyromagnetic ratio of protons in H_2O corrected for diamagnetism of H_2O

Table A-1. Standard symbols of the fundamental constants and their equivalent data base form (continued).

Standard symbol	Symbol used in data base	Symbol definition
$\gamma_p/2\pi$	GAMP-	Gyromagnetic ratio of protons in H ₂ O corrected for diamagnetism of H ₂ O, divided by 2π .
μ_p'/μ_B	MUPP/MUB	Magnetic moment of protons in H ₂ O in Bohr magnetons
μ_p/μ_B	MUP/MUB	Proton magnetic moment in Bohr magnetons
μ_e/μ_p	MUE/MUP	Ratio of electron and proton magnetic moments
μ_p	MUP	Proton magnetic moment
μ_p'/μ_N	MUPP/MUN	Magnetic moment of protons in H ₂ O in nuclear magnetons
μ_p/μ_N	MUP/MUN	Magnetic moment of protons in H ₂ O in nuclear magnetons, corrected for diamagnetism of H ₂ O
μ_N	MUN	Nuclear magneton $\left(c \cdot \frac{e \cdot h}{4\pi m_p \cdot c} \right)$
μ_μ/μ_p	MUMO/MUP	Ratio of muon and proton magnetic moments
μ_μ	MUMO	Muon magnetic moment
m_μ/m_e	MMO/ME	Ratio of muon mass to electron mass
m_μ	MMO	Muon rest mass
λ_c	LAMC	Compton wavelength of the electron $\left(\frac{h}{m_e \cdot c} = \frac{\alpha^2}{2R_\infty} \right)$
λ_c	LAMC-	Compton wavelength of the electron divided by 2π
$\lambda_{c,p}$	LAMCP	Compton wavelength of the proton ($h/m_p \cdot c$)
$\lambda_{c,p}$	LAMCP-	Compton wavelength of the proton divided by 2π
$\lambda_{c,n}$	LAMCN	Compton wavelength of the neutron ($h/m_n \cdot c$)
$\lambda_{c,n}$	LAMCN-	Compton wavelength of the neutron divided by 2π
V_m	VM	Molar volume of ideal gas at standard temperature and pressure
R	R	Molar gas constant ($P_0 \cdot V_m/T_0$, $T_0 = 273.15$ K, $P_0 = 101.325 \times 10^3$ Pa = 1 atm)
k	K	Boltzmann constant (R/N_A)
σ	SIG	Stefan-Boltzmann constant
c_1	CL	First radiation constant ($2\pi h \cdot c^2$)

Table A-1. Standard symbols of the fundamental constants and their equivalent data base form (continued).

Standard symbol	Symbol used in data base	Symbol definition
c_2	C2	Second radiation constant ($h \cdot c/k$)
G	G	Gravitational constant
μ_0	MU0	Permeability of vacuum
c	C	Speed of light in vacuum
ϵ_0	EPS0	Permittivity of vacuum ($1/\mu_0 \cdot c^2$)
α	ALP	Fine structure constant
L	L	Loschmidt constant (N_A/V_m)

```

FUNDAMENTAL CONSTANTS OF NATURE

* C REFERENCE: E. RICHARD COHEN AND B. N. TAYLOR, @THE 1973 LEAST-SQUARES
* C ADJUSTMENT OF THE FUNDAMENTAL CONSTANTS, @ J. PHYS. CHEM.
* C REF. DATA, VOL. 2, NO. 4, PG. 663 (1973).
* C
* C REFERENCE: E. RICHARD COHEN, @FUNDAMENTAL PHYSICAL CONSTANTS, @
* C PHYSICS TODAY, SEPTEMBER 1974

NOLIST
CHANGE KEY 14 5 END

DEFINE ARRAY
  IDN      I      1-RECORD IDENTIFICATION NUMBER
  SYMBOL   T      2-COMPUTERIZED OR STANDARD SYMBOL OF FUNDAMENTAL CONSTANT
  VALUE    F      3-NUMERIC VALUE OF THE CONSTANT
  UNCERT   F      4-UNCERTAINTY IN THE NUMERIC VALUE
  SCALE    I      5-POWER OF 10 SCALE FACTOR FOR VALUE AND UNCERTAINTY
  UNIT     T      6-SI UNITS OF THE CONSTANT
  DEFIN    T      7-DEFINITION OF SYMBOL
5 END

CHANGE KEY
72 5 END

* C ALL QUANTITATIVE DATA ARE IN SI UNITS

DEFINE C-M IDN 4 IDN 5 END
DEFINE C-M SYMBOL 10 SYMBOL 5 END
DEFINE C-M VALUE F19.13 VALUE 5 END
DEFINE C-M UNCERT F17.13 UNCERTAINTY 5 END
DEFINE C-M SCALE 12 SCALE FACTOR 5 END
DEFINE C-M UNIT 20 UNITS 5 END
DEFINE C-M DEFIN 30 DEFINITION 5 END

TAPE-DUMP ALL 5 END
SAVE-FILES

DEFINE DF COUNT (VALUE) VAL = VALUE * POWR(10,SCALE<0>) 5 END
DEFINE DF COUNT (VALUE) ABS = UNCERT<0> * POWR(10,SCALE<0>)* 5 END
DEFINE DF COUNT (VALUE) PPM = 1/(UNCERT/VALUE)<0>*(10**5)) 5 END

DEFINE C-N VAL E17.11 CONSTANT 5 END
DEFINE C-N ABS E11.2 UNCERTAINTY (ABSOLUTE) 5 END
DEFINE C-N PPM E11.2 UNCERTAINTY (IN PPM) 5 END 3?

```

Fig. A-1. The user interface, MC-CONST, used in conjunction with the data base CONST-75.

Table A-2. The card-image file used to create the SYMBOL, VALUE, UNCERT, SCALE, and UNIT arrays of the fundamental constants data base.

Symbol used in data base	Significant figures of constant	Significant figures of uncertainty	Power-of- ten multiplier	Units (SI)
E	1.6021892	0.0000046	-19	C
H	6.626176	0.000036	-34	J•s
H-	1.0545887	0.0000057	-34	J•s
NA	6.022045	0.000031	23	1/mol
U	1.6605655	0.0000086	-27	kg
ME	9.109534	0.000047	-31	kg
MP	1.6726485	0.0000086	-27	kg
MP/ME	1836.15152	0.00070		
MN	1.6749543	0.0000086	-27	kg
E/ME	1.7588047	0.0000049	11	C/kg
PHI0	2.0678506	0.0000054	-15	Wb
H/E	4.135701	0.000011	-15	J•s/C
2E/H	4.835939	0.000013	14	Hz/V
H/2ME	3.6365455	0.0000060	-04	J•s/kg
H/ME	7.273891	0.000012	-04	J•s/kg
F	9.648456	0.000027	04	C/mol
RINF	1.097373177	0.000000083	07	1/m
A0	5.2917706	0.0000044	-11	m
RE	2.8179380	0.0000070	-15	m
SIG	0.6652448	0.0000033	-28	m ²
GE/2	1.0011596567	0.0000000035		
GMO/2	1.00116616	0.00000031		
MUB	9.274078	0.000036	-24	J/T
MUE	9.284832	0.000036	-24	J/T
GAMPP	2.6751301	0.0000075	08	1/s•T
GAMPP-	4.257602	0.000012	07	Hz/T
GAMP	2.6751987	0.0000075	08	1/s•T
GAMP-	4.257711	0.000012	07	Hz/T
MUPP/MUB	1.52099322	0.00000010	-03	
MUP/MUB	1.521032209	0.000000016	-03	
MUE/MUP	658.2106880	0.0000066		

Table A-2. The card-image file used to create the SYMBOL, VALUE, UNCERT, SCALE, and UNIT arrays of the fundamental constants data base (continued).

Symbol used in data base	Significant figures of constant	Significant figures of uncertainty	Power-of- ten multiplier	Units (SI)
MUP	1.4106171	0.0000055	-26	J/T
MUPP/MUN	2.7927740	0.0000011		
MUP/MUN	2.7928456	0.0000011		
MUN	5.050824	0.000020	-27	J/T
NUMO/MUP	3.1833402	0.0000072		
MUMO	4.490474	0.000018	-26	J/T
MMO/ME	206.76865	0.00047		
MMO	1.883566	0.000011	-28	kg
LAMC	2.4263089	0.0000040	-12	m
LAMC-	3.8615905	0.0000064	-13	m
LAMCP	1.3214099	0.0000022	-15	m
LAMCP-	2.1030892	0.0000036	-16	m
LAMCN	1.3195909	0.0000022	-15	m
LAMCN-	2.1001941	0.0000035	-16	m
VM	22.41383	0.00070	-03	m ³ /mol
R	8.31441	0.00026		J/mol·K
K	1.380662	0.000044	-23	J/K
SIG	5.67032	0.00071	-08	W/m ² ·K ⁴
C1	3.741832	0.000020	-16	W/m ²
C2	1.438786	0.000045	-02	m·K
G	6.6720	0.0041	-11	m ³ /s ² ·kg
MUθ	1.2566370614		-06	h/m
C	2.99792458	0.000000012	08	m/s
EPSθ	8.85418782	0.000000007	-12	c ² /J·m
ALP	0.0072973506	0.0000000060		
L	2.686754	0.000084	25	1/m ³

FUNDAMENTAL CONSTANTS OF NATURE				
SYMBOL	CONSTANT	UNCERTAINTY (ABSOLUTE)	UNCERTAINTY (IN PPM)	UNITS
E	1.60218920000E-19	4.60E-25	2.87E-06	C
H	6.5817600000E-34	3.60E-39	5.43E-06	J*S
H-	1.05458870000E-34	5.70E-40	5.40E-06	J*S
NA	6.02204500000E+23	3.10E-16	5.15E-06	1/MOL
U	1.66056550000E-27	8.60E-33	5.10E-06	KG
ME	9.10938300000E-31	4.70E-36	5.16E-06	KG
MD	1.67264950000E-27	8.60E-33	5.14E-06	KG
MP/ME	1.83615150000E+03	7.00E-04	3.81E-01	
MN	1.67495430000E-27	8.60E-33	5.13E-06	KG
E/ME	1.75880470000E+11	4.90E-05	2.79E-06	C/KG
PH10	2.06785060000E-15	5.40E-21	2.61E-06	HR
H/E	4.13570100000E-15	1.10E-20	2.66E-06	(J*S)/C
2E/H	4.83993900000E+14	1.30E-09	2.69E-06	HZ/V
H/2ME	3.63694550000E-04	6.00E-10	1.65E-06	(J*S)/KG
H/ME	7.27389100000E-04	1.20E-09	1.65E-06	(J*S)/KG
F	9.64845600000E+04	2.70E-01	2.81E-06	C/MOL
RINF	1.09733177000E+07	8.30E-01	7.56E-02	V/M
AD	5.29177060000E-11	4.40E-17	8.31E-01	M
RE	2.61793800000E-15	7.03E-21	2.48E-06	M
SIGE	6.65244800000E-29	3.30E-34	4.96E-06	M**2
CE/2	1.00115965670E+00	3.50E-09	3.50E-03	
OMO/2	1.00116616000E+00	3.10E-07	3.10E-01	
MUB	9.27407800000E-24	3.60E-29	3.88E-06	J/T
MUE	9.28483200000E-24	3.60E-29	3.88E-06	J/T
GAMPP	2.67513010000E+08	7.50E+02	2.80E+00	1/(5*F)
GAMPP-	4.25760200000E+07	1.20E+02	2.82E+00	HZ/T
GAMP	2.67198700000E+08	7.50E+02	2.80E+00	1/(5*F)
GAMP-	4.25771100000E+07	1.20E+02	2.82E+00	HZ/T
MUPP/MUB	1.52093322000E-03	1.50E-10	6.57E-02	
MUP/MUB	1.52103220900E-03	1.60E-11	1.05E-02	
MUE/MUP	6.58210588000E-02	6.60E-05	1.00E-02	
MUP	4.10617100000E-26	5.50E-32	3.93E-01	J/T
MUPP/MUN	2.79277400000E+00	1.10E-06	3.94E-01	
MUP/MUN	2.79284560000E+00	1.10E-06	3.94E-01	
MUN	5.05082400000E-27	2.00E-32	3.96E+00	J/T
MUM0/MUP	3.18334020000E+00	7.20E-05	2.26E+00	
MUM0	4.49047400000E-26	1.80E-31	4.01E+00	J/T
MPO/ME	2.06786650000E+02	4.70E-04	2.27E+00	
MNO	1.83565600000E+28	1.10E-33	5.84E+00	KG
LAMC	2.42630890000E-12	4.00E-18	1.65E+00	M
LAMC-	3.8E159050000E-13	6.40E-19	1.66E+00	M
LAMCP	1.32140990000E-15	2.20E-21	1.66E+00	M
LAMCP-	2.10308920000E-16	3.60E-22	1.71E+00	M
LAMCN	1.31369090000E-15	2.20E-21	1.67E+00	M
LAMCN-	2.10019410000E-16	3.50E-22	1.67E+00	M
VM	2.24130300000E-02	7.00E-07	3.12E+01	M**3/MOL
R	9.31441000000E+00	2.60E-04	3.13E+01	J/(MOL*K)
K	1.38065200000E-23	4.70E-28	3.19E+01	J/K
SIG	4.6102000000E-08	7.10E-12	1.25E+02	M/(M**2)*(K**4)
C1	3.74163200000E-16	2.00E-21	5.34E+00	M*(M**2)
CE	1.43878600000E-02	4.50E-07	3.13E+01	M*K
G	6.67200000000E-11	4.10E-14	6.15E-02	M**3/(5*F**2)*KG
MU0	1.25662450000E-06	0.00E+00		M/M
C	2.99792458000E-08	1.20E+00	4.00E-03	M/S
EPS0	8.85418782000E-12	7.00E-20	7.91E-03	(C**2)/(J*M)
ALP	7.29735600000E-03	6.00E-09	6.22E-01	
L	2.68675400000E+25	8.40E-20	3.13E+01	1/M**3

Fig. A-2. A printout of the fundamental constants using the defined variable feature of MASTER CONTROL.

FUNDAMENTAL CONSTANTS OF NATURE				
SYMBOL	CONSTANT	UNCERTAINTY (ABSOLUTE)	UNCERTAINTY (IN PPM)	UNITS
H/E	4.13570100000E-15	1.10E-20	2.66E-06	(J*S)/C
2E/H	4.83993900000E+14	1.30E-09	2.69E-06	HZ/V
H/2ME	3.63694550000E-04	6.00E-10	1.65E-06	(J*S)/KG
H/ME	7.27389100000E-04	1.20E-09	1.65E-06	(J*S)/KG

Fig. A-3. A printout of the results of a MASTER CONTROL search on CONST-75 to find those constants that contain both H and E in their symbol.