PHYSICAL CONSTANTS

W. H. J. Childs

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SELECTED FOR STUDENTS

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PREFACE

THE steady support which this book has received has led, except during the war years, to fairly frequent reprinting. Because of this, it has been possible to change the values of individual constants when necessary and to rectify minor mistakes and blemishes. Much has changed in the world of physics in the twenty-odd years since the first edition, and it says much for the original choice of contents that it is still difficult to suggest alternative matter for any of the tables. However, in the present edition a slight increase in size has made it possible to undertake a more extensive overhaul and the opportunity has been seized to include a short section on the M.K.S. system of units, and to expand one or two of the tables, notably that of the stable isotopes. In addition to this, the section on photometric units has been re-written. These alterations and additions should increase still further the usefulness of this collection In conclusion, I wish to thank all who have taken the trouble to write to me to draw my attention to superior determinations, or to mistakes, or simply to offer advice or criticism.

W. H. J. C.

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THE FUNDAMENTAL UNITS OF THE C.G.S. SYSTEM

THE fundamental units are those of Length, Mass, and Time.

Length (L). The metre, at present an arbitrary unit, is the distance at 0° C. between two marks on a standard platinum-iridium bar kept at Paris. Originally intended to be 10^{-7} of the earth quadrant through Paris, it is recognised now that it is only $0{\cdot}99980\ 10^{-7}$ of the quadrant, and, moreover, that the definition itself is faulty. The present more satisfactory definition is that it is 1553164·13 wave-lengths of the red cadmium line, measured in dry air at 15° C. and normal pressure.

Mass (M). The unit of mass, again arbitrary, although originally based on the metre (since it was intended to be the mass of a cubic decimetre of pure water at 4° C.), is the kilogramme. It is a mass of platinum-iridium kept in Paris.

Time (T). The unit is the second, 1/86400 of a mean solar day, which is itself a rather abstract unit. Owing to the complicated motion of the earth it is not easy to find an adequate definition of the second; for most practical purposes it may be based on the interval between two successive intersections of a fixed star by any given meridian. This interval, known as a sidereal day, is equal to 86164 seconds.

From these fundamental units are derived the sub-units:—

Length. Kilometre (km.), decimetre (dm.), centimetre (cm.), millimetre (mm.). Also the micron $\mu = 10^{-3}$ mm. and the millimicron $\mu\mu = 10^{-6}$ mm. 1 angstrom unit (A.U.) = 10^{-8} cm. 1 X-unit (X.U.) = 10^{-11} cm.

Square measure (L^2). Square metre (sq. m.), square centimetre (sq. cm.), etc. 1 Ar = 100 sq. m., 1 Hektar = 10,000 sq. m.

Volume (L^3). Cubic centimetre (c.c.), etc. The practical unit is now the millilitre. The litre (i.e. the volume of 1 kilogramme of pure water at 4° C.) was originally intended to be 1000 c.c., but is now recognised to be 1000·028 c.c. 1 c.c. = 0·999972 millilitre.

Mass. Gramme (gm.), decigramme (dgm.), centigramme (cgm.), milligramme (mgm.). In practice these units are also used as units of force (i.e. Weight). At sea level, in latitude 45°, a kilogramme under gravitational attraction exerts a force of 980616 dynes, or 1 kilogramme weight.

General Definitions and Units

Velocity (LT^{-1}). A point which moves with uniform rate of change of position is said to have uniform velocity. The unit is a rate of change of position of 1 cm. per second.

Angular velocity (T^{-1}), or rate of change of angle. A rate of change of 1 radian (57·296°) per second is the unit.

Acceleration (LT^{-2}) or rate of change of velocity. When the velocity of a point changes at the rate of 1 cm. per second per second it is said to experience unit acceleration.

Angular acceleration (T^{-2}) : rate of change of angular velocity. The unit is 1 radian per second per second.

Force (LMT^{-2}). A mass which moves with acceleration is said to be acted upon by a force which is defined to be the product mass × acceleration. The unit is the Dyne, that force which, acting upon a mass of 1 gm., produces an acceleration of 1 cm. per second per second. The practical unit is the gramme weight, 980·616 dynes. (Sea level, lat. 45°.)

Energy or Work (L^2MT^{-2}). When a force moves its point of application in the direction in which the force is acting, it is said to do work. The work done in this way by a force of 1 dyne moving over a distance of 1 cm. is the unit of work, the Erg. The practical unit is the Joule, 10^7 ergs.

Power (L^2MT^{-3}), or the rate at which work is done. The unit is a rate of 1 erg. per sec. The practical unit is the Watt, 10^7 ergs. per sec. (also 1 volt-ampere or 1 joule per sec.). 1 horse-power equals 746 watts.

Density (ML^{-3}): the mass of unit volume of a substance. A substance of which 1 millilitre has a mass of 1 gm. is of unit density. The specific gravity of a substance is the ratio of its density to that of water.

Pressure ($L^{-1}MT^{-2}$). When a force is applied not at a point but over an area the force per unit area is known as the pressure. The unit is the dyne per sq. cm. A practical unit for meteorological purposes is the Bar, 10^6 dynes per sq. cm. 1 normal atmosphere (0° C., 760 mm. Hg, $g = 980{\cdot}665$) is equal to 1·01325 bar.

Absolute Electrical and Magnetic Units

Charge. The electro-magnetic unit, E.M.U., is the quantity delivered by unit current in one second (10 coulombs). The electro-static unit, E.S.U., repels an equal quantity 1 cm. away *in vacuo* with a force of 1 dyne ($1/3 \times 10^{-9}$ coulomb).

Current. 1 E.M.U., flowing in a circle of radius 1 cm., exerts a force of 2π dynes on a unit pole at the centre (10 amperes). The E.S.U. is a rate of flow equal to unit charge per second ($1/3 \times 10^{-9}$ ampere).

Electromotive force or potential difference. The E.M.U. confers on 1 E.M.U. charge the power to do 1 erg. of work (10^{-8} volt). The E.S.U. confers on 1 E.S.U. charge the power to do 1 erg of work (300 volts).

Resistance. Allows unit E.M.F. to produce unit current. (1 E.M.U. $= 10^{-9}$ ohm, 1 E.S.U. $= 9 \times 10^{11}$ ohms.)

Capacity. The unit is possessed by a conductor on which unit charge can be placed with the expenditure of 1 erg of work. (1 E.M.U. = 10^9 farad, 1 E.S.U. = $1/9 \times 10^{-11}$ farad.) A sphere of radius 1 cm. has in air a capacity of 1 E.S.U.

Magnetic pole strength. 1 E.M.U. is possessed by a pole which repels an equal pole 1 cm. away *in vacuo* with a force of 1 dyne.

Magnetic field strength. 1 E.M.U. is possessed by a field which exerts a force of 1 dyne on unit pole (1 gauss). (1 E.S.U. = $1/3 \times 10^{-10}$ gauss.)

Self or mutual inductance. 1 E.M.U. is possessed by a conductor in which unit E.M.F. is induced by unit change of current per second (10^{-9} henry). (1 E.S.U. = 9×10^{11} henry.)

Practical units.

The practical electrical units are the ampere, the volt, and the ohm. By the Weights and Measures (Electrical Standards) Order, 1949, these units when defined in terms of the c.g.s. electromagnetic units are now the legal units for Great Britain. The working standard in each case is embodied in an apparatus kept at the National Physical Laboratory, Teddington.

The M.K.S. (rationalised) system of units.

A system of units based on the metre, kilogramme, and second is coming into increasing use internationally, and finds favour because in many cases its units coincide with existing practical units. Since unit acceleration in this system is 1 m. per sec.^{2}, and the unit of mass is 1 kg. the unit of force (the newton) is 10^5 dynes. The acceleration due to gravity is 9·81 m. per sec.^{2}, and the practical unit of force, the kilogramme-weight, is 9·81 newtons. The unit of work or energy is the joule (1 newton-metre). Note that in this system the density of water is 1000 kg. per m.^{3}.

By adding as a fourth unit one of the practical electrical units it is possible to develop an internally consistent system in which the electrical units are the practical units ampere, volt, ohm, coulomb, farad, henry, watt. By adding a further postulate, that unit charge and unit pole be associated respectively with unit electric and unit magnetic flux (instead of with 4π units) a system of units known as the rationalised M.K.S. system is obtained, with which many of the equations of electromagnetism are simplified or made more symmetrical and analogies between field theory and circuit theory and between these theories and mechanics are emphasised. Its advantages are especially great when dealing with field problems and microwave engineering.

Units

The value in brackets gives the equivalent number of c.g.s. electromagnetic units.

Ampere. The constant current which produces a force of 2×10^{-7} newtons per m. between two parallel conductors through which it flows, if these conductors are infinitely long, of negligible cross section, and spaced *in vacuo* 1 m. apart. (1/10.)

Coulomb. The total charge transferred when a current of 1 ampere flows for 1 second. (1/10.)

Volt. A difference of potential of 1 volt exists between two points if 1 joule of work is done when 1 coulomb is transferred between them. (10^8.)

Ohm. The resistance of a conductor which passes 1 ampere when a difference of potential of 1 volt exists between its ends. (10^9.)

Unit electric field strength, 1 volt per m. (10^6), exists at a point if the force exerted on 1 coulomb at the point is 1 newton.

Unit total displacement or electric flux, Coulomb ($4\pi/10$). One unit of total displacement is associated with each unit of charge.

Unit displacement density. Coulomb per m.^{2} ($4\pi/10^5$). A density of tubes of displacement such that unit charge is displaced across unit area (1 m.^{2}) placed normal to them.

Unit capacitance, Coulomb per volt, Farad (10^{-9}) is possessed by a conductor if 1 joule of work is expended in giving the conductor unit charge. (With the assumption of the particular units of force and charge it is necessary to write the Coulomb equation in the form

$$F = Q_1Q_2/4\pi\kappa_0 r^2$$

where κ_0 takes the value $8{\cdot}854 \times 10^{-12}$ farad per m.)

Unit magnetic flux, Volt-second, Weber (10^8), is cut in a magnetic field in 1 sec. by a straight conductor maintained perpendicular to the flux, and moving with uniform velocity in a direction perpendicular both to itself and the flux, if a steady E.M.F. of 1 volt is induced in the conductor.

Unit magnetic flux density, Weber per m.^{2} (10^4).

Unit magnetic pole, Weber ($10^8/4\pi$), is associated with each tube of unit magnetic flux.

Unit magnetic field strength, Ampere per m. ($4\pi/10^3$), exists at a point in vacuo at which the flux density is $4\pi/10^7$ webers per m.^{2}.

Unit self or mutual inductance, Weber per ampere, henry (10^9), is possessed by a conductor when an E.M.F. of 1 volt is induced in it by a rate of change of current of 1 ampere per sec.

Heat Units.

The fundamental heat unit is now the joule, 10^7 ergs. The *Calorie* is the amount of heat required to raise the temperature of 1 gm. of water by 1° C. The 15° calorie is the amount required to raise the temperature from 14·5 to 15·5° C.

Mechanical equivalent of heat. One 15° calorie equals 4·1855 joules. One 20° calorie equals 4·1816 joules.

ASTRONOMICAL AND GEODETICAL DATA

Positions of Selected Fixed Stars

Jan. 1, 1958

Name.	Distance in light-years.	Right ascension.			Declination.	
		h.	m.	s.	°	
α Ursae Minor (Pole star) . . .	460	1	54	08	+ 89	04·1
α Tauri (Aldebaran)	57	4	33	30	+ 16	25·6
β Orionis (Rigel) .	540	5	12	31	− 8	15·0
α Aurigae (Capella) .	43	5	13	35	+ 45	57·5
α Canis Majoris (Sirius) . .	8·8	6	43	17	− 16	39·6
α Leonis (Regulus) .	56	10	06	08	+ 12	10·3
α Virginis (Spica) .	360	13	22	58	− 10	56·7
α Bootis (Arcturus) .	40	14	13	45	+ 19	24·0
α Scorpii (Antares) .	125	16	26	50	− 26	20·4
α Lyrae (Vega) .	27	18	35	31	+ 38	44·3
α Aquilae (Altair) .	16	19	48	44	+ 8	45·4
α Pegasi (Markab) .	85	23	02	40	+ 14	58·9

1 light year = $9{\cdot}5 \times 10^{12}$ km.
1 parsec. = $30{\cdot}8 \times 10^{12}$ km.

Constitution of the Atmosphere

Percentage by weight at sea level.		Percentage by weight at sea level.	
75·60	Nitrogen.	$3 \quad 10^{-6}$	Xenon.
23·05	Oxygen.	$8{\cdot}4 \quad 10^{-4}$	Neon.
1·3	Argon.	$7 \quad 10^{-5}$	Helium.
0·047	Carbon dioxide.	$7 \quad 10^{-6}$	Hydrogen.
$14 \quad 10^{-4}$	Krypton.		

Stratosphere begins at approx. 12 km.

Equivalent height of the Heaviside-Kennelly layer (Region E), 100 km.

Equivalent height of the Appleton layer (Region F), 230 km.

Mean temperature gradient = 6·5° C. per km.

Voltage gradient, average value in fine weather = 100 volts per metre.

Miscellaneous Constants

1° of latitude at the poles = 111·71 km.

1° of latitude at the equator = 110·56 km.

Constant of stellar aberration = 20·45″.

Constant of earth's precession = 50·26″ per year.

Nutation = 9·21″.

Gravitational constant (G) = $6{\cdot}670 \; 10^{-8}$ cm.^{3} gm.$^{-1}$ sec.$^{-2}$.

Length of seconds pendulum (period 2 secs.) = g/π^2.

at latitude 45° = 99·357 cm.

Formula for calculating g at any place :—

$$g = 980{\cdot}616 - 2{\cdot}5928 \cos (2 \times \text{latitude}) + 0{\cdot}0068 \cos^2 (2 \times \text{latitude}) - 0{\cdot}0003 \,(\text{ht. in metres}).$$

The Planets

Name.	Mean dist. from sun, 10^6 km.	Period.	Period of axial rotation.	Eccent. of orbit.	Inclin. of orbit to ecliptic.	Equatorial diameter, km.	Oblateness.	Mass, 10^{24} kgm.	Density, gm. cm.$^{-3}$	No. of satellites.	"g," cm. sec.$^{-2}$	Inclin. of equator to orbit.
Mercury .	57·85	87·97 d	—	0·206	7 0	5000	0	0·312	4·76	0	333	—
Venus .	108·11	224·70 d.	30 h.	0·007	3 24	12400	0	4·9	4·9	0	852	—
Earth . .	149·46	365·26 d.	23 h. 56 m.	0·017	0 0	12756·6	1/298	6·0	5·53	1	980·616	23° 27′
Mars . .	227·7	686·98 d. 1 y. 322 d.	24 h. 37 m. 23 s.	0·093	1 51	6783	1/192	0·65	3·96	2	377	23° 30′
Jupiter .	777·6	11 y. 314 d.	9 h. 50 m.	0·048	1 18	142600	1/15	1901·4	1·34	9	2510	3° 7′
Saturn .	1426	29 y. 167 d.	10 h. 14 m.	0·056	2 29	119000	1/9·5	568·8	0·71	10 and 3 rings	1072	26° 45′
Uranus .	2868·3	84 y. 5 d.	10 h. 45 m.	0·047	0 46	51500	1/14	87·7	1·27	4	883	98°
Neptune .	4494·3	164 y. 288 d.	15 h. 48 m.	0·009	1 47	49900	1/40	103	1·58	1	1100	151°
Pluto	5900	247 y. 255 d.	—	—	17 09	—	—	—	—	—	—	—

CONSTANTS OF THE SUN, EARTH AND MOON

Name.	Mean angular diameter.	Diameter, km.	Parallax.	Mass, kgm.	Density.	g, cm. sec.$^{-2}$	Temp. °C.	Period of axial rotation.	Other constants.
Sun	32′ 6·5″	$1{\cdot}392 \times 10^6$	8·81″	$1{\cdot}984 \times 10^{30}$	1·39	$27{\cdot}1 \times 10^3$	approx. 6000	25 d. 9·1 h.	Solar constant $=2{\cdot}00 \pm 0{\cdot}04$ cal. cm.$^{-2}$ min.$^{-1}$
Earth	—	equator 12756·6 polar 12713·7	—	$5{\cdot}98 \times 10^{24}$	5·517	980·616 (lat. 45°)	—	23 h. 56 m. 4·1 m.	Distance to sun $=149{\cdot}67 \times 10^6$ km. Distance to moon $= 384{\cdot}4 \times 10^3$ km. Sidereal year = 365 d. 6 h. 9 m. 10 s. Inclin. of equator to ecliptic = 23° 26′ 53·7″
Moon	31′ 6″	3478	57′ 2·7″	$7{\cdot}36 \times 10^{22}$	3·39	162	approx. 120 (lunar day)	27 d. 7 h. 43 m. 11 s.	Sidereal month = 27 d. 7 h. 43 m. 11 s.

12 o'clock midday (12) at Greenwich. Each country is given with its corresponding time according to the 24-hour system. Countries which use summer time are printed in italics.

BRITISH DOMINIONS, ETC.

Australia—
Northern Territory, 21½.
New South Wales, 22.
Queensland, 22.
South Australia, 21½.
Victoria, 22.
Tasmania, 22.
West Australia, 20.
Barbados, 8.
Brit. N. Borneo, 20.
Cameroons, 13.
Canada—
E. of long. 68°, 8.
Long. 68-89°, 7.
Central, 6.
W. of long. 103°, 5.
Ceylon, 17½.
Cyprus, 14.
Fiji, 24.
Gibraltar, 12.
Gold Coast, 12.
Hong-Kong, 20.
India (except Calcutta), 17½.
Jamaica, 7.
Kenya, 15.
Malay States Fed., 19.
Malta, 13.
Mauritius, 16.
New Zealand, 23½.
Nigeria, 13.
Palestine, 14.
Rhodesia, 14.
Sarawak, 19½.
Seychelles, 16.
Somaliland, 15.
Straits Settlements, 19.
Tanganyika, 15.
Trinidad, 8.
Uganda, 14½.
Union S. Africa, 14.
Zanzibar, 15.

PRINCIPAL FOREIGN COUNTRIES.

Albania, 13.
America, United States—
Atlantic Time, 8.
Eastern Time, 7.
Central Time, 6.
Mountain Time, 5.
Pacific Time, 4.
Alaska, 2.
Argentine, 8.
Austria, 13.
Belgium, 12.
Brazil, E., 9.
Central, 8.
W., 7.
Bulgaria, 14.
Chile, 7.
China, E., 20.
French Indo-, 19.
Columbia, 7.
Costa Rica, 6.
Cuba, 7.
Czechoslovakia, 13.
Denmark, 13.
Dominican, 7.
Egypt, 14.
Eritrea, 15.
Esthonia, 14.
Finland, 14.
France, 12.
Germany, 13.
Greece, 14.
Haiti, 7.
Holland, 12⅓.
Honduras, 6.
Hungary, 13.
Iceland, 11.
Iraq, 15.
Italy, 14.
Japan, Korea, 21.
Latvia, 14.
Lithuania, 13.
Luxembourg, 12.
Mexico, 6, 4.
Morocco, 12.
Norway, 13.
Panama, 7.
Peru, 7.
Poland, 13.
Portugal, 12.
Rumania, 14.
Salvador, 6.
Soviet Russia, 14, 15.
Spain, 12.
Sweden, 13.
Switzerland, 13.
Syria, 14.
Tunis, 13.
Turkey, 14.
Uruguay, 8½.
Venezuela, 7½.
Yugoslavia, 13.