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A New Table of Values of the General Physical Constants

(as of August, 1941)

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IN 1929 I published[1] a set of values of the general physical constants that was consistent and, with a few exceptions, apparently quite satisfactory. A later paper[2] gave a more logical treatment of the related atomic constants e, h, e/m and α, but with no significant changes in the adopted values. The list published in 1929 was satisfactory in the sense that in nearly every case where a test was possible, the apparent best experimental value of a given constant was in satisfactory agreement with the indirectly calculated value. The one serious discrepancy—that between the "spectroscopic" and the "deflection" values of e/m, has now been almost completely eliminated.[3]

Signs of another discrepancy had, however, already begun to appear in 1929—a discrepancy between the value of the electronic charge e obtained from oil-drop work and that obtained by a new method involving the ruled-grating wave-lengths of x-rays.[4] The reality of the discrepancy was rapidly established, and the resulting very unsatisfactory state of affairs continued until 1935, when it was definitely shown that the value of the viscosity of air used by Millikan in his oil-drop work was seriously in error. Numerous recent determinations of the viscosity of air, together with new oil-drop work, have now brought the two values of e into satisfactory agreement. The present grating value is, however, seemingly much more accurate than the oil-drop value, and hence the value of e adopted in the tables of this paper represents merely the grating value.

In evaluating e from the grating wave-lengths of x-rays, the quantity first obtained is not e, but the Avogadro number N_0. One then obtains e from the equation $e=F/N_0$, where F is the Faraday. Hence N_0 is now a fundamental constant, and appears in Table a, whereas e is a *derived* constant and properly belongs in Table c. Merely for convenience I have, however, retained e in Table a.

The 1929 value of e was roughly 4.77×10^{-10} e.s.u. The new value is about 4.80. Such a surprisingly large change necessarily gave rise to a whole set of new discrepancies. In fact, as already stated, it was just because all functions of the atomic constants seemed to be so consistent, provided Millikan's value of e were used, that for some years it appeared to me that his value must be essentially correct.

Among the new discrepancies the greatest, on a percentage basis, involve the radiation constants c_2 and σ. It is, however, quite possible that the true errors in the experimentally determined values of these constants are far greater than the

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[1] R. T. Birge, Rev. Mod. Phys. **1**, 1 (1929). To be denoted G.C.1929.

[2] R. T. Birge, Phys. Rev. **40**, 228 (1932).

[3] (a) R. T. Birge, Phys. Rev. **54**, 972 (1938); (b) Phys. Rev. **60**, 766 (1941).

[4] See G.C.1929, pp. 41–43.

Table a. Principal Constants and Ratios.*

SECTION		
A	Velocity of light	$c=(2.99776\pm0.00004)\times10^{10}$ cm·sec^{-1}
B	Gravitation constant	$G=(6.670\pm0.005)\times10^{-8}$ dyne·cm^2·g^{-2}
C	Liter (=1000 ml)	$l=1000.028\pm0.002$ cm^3
D	Volume of ideal gas (0°C, A_0)	$V_0=(22.4146\pm0.0006)\times10^3$ cm^3·atmos·mole^{-1} $V_0'=22.4140\pm0.0006$ liter·atmos·mole^{-1}
D	Volume of ideal gas (0°C, A_{45})	$V_{45}=(22.4157\pm0.0006)\times10^3$ cm^3·atmos·mole^{-1} $V_{45}'=22.4151\pm0.0006$ liter·atmos·mole^{-1}
E	International ohm (= p abs-ohm)	$p=1.00048\pm0.00002$
E	International ampere (= q abs-amp)	$q=0.99986\pm0.00002$
F	Atomic weights (see Table a′)	
G	Standard atmosphere	$A_0=(1.013246\pm0.000004)\times10^6$ dyne·cm^{-2}·atmos^{-1}
G	45° atmosphere	$A_{45}=(1.013195\pm0.000004)\times10^6$ dyne·cm^{-2}·atmos^{-1}
H	Ice-point (absolute scale)	$T_0=273.16\pm0.01$°K
I	Joule equivalent	$J_{15}=4.1855\pm0.0004$ abs-joule·cal$_{15}^{-1}$
I	Joule equivalent (electrical)	$J_{15}'=4.1847\pm0.0003$ int-joule·cal$_{15}^{-1}$
J	Faraday constant (1) Chemical scale	$F=96501._2\pm10$ int-coul·g-equiv^{-1} $=96487._7\pm10$ abs-coul·g-equiv^{-1} $=9648.7_7\pm1.0$ abs. e.m.u·g-equiv^{-1} $F'=Fc=(2.89247\pm0.00030)\times10^{14}$ abs. e.s.u·g-equiv^{-1}
	(2) Physical scale	$F=96514._0\pm10$ abs-coul·g-equiv^{-1} $=9651.4_0\pm1.0$ abs. e.m.u·g-equiv^{-1} $F'=Fc=(2.89326\pm0.00030)\times10^{14}$ abs. e.s.u·g-equiv^{-1}
K	Avogadro number (chemical scale)	$N_0=(6.0228_3\pm0.0011)\times10^{23}$ mole^{-1}
K	Electronic charge	$e=F/N_0=1.60203_3\pm0.00034)\times10^{-20}$ abs. e.m.u. $e'=ec=(4.8025_1\pm0.0010)\times10^{-10}$ abs. e.s.u.
L	Specific electronic charge	$e/m=(1.7592\pm0.0005)\times10^7$ abs. e.m.u·g^{-1} $e'/m=ec/m=(5.2736_6\pm0.0015)\times10^{17}$ abs. e.s.u·g^{-1}
M	Planck constant	h (see Table c).

* Unless otherwise specified, all quantities in these tables that involve the mole or the gram equivalent are on the chemical scale of atomic weights.

Table a′. Atomic Weights.

(1) Physical scale ($O^{16}=16.0000$)

$H^1=1.00813\pm0.00001_7$ $H^2=2.01473\pm0.00001_9$
$H=1.00827_6\pm0.00001_7$ (from H^1/H^2 abundance $=6900\pm100$)
$He^4=4.00389\pm0.00007$
$C^{12}=12.00386\pm0.00004$ $C^{13}=13.00761\pm0.00015$
$C=12.01465\pm0.00023$ (from C^{12}/C^{13} abundance $=92\pm2$)
$N^{14}=14.00753\pm0.00005$ $N^{15}=15.0049\pm0.0002$
$N=14.01121\pm0.00009_5$ (from N^{14}/N^{15} abundance $=270\pm6$)
$O^{16}=16.0000$ $O^{17}=17.0045$ $O^{18}=18.0049$
$O=16.00435_7\pm0.00008_6$ (from abundance $O^{16}:O^{18}:O^{17}=(506\pm10):1:(0.204\pm0.008)$)

(2) Chemical scale ($O=16.0000$)

Ratio physical to chemical scale
$r=(16.004357\pm0.000086)/16=1.000272\pm0.000005$

$H^1=1.00785_6\pm0.00001_8$ (from physical scale)
$H^2=2.01418_2\pm0.00002_1$ (from physical scale)
$H=1.00800_2\pm0.00001_8$ (from physical scale)
$He^4=4.00280\pm0.00007$ (from physical scale)
$C=12.01139\pm0.00024$ (from physical scale)
$N=14.00740\pm0.00012$ (from physical scale)
$N=14.0086\pm0.0007$ (direct observation)
$Na=22.994\pm0.003$
$Cl=35.457\pm0.001$
$Ca=40.080\pm0.005$
$Ag=107.880\pm0.002$
$I=126.915\pm0.004$

Table b. Additional Quantities Evaluated or Used in Connection with Table a.

SECTION		
A	Ratio of e.s.u. to e.m.u. (direct)	$c' = (2.9971_2 \pm 0.0001) \times 10^{10}\ \mathrm{cm}^{\frac{1}{2}} \cdot \mathrm{sec}^{-\frac{1}{2}} \cdot \text{int-ohm}^{\frac{1}{2}}$ $= (2.9978_4 \pm 0.0001_0) \times 10^{10}\ \mathrm{cm} \cdot \mathrm{sec}^{-1}$
A	Ratio of e.s.u. to e.m.u. (indirect)	$c' = c = (2.99776 \pm 0.00004) \times 10^{10}\ \mathrm{cm} \cdot \mathrm{sec}^{-1}$
B	Average density of earth	$\delta = 5.517 \pm 0.004\ \mathrm{g} \cdot \mathrm{cm}^{-3}$
C	Maximum density of water	$\delta_m(\mathrm{H_2O}) = 0.999972 \pm 0.000002\ \mathrm{g} \cdot \mathrm{cm}^{-3}$
D	Acceleration of gravity (standard)	$g_0 = 980.665\ \mathrm{cm} \cdot \mathrm{sec}^{-2}$
D	Acceleration of gravity (45°)	$g_{45} = 980.616\ \mathrm{cm} \cdot \mathrm{sec}^{-2}$
D	Density of oxygen gas (0°C, A_{45})	$L_1 = 1.42897 \pm 0.00003\ \mathrm{g} \cdot \mathrm{liter}^{-1}$
D	Limiting density of oxygen gas (0°C, A_{45})	$L_{\mathrm{lim}} = 1.427609 \pm 0.000037\ \mathrm{g} \cdot \mathrm{liter}^{-1}$
D	Factor converting oxygen (0°C, A_{45}) to ideal gas	$1 - \alpha = 1.000953_5 \pm 0.000009_4$
E	International coulomb ($= q$ abs-coul)	$q = 0.99986 \pm 0.00002$
E	International gauss ($= q$ abs-gauss)	
E	International henry ($= p$ abs-henry)	$p = 1.00048 \pm 0.00002$
E	International volt ($= pq$ abs-volt)	$pq = 1.00034 \pm 0.00003$
E	International joule ($= pq^2$ abs-joule)	$pq^2 = 1.00020 \pm 0.00004_5$
G	Specific gravity of Hg (0°C, A_0) referred to air-free water at maximum density	$\rho_0 = 13.59542 \pm 0.00005$
G	Density of Hg (0°C, A_0)	$D_0 = 13.59504_0 \pm 0.00005_7\ \mathrm{g} \cdot \mathrm{cm}^{-3}$
J	Electrochemical equivalents (chemical scale)	
	silver (apparent)	$E^*_{\mathrm{Ag}} = 1.11800 \times 10^{-3}\ \mathrm{g} \cdot \text{int-coul}^{-1}$
	(corrected)	$E_{\mathrm{Ag}} = (1.11807 \pm 0.00012) \times 10^{-3}\ \mathrm{g} \cdot \text{abs-coul}^{-1}$
	iodine (apparent)	$E^*_{\mathrm{I}} = (1.315026 \pm 0.000025) \times 10^{-3}\ \mathrm{g} \cdot \text{int-coul}^{-1}$
	(corrected)	$E_{\mathrm{I}} = (1.31535 \pm 0.00014) \times 10^{-3}\ \mathrm{g} \cdot \text{abs-coul}^{-1}$
K	Effective calcite grating space (18°C), Siegbahn system	$d_{18}'' = 3.02904 \times 10^{-8}\ \mathrm{cm}$
K	True calcite grating space (20°C), Siegbahn system	$d_{20}' = 3.02951_2 \times 10^{-8}\ \mathrm{cm}$
K	True calcite grating space (20°C), c.g.s. system	$d_{20} = (3.03567_4 \pm 0.00018) \times 10^{-8}\ \mathrm{cm}$
K	Ratio of grating and Siegbahn scales of wave-lengths	$\lambda_g/\lambda_s = 1.002034 \pm 0.000060$
K	Density of calcite (20°C)	$\rho = 2.71029 \pm 0.00003\ \mathrm{g} \cdot \mathrm{cm}^{-3}$
K	Structural constant of calcite (20°C)	$\phi = 1.09594 \pm 0.00001$
K	Molecular weight of calcite (chemical scale)	$M = 100.091_4 \pm 0.005$
L	Rydberg constant for hydrogen (H^1)	$R_{\mathrm{H}} = 109677.581_2 \pm 0.007_5\ \mathrm{cm}^{-1}$ (I. A. scale)
L	Rydberg constant for deuterium (H^2)	$R_{\mathrm{D}} = 109707.419_3 \pm 0.007_5\ \mathrm{cm}^{-1}$ (I. A. scale)
L	Rydberg constant for helium	$R_{\mathrm{He}} = 109722.263 \pm 0.012\ \mathrm{cm}^{-1}$ (I. A. scale)
L	Rydberg constant for infinite mass	$R_\infty = 109737.303 \pm 0.017\ \mathrm{cm}^{-1}$ (I. A. scale) or $\pm 0.05\ \mathrm{cm}^{-1}$ (c.g.s. system)

apparent experimental uncertainties. Hence these discrepancies need not be taken too seriously. On the other hand, there is a discrepancy that, until very recently, has appeared to be very large and very serious. It may be expressed most simply as follows. If one substitutes in the Bohr formula for the Rydberg constant the very accurately known value of R_∞ and the apparent best directly observed values of e and e/m, the resulting calculated value of h/e is significantly greater than any directly observed value. I pointed out[5] the seriousness of the situation, just as soon as the new "high" value of e had been definitely established. This general problem has since been treated in detail by a number of writers, among whom may be mentioned Dunnington[6] and DuMond.[7]

Very recent experimental evidence indicates that there may have been serious systematic errors in the previous direct determinations of h/e, and that, with the elimination of such errors, the discrepancy just mentioned may disappear. Such a statement applies, in particular, to the experimental determination of h/e by means of the Duane-Hunt limit of the continuous x-ray spectrum, a method that now provides much the most precise evaluation of h/e.

Even before the recent experimental data on h/e had appeared, I felt that the preponderance of evidence indicated rather definitely that the "indirect" rather than the "direct" value of h/e

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[5] R. T. Birge, Phys. Rev. **48**, 918 (1935); Nature **137**, 187 (1936).

[6] F. G. Dunnington, Rev. Mod. Phys. **11**, 65 (1939).

[7] J. W. M. DuMond, Phys. Rev. **56**, 153 (1939); **58**, 457 (1940).

Table c. Partial List of Derived Quantities.*

Planck constant

$$h=\left\{\frac{2\pi^2c^3F^5}{R_\infty N_0^5(e/m)}\right\}^{\frac{1}{3}}=(6.624_2\pm0.002_4)\times10^{-27}\text{ erg}\cdot\text{sec}$$

$$h/e=\left\{\frac{2\pi^2c^3F^2}{R_\infty N_0^2(e/m)}\right\}^{\frac{1}{3}}=(4.1349_0\pm0.0007_1)\times10^{-7}\text{ erg}\cdot\text{sec}\cdot\text{e.m.u.}^{-1}$$

$$h/e'=h/ec=\left\{\frac{2\pi^2F^2}{R_\infty N_0^2(e/m)}\right\}^{\frac{1}{3}}=(1.3793_3\pm0.0002_3)\times10^{-17}\text{ erg}\cdot\text{sec}\cdot\text{e.s.u.}^{-1}$$

Atomic weight of electron.................................$E=F/(e/m)$

(physical scale) $=(5.4862_4\pm0.0017)\times10^{-4}$

(chemical scale) $=(5.4847_5\pm0.0017)\times10^{-4}$

Band spectra constant connecting wave number and moment of inertia.

$$h/8\pi^2c=\left\{\frac{F^5}{256\pi^4R_\infty N_0^5(e/m)}\right\}^{\frac{1}{3}}=(27.98_{65}\pm0.01_0)\times10^{-40}\text{ g}\cdot\text{cm}$$

Boltzmann constant...................$k=R_0/N_0=V_0A_0/T_0N_0=(1.38047_4\pm0.00026)\times10^{-16}$ erg·deg^{-1}

Charge in electrolysis of one gram of H..................$F/H=9572.1_{73}\pm1.0$ abs. e.m.u·g^{-1}

Charge in electrolysis of one gram of H^1..........$e/M_{\mathrm{H}^1}=F/H^1=9573.5_{60}\pm1.0$ abs. e.m.u·g^{-1}

Compton shift at 90°..................$h/mc=\left\{\frac{2\pi^2F^2(e/m)^2}{R_\infty N_0^2}\right\}^{\frac{1}{3}}=(0.024265_{14}\pm0.000005_7)\times10^{-8}$ cm

Energy in ergs of one abs-volt-electron......$E_0=10^8e=10^8F/N_0=(1.60203_3\pm0.00034)\times10^{-12}$ erg

Energy in calories per mole for one abs-volt-electron per molecule.

$$\frac{F(\text{abs. coul. per gram equiv})}{J_{15}(\text{abs. joules per cal})}=23052._{85}\pm3._2\text{ cal}_{15}\cdot\text{mole}^{-1}$$

Fine structure constant.........$\alpha=2\pi(e')^2/hc=\left\{\frac{4\pi R_\infty F(e/m)}{N_0}\right\}^{\frac{1}{3}}=(7.2976_6\pm0.0008_6)\times10^{-3}$

$1/\alpha=137.030_2\pm0.016$

$\alpha^2=(5.3256\pm0.0013)\times10^{-5}$

Gas constant per mole........................$R_0=V_0A_0/T_0=(8.31436\pm0.00038)\times10^7$ erg·deg^{-1}·mole^{-1}

$R_0'=R_0\cdot10^{-7}/J_{15}=1.98646_7\pm0.00021$ cal$_{15}$·deg^{-1}·mole^{-1}

$R_0''=V_0'/T_0=(8.20544_7\pm0.00037)\times10^{-2}$ liter·atmos·deg^{-1}·mole^{-1}

$R_0'''=R_0/A_0=V_0/T_0=82.0566_7\pm0.0037$ cm^3·atmos·deg^{-1}·mole^{-1}

also $R_0T_0=V_0A_0=(2.27115_0\pm0.00006)\times10^{10}$ erg·mole^{-1}

Loschmidt number (0°C, A_0)......................$n_0=N_0/V_0=(2.6870_{12}\pm0.0005_0)\times10^{19}$ atmos^{-1}·cm^{-3}

Magnetic moment of one Bohr magneton......$\mu_1=(h/4\pi)(e/m)=\frac{1}{4\pi}\left\{\frac{2\pi^2c^3F^5(e/m)^2}{R_\infty N_0^5}\right\}^{\frac{1}{3}}$

$=(0.9273_{45}\pm0.0003_7)\times10^{-20}$ erg·gauss^{-1}

Magnetic moment per mole for one Bohr magneton per molecule

$$\mu_1N_0=\frac{1}{4\pi}\left\{\frac{2\pi^2c^3F^5(e/m)^2}{R_\infty N_0^2}\right\}^{\frac{1}{3}}=5585.2_4\pm1.6\text{ erg}\cdot\text{gauss}^{-1}\cdot\text{mole}^{-1}$$

must be substantially correct. On the basis of this assumption I prepared, in August 1939, a new list of values of the general physical constants, and issued it in mimeographed form.[8] The purpose of this preliminary list was merely to invite corrections and suggestions, to be used in a detailed paper on the subject that I hoped to prepare as soon as possible. For a number of reasons such a detailed paper has not yet been written, but I have now completed my study of the fundamental constants and of the various auxiliary constants needed in the evaluation of the fundamental constants. The final incentive for this work came, very frankly, in the form of an invitation to write a comparatively short paper on the subject for the *Reports on Progress in Physics*, issued yearly by the Physical Society of London. The manuscript of that paper has just been mailed to London, but because of the present international situation, there may be some delay in publication. It seems desirable, however, to make the new list of constants available as promptly as possible. Hence I am

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[8] Copies of this list were sent to many persons, and values taken from it have since been quoted in various published papers.

Table c. Partial List of Derived Quantities.—(*Continued*).

Mass of α-particle	$M_\alpha = (\mathrm{He}-2E)/N_0 = (6.6442_2 \pm 0.0012)\times 10^{-24}\ \mathrm{g}$
Mass of atom of unit atomic weight	$M_0 = 1/N_0 = (1.66035 \pm 0.00031)\times 10^{-24}\ \mathrm{g}$
Mass of electron	$m = e/(e/m) = (F/N_0)/(e/m) = (9.1066_0 \pm 0.0032)\times 10^{-28}\ \mathrm{g}$
Mass of H¹ atom	$M_{\mathrm{H}^1} = \mathrm{H}^1/N_0 = (1.67339_3 \pm 0.00031)\times 10^{-24}\ \mathrm{g}$
Mass of proton	$M_p = (\mathrm{H}^1 - E)/N_0 = (1.67248_2 \pm 0.00031)\times 10^{-24}\ \mathrm{g}$
Radiation density constant	$a = 8\pi^5k^4/15c^3h^3 = \left(\frac{V_0A_0}{T_0}\right)^4 \frac{4\pi^3N_0R_\infty(e/m)}{15c^6F^5}$ $= (7.569_{42} \pm 0.004_9)\times 10^{-15}\ \mathrm{erg\cdot cm^{-3}\cdot deg^{-4}}$
Ratio mass H¹ atom to mass electron	$M_{\mathrm{H}^1}/m = (e/m)(\mathrm{H}^1/F) = 1837.5_{61} \pm 0.5_6$
Ratio mass proton to mass electron	$M_p/m = (e/m)\left(\frac{\mathrm{H}^1-E}{F}\right) = 1836.5_{61} \pm 0.5_6$
Second radiation constant	$c_2 = hc/k = \frac{c^2T_0}{V_0A_0}\left\{\frac{2\pi^2F^5}{R_\infty N_0^2(e/m)}\right\}^{\frac{1}{2}} = 1.4384_8 \pm 0.0003_4\ \mathrm{cm\cdot deg}$
Specific charge of α-particle	$2e/M_\alpha = \frac{2F}{\mathrm{He}-2E} = 4822.3_3 \pm 0.5_1\ \mathrm{abs.\ e.m.u\cdot g^{-1}}$
Specific charge of proton	$e/M_p = \frac{F}{\mathrm{H}^1-E} = 9578.7_7 \pm 1.0\ \mathrm{abs.\ e.m.u\cdot g^{-1}}$
Stefan-Boltzmann constant	$\sigma = ac/4 = 2\pi^5k^4/15c^2h^3 = \left(\frac{V_0A_0}{T_0}\right)^4 \frac{\pi^3N_0R_\infty(e/m)}{15(Fc)^5}$ $= (5.672_{83} \pm 0.003_7)\times 10^{-5}\ \mathrm{erg\cdot cm^{-2}\cdot deg^{-4}\cdot sec^{-1}}$
Wave-length associated with one abs-volt**	$\lambda_0 = 10^{-8}c^2(h/e') = \frac{c^2}{10^8}\left\{\frac{2\pi^2F^2}{R_\infty N_0^2(e/m)}\right\}^{\frac{1}{2}} = (12395._4 \pm 2._1)\times 10^{-8}\ \mathrm{cm\cdot abs\text{-}volt}$
Wave number associated with one abs-volt	$s_0 = 1/\lambda_0 = \frac{10^8}{c^2}\left\{\frac{R_\infty N_0^2(e/m)}{2\pi^2F^2}\right\}^{\frac{1}{2}} = 8067.4_9 \pm 1.4\ \mathrm{cm^{-1}\cdot abs\text{-}volt^{-1}}$
Wien's displacement law constant***	$A = c_2/4.965114 = 0.28971_8 \pm 0.00007\ \mathrm{cm\cdot deg}$
Zeeman displacement per gauss	$(e/m)/4\pi c = (4.6699_1 \pm 0.0013)\times 10^{-5}\ \mathrm{cm^{-1}\cdot gauss^{-1}}$

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* In order to be able to calculate, by propagation of errors, the probable error in a derived quantity, it is necessary to express the quantity explicitly in terms of the various fundamental quantities of Table a, or of Table b, and that has been done in each case. Since in this paper e and h are treated as derived quantities, they do not therefore appear in such explicit expressions. But in calculating ***numerical*** values of derived quantities, the work can often be greatly simplified by using the values of other previously calculated derived quantities—in particular e and h. In order to show how certain derived quantities depend on quantities like e and h, such alternative expressions are given in many cases.

** The factor 10^{-8} was accidentally omitted in G.C.1929, in the equation for λ_0.

*** The factor 4.965114 is the root of $e^{-\beta} + (\beta/5) - 1 = 0$.

presenting, in the present paper, tables of constants taken verbatim from the manuscript just mentioned. Only such explanation as seems necessary to make the tables intelligible is given here. I hope, however, to publish in the not too distant future an extended paper, of the same type as G.C.1929, in which the origin of every quantity given in the tables will be fully explained.

As already stated, the most reliable value of h/e now appears to be that calculated indirectly by means of the Rydberg constant formula, and this indirect value is adopted. Hence both h and h/e become *derived* constants and accordingly appear in Table c. Other quantities, such as the gas constant per mole, the Boltzmann constant, the Stefan-Boltzmann constant, and the radiation constants, which were given in Table b of G.C.1929, now appear in Table c, since only the indirect (i.e., *derived*) value is given. In general, however, Tables a, b and c of the present paper correspond to the similarly designated tables of G.C.1929. Because of the greatly increased number of necessary atomic weights, they have now been collected in a separate Table a′. No probable errors are assigned to O^{17} and O^{18} since such errors as exist have a completely negligible effect on the resulting value of O (=16.004357). It should be noted also that the present Table c is very incomplete. In the projected detailed paper, I expect to include all of the items given in Table c of G.C.1929, and I should be glad to get suggestions as to other derived constants that might well be included. With the exception of h/e and h, the items of Table c are now in alphabetic order. I tried, in Table c of G.C.1929, to group together naturally related constants, but the result seems to have been quite unsatisfactory, so far as practical use of the tables is concerned.

The present list of values differs but little from the mimeographed list of August, 1939. The one important change is in the value of the Faraday F. I now adopt $96501._2$ int. coulombs, on the chemical scale. The new value represents a weighted average of the values 96494 and 96511 given by the silver and iodine voltameters, respectively, whereas previously I adopted merely the silver voltameter value.

On the other hand, there are many differences between the present list and that of G.C.1929. In fact, with the exception of the atomic weight of silver,[9] there is not a single experimental value in Tables a and b that has not been changed, in greater or lesser amount! The most important change involves the value of e, and because of that change alone, not only h but also nearly every other derived constant suffers a significant change in value. It is worth noting, in this connection, that the latest directly observed values of certain functions of e, h and m, such as $(e/m)(h/e)^2$, h/m, e^2/h and $(e/m)(e/h)$, agree in a very satisfactory way with the values of e, h and m here adopted. As already indicated, the latest experimental results for h/e are in good agreement with the indirect value; in fact, they lie actually just *above* the indirect value.

The value of the Rydberg constant R_∞ has been changed by a significant amount, as the result of an important recent investigation.[10] Full details regarding the present adopted value of R_∞, as well as that of e/m, are contained in a recent paper by the writer.[3b] Many changes in the 1929 list have been made necessary as a result of the discovery of isotopes of oxygen and of hydrogen. The existence of isotopes of oxygen makes possible two scales of atomic weights, the physical and the chemical scales, and it is most important to specify on which scale any published value is based. The existence of the hydrogen isotope H^2 leads to the conclusion that the symbol H, as used in G.C.1929, referred in some places to the normal mixture of hydrogen isotopes, whereas in other places it represented merely the isotope H^1.

In order to conform as closely as possible to recent committee recommendations, I have made several changes of symbols, and also of names. One important change of symbols is, however, now being made entirely on my own responsibility. Since in Table c explicit expressions are given for each derived constant, it is essential that each adopted symbol denote not only a specified quantity, but also that quantity in terms of just one specified unit.[11] Now in G.C.1929 and in various papers since then, I have followed the customary but quite pernicious practice of using e to denote the electronic charge in e.s.u., but e/m to denote the specific electronic charge in e.m.u. In now adopting a single system of units for e and e/m, I have considered the fact that all electrical quantities are measured experimentally in practical units (volts, ohms, etc.) and that one may then obtain the corresponding result in e.m.u. by a mere shift of decimal point. Hence in this paper electrical quantities are normally expressed in e.m.u. and are specified by *unprimed* symbols, whereas *primed* symbols are used for the same quantities in e.s.u. Thus F and e/m have the same meaning as in G.C.1929, but now e' is used for 4.80×10^{-10} e.s.u., and $e\ (=e'/c)$ denotes 1.602×10^{-20} e.m.u., with similar changes for h/e. The mass of the electron m is now given, as it should be, by $e/(e/m)$, whereas in G.C.1929 it was necessary to evaluate it from $e/(e/m)c$.

One of the most puzzling questions, in preparing tables such as those presented, concerns the proper designation of certain units. An entire paper could well be devoted to this matter, but I wish to note here merely that certain changes have now been made in the designations used in G.C.1929, and further changes are really demanded, as a matter of logic. What is required is a self-consistent set of designations such that, for instance, when we write $R_0T_0=V_0A_0$ (see Table

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[9] The irony here is that I *now* believe that even this quantity should have been changed from 107.880 to 107.878. In order to allow for such a possibility, I have increased the probable error of the adopted 107.880 value from 0.001 to 0.002.

[10] J. W. Drinkwater, Sir Owen Richardson, and W. E. Williams, Proc. Roy. Soc. **A174**, 164 (1940).

[11] The only exception is F, which in Table a is used for three different units, but in Table c always refers to the Faraday in abs.e.m.u., unless otherwise specified.

c), the designations of the four quantities involved, as well as their numerical values, will be such as to make the two sides of the equation identical. It is for just this reason that names such as mole^{-1}, g-equiv^{-1}, atmos^{-1} etc. appear in the designation of certain units. Furthermore, in order to be able to obtain such a check in all cases (in particular, in cases involving the electron-volt) it will be necessary to write $e' = 4.80 \times 10^{-10}$ e.s.u$\cdot$electron^{-1}, in place of the customary e.s.u., with a corresponding change in other units involving e or e'. Similarly the mass of the electron (m) should be designated g$\cdot$electron^{-1}.

In Tables a and b the section designations (A to M) of G.C.1929 are retained. These designations are helpful in showing which of the fundamental constants of Table a is connected with each of the auxiliary constants of Table b.

In conclusion I wish to express the opinion that, as a result of the very extensive and carefully planned experimental work on the general physical constants that has been carried out since 1929, the entire situation is now in a greatly improved state. Furthermore it is much more generally admitted than was the case in 1929 that even the most extensive and expensive investigations are likely to be afflicted with large and totally unsuspected sources of systematic error. For just this reason it is most essential that every important constant be measured by means of as many different methods as possible, and it is also desirable that the various methods differ as much as possible. It is only when thoroughly consistent results have been obtained from radically different methods that any real reliance can be placed on the final weighted average value.