Springer Series in Materials Science 122

S. V. Gupta

Units of Measurement

History, Fundamentals and Redefining the SI Base Units

Second Edition

Springer

Springer Series in Materials Science

Volume 122

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S. V. Gupta
National Physical Laboratory
New Delhi, India

ISSN 0933-033X ISSN 2196-2812 (electronic)
Springer Series in Materials Science
ISBN 978-3-030-43968-2 ISBN 978-3-030-43969-9 (eBook)
https://doi.org/10.1007/978-3-030-43969-9

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In loving memory of my wife Mrs. Prem Gupta

Preface to the Second Edition

Doing well in the first edition of the book has inspired me to write the second edition. The necessity and urgency arose due to redefining the SI base units in terms of fundamental constants and realization of the base units in terms of the defining constants. Each of the SI base units has been redefined in terms of a fundamental constant. Some of the units like second and metre were derived from the fundamental constants. Like the second was the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom. Now only the wording has changed. Same was the case of the base unit of length—metre, it was the distance travelled by light in vacuum during the interval of 1/299 792 458 of a second. Now the second is such that velocity of light is 299 792 458 ms^{-1}. In case of base units of mass, electric current and temperature, there are drastic changes. The unit of mass—kilogram—is such that Planck’s constant has a predefined value. Similarly unit of electric current—ampere—is such that electronic charge is 1.602 176 634 $\times 10^{-19}$ C. Boltzmann constant is used to define kelvin—the unit of temperature.

Realization of kilogram is drastically changed. The two methods, namely, electromechanical method through Kibble balance and XRCD (X-ray-crystal-density) method, have been described. Basics of Boltzmann constant and its determination by various methods have been described. Any of the methods preferably acoustic gas thermometry may be used to establish kelvin in terms of Boltzmann. On taking Planck's constant and electronic charge as redefining constants, i.e. each has a fixed value in SI units with zero uncertainty, Josephson constant and quantum Hall resistance have also become constant, so can be used to define as other electrical SI units.

I wish to thank Dr. D. K. Aswal, Director of National Physical Laboratory and President of the Metrology Society of India, New Delhi, who agreed to bring out this book.

Delhi
January 2020

S. V. Gupta

Preface to the First Edition

Professor A. R. Verma, former Director National Physical Laboratory, New Delhi inspired me for writing about the units of measurements as a chapter in my forthcoming book on Practical mass measurement. While travelling through India I have found excellent examples of metrology in our historical monuments and old temples. In Tiruchirappalli, I visited a temple which was in the centre of the city and had several identical big arch-shaped gates. The pathways were perpendicular to each other and all the gates along the road were exactly in one straight line. Inside the innermost sanctuary where the main deity was placed there was a small opening in the roof. The opening was positioned in such a way that every morning when the sun rose its first ray would pass through this opening and fall on the deity round the year. This made me think about the metrology in ancient times. So I wrote a chapter on metrology in olden days and its development in brief up to the present.

The International System of Units of measurement adopted in 1962 has seven base units as well as a host of derived and dimensionless units. The International Bureau of Weights and Measures occasionally publishes a booklet, which is an authentic document. Most of the National Measurement Laboratories like those in the USA and the UK strictly copy it and, in some cases, translate the document in their national languages. To make it clear that the number of base units need not be seven all the time, I discussed various three- and four-dimensional measuring systems. I established that minimum four base units are required in terms of which all other units of measurements can be expressed.

I have also attempted to provide a brief history of CGS and FPS systems. It has been found that FPS system is a few hundred years older that CGS or metric systems. Most of the national laboratories have strictly followed the latest available BIPM document. I have also followed the BIPM document on SI units 8th Edition of 2006. In this edition, a chapter on quantities, units and dimensions along with units used in specialized fields of health, biology and human health have been included. I have included them as such with all their notes and explanations. The new elements that I have added are the reasoning to arrive at the derived units, the explanation of base unit of ampere and the intensity of illumination, and the unification of electrostatic and electromagnetic units. Chapter 8 of the book deals with the future definitions of base units and their effects. One of the chapters also gives the brief life history of scientists who have been honoured by assigning their name to a unit.

The book is written in such a way that it caters to the need of one and all. Students of class X and above can profitably use Chapters 1 to 8 barring certain portions of Chapter 1, 2, 3 and 5. Biographies of the scientists associated with units of measurements will definitely be inspiring to young students and metrologists. The last two chapters are for specialists who are interested in redefining the units of measurements or in the evolution of a new measurement system based on fundamental constants. Metrologists at all levels will be delighted to know the origin of the names for base units and derived units.

I acknowledge the great help which I received from Dr. R. S. Davis, Head of Mass BIPM, Professor A. J. Wallard, Director BIPM, and Dr. Claudine Thomas, Secretary Consultative Committee of Units (CCU) at BIPM. They explained to me the meaning of the redefinition of the unit, keeping the same name and effect as the old unit. I wish to thank Dr. Vikram Kumar, Director National Physical Laboratory and President of the Metrology Society of India, New Delhi, who agreed to bring out this document. I will fail in my duty if I do not express my most sincere thanks to the referees to whom manuscript was sent. Each of them has gone into minute details and offered editorial suggestions. My thanks are also due to my daughter Mrs. Reeta Gupta, Scientist, National Physical Laboratory, New Delhi.

Delhi S. V. Gupta
June 2009

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Acronyms

Acronyms for International Organizations

BAAS	British Association for the Advancement of Science
BIH	Bureau International de l'Heure
CARICOM	Caribbean Community
CIE	International Commission on Illumination/Commission Internationale de l'Éclairage
IAU	International Astronomical Union
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission/Commission Électrotechnique Internationale
IERS	International Earth Rotation and Reference Systems Service
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
OIML	International Organization of Legal Metrology/Organisation Internationale de Métrologie Légale
SUNAMCO	Commission for Symbols, Units, Nomenclature, Atomic Masses and Fundamental Constants, IUPAP
TAI	International Atomic Time/Temps Atomique International
WHO	World Health Organization

Acronyms for Metre Convention and Associated Organizations

BIPM	International Bureau of Weights and Measures/Bureau International des Poids et Mesures
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration/ Comité Consultatif de l'Acoustique, des Ultrasons et des Vibrations

CCDS*	Consultative Committee for the Definition of the Second/Comité Consultatif pour la définition de la Seconde, see CCTF
CCE*	Consultative Committee for Electricity/Comité Consultatif d'Électricité, see CCEM
CCEM	(formerly the CCE) Consultative Committee for Electricity and Magnetism/Comité Consultatif d'Électricité et Magnétisme
CCL	Consultative Committee for Length/Comité Consultatif des Longueurs
CCM	Consultative Committee for Mass and Related Quantities/Comité Consultatif pour la Masse et les Grandeurs Apparentées
CCPR	Consultative Committee for Photometry and Radiometry/Comité Consultatif de Photométrie et Radiométrie
CCQM	Consultative Committee for Amount of Substance: Metrology in Chemistry/Comité Consultatif pour la Quantité de Matière : Métrologie en Chimie
CCRI	Consultative Committee for Ionizing Radiation/Comité Consultatif des Rayonnements Ionisants
CCT	Consultative Committee for Thermometry/Comité Consultatif de Thermométrie
CCTF	(formerly the CCDS) Consultative Committee for Time and Frequency/Comité Consultatif du Temps et des Fréquences
CCU	Consultative Committee for Units/Comité Consultatif des Unités
CGPM	General Conference on Weights and Measures/Conférence Générale des Poids et Mesures
CIPM	International Committee for Weights and Measures/Comité International des Poids et Mesures
CODATA	Committee on Data for Science and Technology IAU
CR	Comptes Rendus of the Conférence Générale des Poids et Mesures, CGPM
PV	Procès-Verbaux of the Comité International des Poids et Mesures, CIPM

Note: * Organizations marked with an asterisk either no longer exist or operate under a different acronym.

Acronyms for Scientific Terms

CGS	Three-dimensional coherent system of units based on the three
EPT-76	Provisional Low Temperature Scale of 1976/Échelle provisoire de température de 1976
IPTS-68	International Practical Temperature Scale of 1968
ITS-90	International Temperature Scale of 1990 mechanical units centimetre, gram and second

MKS	System of units based on the three mechanical units metre, kilogram and second
MKSA	Four-dimensional system of units based on the metre, kilogram, second and the ampere
SI	International System of Units/Système International d'Unités
TCG	Geocentric Coordinated Time/Temps-coordonnée Géocentrique
TT	Terrestrial Time
UTC	Coordinated Universal Time
VSMOW	Vienna Standard Mean Ocean Water

Chapter 1
Old Units of Measurement in India

The examples of old units of measurement have been divided into three parts, namely, Sect. 1.1 is for time intervals, Sect. 1.2 is for length intervals and Sect. 1.3 is for weight and volume.

1.1 Time Intervals

1.1.1 Introduction

1.1.1.1 Source of Information

Religious activities and scientific activities are also made part of the religious routine. Hindu religion is basically the way of living through various faiths. All literature regarding measurement is also hidden in the old religious books. There are 4 *Veda* and 18 *puran*s like *Srimad Bhagwad Puran*, *Bhavishya Puran*, *Agni Puran*, *Narad Puran*, *Vishnu Puran*, *Harivans Puran* and so on. *Srimad Bhagwad Gita*, *Mahabharat* and *Ramayan* are the other scriptures where knowledge is hidden under slokas (verses). Many Sastras like *Surya Siddhant* need to be mentioned.

Astronomy was the most advanced field out of the best of six sciences enunciated in *Vedas* [1]. So measurement of time and length was of paramount importance to ancient Indians.

1.1.1.2 Concept of Time

According to *Surya Siddhant* [2], the time is of two kinds. The former is continuous endless cycle with no origin or end, which destroys all (animates and

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S. V. Gupta, *Units of Measurement*, Springer Series in Materials Science 122,
https://doi.org/10.1007/978-3-030-43969-9_1

in-animates) and is also the cause of creation and preservation of everything. It is a continuous entity with no beginning or end. The second one is the time interval, which can be known; this is again of two kinds. One is measurable and the other is immeasurable. It may be immeasurable due to either its largeness like the day of *Brahma* of 4.32 billion years or being very small like *truti* 0.031 μs in Table 1.8.

1.1.1.3 Types of Time Scales

According to Surya Siddhant [2], there are nine types of standard time scales. Their names are (1) *Brahma*, (2) *Divya*, (3) *Prajapati*, (4) *Pitra*, (5) Jupiter, (6) Solar, (7) Terrestrial, (8) Lunar and (9) Sidereal. Each of these depends upon how the day is defined. Out of these nine scales, four, namely, Sidereal, Lunar, Terrestrial and Solar, are mostly used [2].

Terrestrial Day

The time between two consecutive sunrises is the terrestrial day. Its Hindi name is *Savan*.

Sidereal Day

Duration of one complete revolution of starry sphere is the Sidereal day. The sidereal day, in terms of SI units, is 23 h 56 m 4.1 s, slightly shorter than the solar day. The reason is the Earth's orbital motion about the Sun.

Solar Day

The solar day is the duration of time, which the Earth takes to make one complete revolution on its axis relative to the Sun. The solar day is the duration of day plus night at the equinoctial time (when the duration of day and night is equal).

Lunar Day

The lunar day is the time interval which Earth's Moon takes to complete one rotation on its axis with respect to the Sun. Due to tidal locking, it is also the time the Moon takes to complete one orbit around Earth and return to the same phase [3]. Lunar day is also the duration which Moon takes to describe 12° from the Sun.

1.1.2 *Time Intervals*

Oldest system for time measurement comes from India. Indian scriptures are full of information about the use of different time intervals. Smaller time intervals are in terms of the fractions of the day, while larger time intervals are multiples of a day or year. The span of time intervals is vast. *Vedic* and *Puranic* texts describe units of time intervals from *truti*, which is as small as 0.031 μs, to the age of *Brahma*, which is as large as 311.04 trillion years.

There are quite a few versions of smaller time intervals especially time intervals which are fraction of a day. From a day onward, the time intervals are practically the same.

1.1.2.1 Mention of Permanu, Anu and Treserenu in Shrimad Bhagwad Puran

The verse 1 of the *Srimad Bhagwad* Puran [5] states that the smallest particle of material substance, which has not yet combined with any other similar particles, is called "*permanu*, परमाणु" (a sub-atomic particle of matter). *Permanu* exists in both the dormant and manifest states of material existence. It is the combination of more than one *permanu* (sub-atomic particle) which gives rise to the illusory concept of a (material) unit. A combination of two *permanu* constitutes an "anu, अणु" (atom); and three "anu" (atoms) make one "*tresrenu*, त्रसरेणु" [6]. *Tresrenu* is visible to the naked eye and can be seen wandering in the air while viewed through rays of sunlight entering a dark room through a latticed window. Perhaps, this was the beginning of concept of defining time intervals in terms of *permanu* and *anu*.

1.1.2.2 Time Intervals as Fraction of a Day

Two sets of time intervals in which day has been divided into 182,250,000 parts [6–8], smallest part being named as truti equal to 473 μs approximately, are given in Tables 1.1 and 1.2.

Similar to the above table, there is another set of time intervals in which *permanu* and *anu* have been replaced by celestial atoms [8].

1.1.2.3 Time Intervals in Terms of Nimesh

In some scriptures, it is given that 1 निमेष is the time taken to pronounce a letter with one syllable *maatraa* मातरा or time taken for twinkling of eye.

Table 1.1 Smaller time intervals as given in Bhagwat

Name in Roman script		In Hindi	Equivalence in SI
permanu		परमाणु	Sub-atomic particle, indivisible and cannot contain life
2 *permanu*	1 *anu*	अणु	Combination of *permanu* is the smallest particle, which can freely exist
3 *aṇu*	*1 tresreṇu*	त्रसरेणु	A particle of dust; this can be seen coming from a window flying around in sunrays, can contain life and is divisible
3 *tresareṇu*	*truṭi*	त्रुटि	Whatever time the Sun takes to cross 3 Tresarenu is Truti, which equals nearly 473 µs
100 *truṭi*	*vedha*	वेघ	47.3 ms
3 *vedha*	*lava*	लव	0.14 s
3 *lava*	*nimeṣh*	निमेष	0.43 s
3 *nimesh*	*kṣaṇa* or *chhun*	क्षण	1.28 s
5 *kṣaṇa* or *chhun*	*kaaṣṭhaa*	काषठा	6.4 s
15 *kāṣṭhā*	*laghu*	लघू	1.6 min
15 *laghu*	*dand*, nadika	दण्ड, नाडिका	24 min
2 *dand* or *nadika*	*muhoort*	महूरत	48 min
6 or 7 *nadika*	*prahar*	प्रहर	Variable value depends upon time of the year
30 *muhooūrt*	*ahorātram* (Day)	अहोरातरम	24 h
30 *ahorātram*	*maash* (Month)	मास	30 days
2 *maash*	*ritu* (Season)	रितु	2 months
3 *ritu*	*ayan*	अयन	6 months
2 *ayan*	*samvatsara* (year)	समवतसर	360 days

Note *Depending upon the increase or decrease of the day time, there are 6 or 7 *nadika* in a *prahar*, which is also called as *yam*. Prahar is one-fourth of the day or night. The *prahar* is not of a fixed time. It depends upon whether we are talking about it for a day or for a night. In summer daytime, its value will be bigger in comparison to that at night time. The reverse will happen in winter season

**Dividing 86,400 s (the duration of the complete day) by number of partitions made of the day gives the value of the smallest time interval. The value of other time intervals is calculated by multiplying with successive multiplication numbers

Time Interval from Vishnu Puran

There is a set of time intervals given in *Vishnu Puran* [9] and *Harivans Puran* [10]; the day has been divided into 405,000.

Table 1.2 Smaller units of time used in the Vedas

Name in Roman script		In Hindi	Equivalence in SI
Celestial atom अणु		It is the smallest particle, which can freely exist	
6 celestial atoms	*tresrenu* त्रसरेणु	A particle of dust; this can be seen coming from a window flying around in sunrays, can contain life and is divisible	
3 *tresrenu*	1 *truti*	त्रुटि	473 µs
100 *truti*	1 *vedha*	वेघ	47.3 ms
3 *vedha*	1 *lava*	लव	0.14 s
3 *lava*	1 *nimesh*	निमेष	0.43 s
3 *nimesh*	1 *kshana*	क्षण	1.28 s
5 *kshana*	1 *kaashthaa*	काषठा	6.4 s
15 *kashtha*	1 *laghu*	लघू	1.6 min
15 *laghu*	1 *nadika* or *dand*	नाडिका दण्ड	24 min
2 *dand*	1 *muhoort*	महूरत	48 min
6 or 7 *dand*	1 *yam*	यम	Variable
4 *yam*	1 day or night	दिन य रात	Variable
8 *yam*	1 day and night	दिन और रात	24 h

Table 1.3 Time intervals in Vishnu Puraan

Name in Roman script		In Hindi	Equivalence in SI
nimesh		निमेष	0.2133 s
15 *nimesh*	*kaashthaa*	काषठा	3.2 s
30 *kaashthaa*	*kalaa*	कला	1.6 min
30 *kalaa*	*muhoort*	महूरत	48 min
30 *muhoort*	day and night	दिन और रात	24 h
15 days	1 *paksh*	पक्ष	
2 *paksh*	1 *maash*	मास	
2 maash	*ritu*	रितु	
3 *ritu*	1 *ayan*	अयन	
2 *ayan*	1 year	वर्ष	

Two ayans are, respectively, named as *Uttarayan* उत्तरायन, and *Dakshinayan* दक्षिणायन.

Time Intervals from Bhavishya Puran

Verse 231.15 of *Vishnu Puran* [9] states that for humans, Sun divides time into day and night. The day is for work and night is for sleep. A similar set of time intervals as given in Table 1.3 with two added steps from *kalaa* कला to *chhun* क्षन

Table 1.4 Smaller time intervals given in Bhavishya Puraan

Name in Roman script		Hindi	Equivalence in SI
nimesh		निमेष	0.018 s
15 *nimesh*	1 *kaashthaa*	काषठा	0.266 s
30 *kaashthaa*	1 *kalaa*	कला	8 s
30 *kalaa*	1 *kshan or chhan*	क्षण	4 min
12 *kshan* or *chhan*	*muhoort*	महूरत	48 min
30 *muhoort*	1 day and night	दिन और रात	24 h
30 day	1 month	मास	
2 months	1 *ritu*	रितु	
3 seasons	1 *ayan*	अयन	
2 ayan	1 *samvatsar*	समवतसर	

Table 1.5 Smaller time interval with an extra step Chhun and muhoort

Name in Roman script		In Hindi	Equivalence in SI
1 *nimesh*		निमेष	0.018 s
15 *nimesh*	1 *kaashthaa*	काषठा	2.7 s
30 *kaashthaa*	1 *kalaa*	कला	8 s
30 *kalaa*	1 *chhun*	क्षण	4 min
6 *chhun*	1 *ghadi*	घडिं	24 min
2 *ghadi*	1 *muhoort*	महूरत	48 min
30 *muhoort*	1 day	दिन	24 h
30 days	1 month	मास	
15 days	1 *paksh*	पक्ष	
2 *paksh*	1 month	मास	
2 months	1 season	रितु	
3 seasons	1 *ayan*	अयन	
2 *ayan*	1 year, Samvatsar	समवतसर	

and *chun* to *muhoort* महूरत are given in *Bhavishya Puran* [11]. These are given in Table 1.4 (4,860,000 parts in day).

A similar table with an extra step from *kala* कला to *chhunn* क्षन, *chhun* क्षन to *ghadi* घडिं and *ghadi* to *muhoort* महूरत [10] is given Table 1.5. A day is 4 860 000 parts.

1.1.2.4 Smaller Time Intervals in Steps of 60

Time Intervals Given in Steps of 60

Shushma [12] gave a set of time intervals in steps of 60. These are given in Table 1.6. Here we see that smallest time interval is *tatpar* त्तपर. It is 777 600 000th part of the day i.e. 0.111 ms.

Table 1.6 Smaller time intervals in terms of tatpar

Name in Roman script		In Hindi	Equivalence in SI
tatpar		त्तपर	0.111 ms
60 *tatpar*	1 *paraa*	परा	6.667 ms
60 *para*	1 *vilipt*	विलिपत	0.4 s
60 *vilipit*	1 *lipt*	लिपत	24 s
60 lipt	1 *ghatikaa* or *dand*	घटिका	1440 s
60 *ghatikaa*	1 day and night	दिन और रात	86,400 s

Table 1.7 Smaller time intervals from Surya Siddhant

Name in Roman script		Hindi	Equivalence in SI
pran		प्राण	4 s
6 *pran*	1 *pal*	पल	24 s
60 *pal*	1 *ghatika*	घटिका	24 min
60 *ghatika*	1 *nakshatra* sidereal day	नक्षेत्र आहौराात्रम	24 h
30 *nakshatra*	1 *maash*	मास	30 days

A set of smaller time intervals is given by Sushma Gupta [12]. In which the complete day has been divided into 291,600,000 parts in six unequal steps, the smallest of the time interval is truti which is approximately 0.0296 ms.

Yet, another set of smaller time intervals is given by the same author [12], in which the day is divided into 725,920,000 parts, smallest time interval named as truti which is equivalent to 0.0033333 s (Table 1.7).

Time Intervals from Surya Siddhant

A set of smaller time intervals is given in *Surya Siddhant* [13] and reproduced in Table 1.7. It may be seen that steps are in terms of 60 or its sub-multiple. Smallest time interval is 4 s, which is suitable for day-to-day use.

Time Intervals with Multiple Names

In the following Table 1.8, it may be seen that different names have been assigned to the same time interval. Source is Hindu units of time from Wikipedia [14].

Time Interval in Steps of 30

A set of time intervals in steps of 30 except the first step for *truti* [14] is given in Table 1.9. Here, a complete day is divided into 2,430,000,000 parts.

Table 1.8 Smaller time intervals with multiple names

Name in Roman script		Hindi	Equivalence in SI
truti		त्रुटि	0.031 μs
60 *truti*	*renu*	रेणु	1.86 μs
60 *renu*	*lava*	लव	0.11 ms
60 *lava*	līkṣaka	लिकषक	6.696 ms
60 *likshaka*	*lipta*	लिपत	0.401 s
	vipala	विपल	
60 *lipta*	*pal*	पल	24.1056 s
	vighaṭi	विघटि	
	vinaadī	विनाडि	
60 *vighati*	*ghaṭi*	घटि	24 min
	naadī	नाडि	
	dand	दँड	
2 ghati	*muhoort*	महूरत	48 min
60 ghati	nakṣatra	नक्षेत्र	24 h
30 muhoort	*ahoratram*	आहौरात्रम	24 h

Table 1.9 Time intervals in steps of 30

Name in Roman script		In Hindi	Equivalence SI
truti		त्रुटि	35.5 μs
100 *truti*	*tatpara*	त्तपर	3.55 ms
30 *tatpara*	*nimesh*	निमेष	106.7 ms
30 *nimesh*	*kaaṣṭhaa*	काषठा	3.2 s
30 *kaashthaa*	kalaa	कला	1.6 min
30 *kala*	*muhoort*	महूरत	48 min
30 *muhoort*	*nakṣatra*, *ahorātram*	नक्षेत्र आहौरात्रम	24 h

Ahoratram आहौरात्रम is the sidereal day

Table 1.10 Smaller range of Time intervals

Name in Roman script		In Hindi	Equivalence in SI
1 *vipal*		विपल	0.4 s
60 vipal	1 *pal*	पल	24 s
2 *pal*	1 *kalaa*	कला	48 s
30 *kalaa*	1 ghati	घटि	24 min
2.5 *ghati*	1 *hora*	हौरा	1 h

Another set of time intervals given in [15] with fewer steps is cited in Table 1.10. In this set, the day has been divided into 9000 parts, smallest time interval is vital equivalent to 0.4 s.

1.1.3 Sidereal Metrics

Time measurement in ancient India under the heading sidereal metrics [16] is given in Table 1.11. The sidereal day is the duration between two consecutive sunrises. In this case, one complete day has been divided into 21,600 parts.

1.1.4 Time Intervals in Chanakiya Arthsashtra

The time intervals as given by Chanakiya [17] are tabulated in Table 1.12. Here, a day is 1,440,000 parts.

Table 1.11 Sidereal metrics

Name in Roman script		In Hindi	Equivalence in SI
permanu		परमाणू	4 s
6 *permanu*	*vighati*	वघटि	24 s
60 *vighati*	*Gadhuya*	घडि	1440
2 *gadhuya*	*muhoort*	महूरत	2880 s
30 *muhoort*	*nakshatra ahoratram*	नक्षेञ आहौराञम	86,400 s

Table 1.12 Time intervals

Name of the units		SI equivalent	By Patrick
tuta		0.06 s	0.053 s
2 *tuta*	1 *lava*	0.12 s	0.107 s
2 *lava*	1 *nimesa*	0.24 s	0.2133 s
5 *nimesa*	1 *kasta*	1.2 s	3.2 s
30 *kasta*	1 *kala*	36 s	36 s
40 *kala*	1 *nalika*	24 min	24 min
2 *nalika*	1 *muhurta*	48 min	48 min
15 *Muhurta*	1 day or 1 night of the month of *Chaitra* or *Asvayuja*	12 h	12 h
30 *muhurta*	One day and night	24 h 86,400 s	24 h
15 complete days	1 fortnight	15×24 h	360 h
2 fortnights	1 month	30×24 h	720 h
2 months	1 season	60×24 h	1440 h
3 seasons	1 *ayan*	180×24 h	4320 h
2 *ayan*	1 year	360×24 h	8664 h
5 year	1 *yug*		5 years