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METROLOGY AND COINAGE IN ANCIENT INDIA AND CONTEMPORARY WORLD

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For the study of Metrology in ancient India, one has to base his studies on the ancient literature available, as well as on the archaeological findings. To build up a consistent description, we include the period from the Harappan or Ṛgvedic era to the Kuṣāṇa era, i.e., 2500 B.C. to 100 A.D.

In this paper it is shown that 'Aryan' unit of length 'Daṇḍa', identified as metre, has the same relation with earth's dimensions as we have in this modern age (1793 AD). Further the derivation of Indus inch, Greek inch and Attic inch from the unit 'Aṅgula' definitely prove that these belong to the same single universal system where 'Aṅgula' is 96th part of one daṇḍa or metre.

The study of weights and coinage may be divided into two broad divisions. Firstly, the theoretical discussions about the different weight standards and denominations used by different global civilizations at different periods based on the documental and literary references, then their adoption for minting the coins and their possible co-relations. The scientific investigations lead to prove that the Aryan unit of mass, the 'māṣa' is the mass of one cubic aṅgula of water. Thus, this unit mass is a scientifically based unit like gramme. Further we find that not only it provides a nice co-relation between different weight systems that were in use in India but also indicates its probable adoption by the various weight systems like Indus, Babylonian, Assyrian, Greek, Persian, Roman and British.

INTRODUCTION

For the study of metrology in ancient India, one has to base his studies on the ancient literature available as well as on the archaeological findings. To build up a consistent description, we include the period from the Harappan or Ṛgvedic era to the Kuṣāṇa era, i.e. 2500 BC to 100 AD.

In ancient India it seems that the unit of length was based on the length unit 'aṅgula' right from thê Vedic period down to that of Kuṣāṇa. The important multiples were parva of 3 aṅgula, *dhanurgraha* (*Muṣṭi*) of 4 aṅgula, vitasti of 12 aṅgula, hasta of 24 aṅgula, daṇḍa of 96 aṅgula and yojana of 8000 daṇḍa, where the relations of 'aṅgula' and yojana have been associated with the circumference and radius of the earth in the similar fashion as in the late eighteenth century A.D. and has wide acceptance in the modern scientific world.

The Indus inch[1] discovered at the sites of Harappa and Mohan-jo-Daro is nothing but the edge of the cube of the equivalent volume of a sphere of one muṣṭi of 4 aṅgula diameter. Further, it can be shown that the Greek inch[2] and Attic inch[2] are radii of the spheres of equivalent volumes of the cubes of one parva of 3 aṅgula and one muṣṭi of 4 aṅgula respectively.

What has been said above may be expressed as follows:

3 aṅgula	= 1 parva
4 aṅgula	= 1 muṣṭi
12 aṅgula	= 1 vitasti
24 aṅgula	= 1 hasta
96	= 1 daṇḍa
2000 daṇḍa	= 1 krośa
4 krośa	= 1 yojana

Ancient Unit 'Daṇḍa' and its Relation to Earths Perimeter

It will be interesting here if we discuss the first stanza of Puruṣa Sūkta of Ṛgveda where 'aṅgula' term appears. Puruṣa Sūkta is supposed to describe the evolution which took place on the earth. This evolution is possible only when one considers the surrounding atmosphere as one system and it seems that this sphere has been literally symbolized by the word 'Puruṣa'. The first Stanza of Puruṣa Sūkta[3] may be arranged in the prose form as follows:

Sahasra śīrṣā sahasrākṣaḥ sahasrapāt saḥ
Puruṣaḥ viśvataḥ bhūmīṃ vṛtvā daśāṅgulaṃ atyatiṣṭhat.

The perimeter of 1000 x 2000 x 2000 (aṅgula) symbolized as puruṣa which externally encircling the earth remains afar by ten aṅgula.

Then the circumference of the earth must be 24/25 of the perimeter of puruṣa.

Thus the circumference of the earth

$$= \frac{24}{25} \text{ of } 1000 \times 2000 \times 2000 \text{ aṅgula}$$

$$= \frac{24}{25} \times 4 \times 10^9 \text{ aṅgula} = 4 \times 10^7 \text{ daṇḍa}$$

According to Sūrya Siddhānta[4] the radius of the earth is 800 yojana. The radius in daṇḍa unit will be 64,00,000 daṇḍa. Therefore, the circumference of the earth $= 2 \pi\ 64 \times 10^5$ daṇḍa

$= 4 \times 10^7$ daṇḍa

Thus we find that whether in Ṛgveda or Jyotiṣa (Indian Astronomy), the value of the perimeters of the earth are numerically the same.

METRIC UNIT OF LENGTH, THE 'METRE'

On 1st August 1793, in France 'The Metre'[2] was originally defined as one tenth million of the quadrant from the equator to the north pole through Drunkirk and was widely accepted by the scientific world.

In the modern scientific age the equatorial circumference of the earth is measured and comes out to be 24900 miles[5] which when converted into metre stands 4×10^7 metre.

Thus, this numeral equvalence of ancient Indian and modern sicentific values of the equatorial circumfernce clearly yields

1 Daṇḍa = 1 Metre

1 aṅgula $= \frac{100}{96}$ cms = 1.0416 cms.

Thus the other denominations are as follows:

1 parva	= 3 aṅgula	= 3.125 cms.
1 muṣṭi	= 4 aṅgula	= 4.16 cms. = 1.64", and
1 yojana	= 8000 meter = 8 km. = 4 krośa = 5 miles	

THE 'INDUS INCH' MAY BE CONSIDERED NOW

The volume of a sphere of one 'Muṣṭi' diameter

$$= \frac{4}{3} \pi . \left[\frac{4.\overline{16}}{2}\right]^3 = 37.695\text{cc} = (3.3529\text{cms})3 = (1.32")3$$

Thus if a cube of 1.32 inch is formed, then the volume of this cube will be equal to that of a sphere of one musti diameter. Archaeologically the measure of Indus inch is 1.32".

This suggests that there was a peaceful relation too with Ṛgvedic and Harappan people. A similar conclusion may also be arrived at after the discussions of the various weight systems.

GREEK INCH[2]

Let us consider a sphere of r' of volume equal to that of a cube of edge of length of one parva (or 3 aṅgula). Then

$$= \frac{4}{3} \pi r'^3 = (3.125 \text{ cms})^3 \text{ or } r' = 1.938 \text{ cms.} = 0.76''$$

Thus the 'Greek Inch' unit is the radius of the sphere of equivalent volume of a cube of 1 'parva' (or 3 aṅgula) edge.

ATTIC INCH 2

Similarly, let us cinsider a sphere of r" or volume equal to that of a cube of edge of length of one muṣṭi (or 4 aṅgula), then

$$= \frac{4}{3} \pi r''^3 = (4.16 \text{ cms})^3 \text{ or } r'' = 2.58 \text{ cms.} = 0.016''$$

These findings clearly show that 'Aryan' unit of length 'Daṇḍa' identified as metre has the same relation with earth's dimensions as we have in this modern age. Further, the derivations of Indus inch, Greek inch and Attic inch from the unit 'aṅgula' definitely prove that these belong to the same single universal system.

UNIT AND DERIVED UNITS OF WEIGHT STANDARDS

The study of weights and coinage may be divided into two broad divisions. Firstly, the theoretical discussions about the different weight standards and denominations used by different global civilizations at different periods based on the documental and literary references, then their adoption for minting the coins and their possible correlations.

In India, there were various units of weight standards in use and these are clearly mentioned in various ancient literatures such as *Ṛgveda, Pāṇini Aṣṭādhyāyī, Mahābhārata, Smṛtis', Caraka Saṃhitā* etc. They may be chronologically arranged as shown in the Table-II. Further, if we do some exercise to scientifically investigate the different weight systems and their denominations, which seem to be independent in different periods, it appears that arbitrary choices were in use in India. Moreover, one may also find the relation between Indus, Babylonian, Indo-Greek, Persian, Roman and British weight systems, and probably one may find how they were scientifically based on the vedic weight standards, namely.

10 kṛṣṇala = 4 aṇḍaka = 1 māṣa

16 māṣa = 1 suvarṇa (the gold *pala* or vedic *pala*).

SCIENTIFIC INVESTIGATIONS

Kauṭilya states: "Sarva dhātūnāṃ gaurava vṛddhau sattvavṛddhiḥ" which means the increase in density (gaurava vṛddhiḥ) is increase in matter/price (sattva) for all metals (dhātu) of equal volumes. In ancient periods metals were used for exchange in the form of coins (punch marked).

In order to retain the size and shape of the coins or blocks of different metals it is very likely that for the different weight standards referred to different metals were in use. To keep their size comparable one may define different units of weights for different metals so that they may be inversely proportional to their respective densities. Considering the gold standard '*Suvarṇa*' or gold *pala* or Vedic *Pala* as the basis of other weight units, 'pala' referred to the respective metals can be derived. For instance as the densities of gold, silver, copper, and iron are 19.3, 10.5, 8.96, and 7.86 respectively, we may have

$$\text{Silver pala} = \frac{19.3}{10.5} \times \text{Suvarṇa} = 1.8 \times \text{Suvarṇa.}$$

$$\text{Copper pala} = \frac{19.3}{8.96} \times \text{Suvarṇa} = 2.1 \times \text{Suvarṇa.}$$

$$\text{Iron pala} = \frac{19.3}{7.86} \times \text{Suvarṇa} = 2.5 \times \text{Suvarṇa.}$$

It appears that Indians have approximated the density ratios to nearest whole numbers, and if we allow this,

Silver pala = Copper pala = 2 Suvarṇa = 2 x 16 māṣa = 32 māṣa
and Iron pala = 3 Suvarṇa = 3 x 16 māṣa = 48 māṣa.

Thus 1 dharaṇa = 3.2 māṣa = 32 kṛṣṇala
1 karṣa = 8 māṣa = 80 kṛṣṇala

These units are same as those Kauṭilya describes as Āyamānī weight system.

A similar weight system as described by Caraka[6] as pala (muṣṭi) equivalent to 48 māṣa is nothing but Iron pala of Āyamānī view.

Further Kauṭilya describes various balances (tulā) in three sets and gives the sizes of iron rods and their weights in lauha (iron) *pala*. Assuming as a common man's approach the diameters as 1,2 and 2.5 aṅgula respectively one may calculate the density of iron in māṣa per cubic anguli unit and tabulate as follows:

Mean density of iron for eighteen balances = 7.7 māṣa per cubic aṅguli.

Table-I
Calculated densities of different balance rods of Kautilya

Set Balance	Lenght in anguli	Weight in pala Iron	Dia-meter	Density: māṣa per cubic aṅguli
1. First ten balances having pans on both ends	8	1	1	7.64
2. (Samvartta)				
Āyamānī	72	32	2	7.42
Vyāvahārikī	60	33		7.64
Bhājanī	60	31		7.89
Antahpura-bhājanī	54	29		8.20
3. (Parimāṇī)				
Āyamānī	96	70	2.5	7.13
Vyāvahārikī	90	68		7.30
Bhājanī	84	66		7.68
Antaḥpura-bhājanī	78	64		8.02

Thus we find that the numerical value of the density of iron in māṣa per cubic aṅguli is more or less same as in gm per cc. Therfore, the māṣa should be the mass of one cubic aṅguli of water.

1 māṣa = 1 cubic aṅguli of water = $(1.04167)^3$ gms
= 1.13 gms, or, 17.5 grains (gt)

where 1 aṅguli = 1.04167 cms as we have already derived.

Indus System 1

The first series of the weights discovered at Indus valley (7) and denoted as A,B,C,D,E,F,G,H,I,J,K,L,M and N can now be easily shown to be in accordance with what has been described in Caraka Saṃhitā and pala or muṣṭi as Āyamānī Lauha pala or 48 māṣa which has been indentified as weight 'H' in the Table-II.

Indus System 2

The second weight series discovered has denominations like Caraka Saṃhitā with only difference that in this case pala or muṣṭi may be taken as Bhājanī lauha pala, where the density ration of gold to iron be taken as 2.5 (the ratio obtained by bhājana

Table II

The Various Ancient Global Weight Systems

Period	System	Based on Documental and Literary References			Based on Archaeological References		
		Weights & their Denominations	Designation	Weight	Symbol / Name	Weight	Remarks
1200 to 800 B.C.	(i) Vaidika System	10 Kṛṣṇala	1 Māṣa	1.1300 gm			Yet there is no Archaeological evidence
		4 Māṣa	1 Śāṇa	4.5200 gm			
		4 Śāṇa	1 Suvarṇa or Hiraṇya Pala	18.0800 gm			
		4 Suvarṇa	1 Niṣka	72.3200 gm			
	(ii) Indus System I	12 Aṇḍaka	1 A.L. Śāṇa (Āyamānī Louha Śāṇa)	3.3900 gm			In accordance with Caraka Saṃhitā
		3 Aṇḍaka	Pādaśāṇa	0.8475 gm	A	0.87 gm	
		6 Aṇḍaka	Śāṇaradha	1.6950 gm	B	1.76 gm	
		8 Aṇḍaka	2 Māṣaka	2.2600	C	2.28 gm	
		3 Māṣaka	1 A.L. Śāṇa	3.3900	D	3.41 gm	
		2 A.L. Śāṇa	1 Draṅkṣaṇa or Kola or Badar	6.7800 gm	E	6.82 gm	
		4 A.L. Śāṇa	1 Al. Karṣa	13.5600 gm	F	13.81 gm	
		8 A.L. Śāṇa	1 Palārdha or Muṣṭyardha	27.1200 gm	G	27.38 gm	
		16 A.L. Śāṇa	1 Muṣṭi	54.2400 gm	H	54.23 gm	
		40 A.L. Śāṇa		135.6000 gm	J	135.95 gm	
		50 A.L. Śāṇa		169.5000 gm	K	174.50 gm	
		80 A.L. Śāṇa	5 Muṣṭi	271.2000 gm	L	272.90 gm	
		160 A.L. Śāṇa	10 Muṣṭi	542.4000 gm	M	546.70 gm	
		400 A.L. Śāṇa	25 Muṣṭi	1356.0000 gm	N	1375.00 gm	
		4 Aṇḍaka	1 Māṣa			1.1825 gm	
		2.5 Māṣa	1 B.L. Śāṇa (Bhājanī Lauha Śāṇa)			2.96225 gm	

Period	System	Based on Documental and Literary References			Based on Archaeological References		
		Weights & their Denominations	Designation	Weight	Symbol / Name	Weight	Remarks
	(iii) Indus System II	1/3 B.L. Śāṇa		0.9850 gm	P	0.98 gm	
		2/3 B.L. Śāṇa		1.9700 gm	Q	2.07 gm	
		1 B.L. Śāṇa		2.9560 gm	R	3.03 gm	
		4/3 B.L. Śāṇa		3.9420 gm	S	3.92 gm	
		8 B.L. Śāṇa		23.6500 gm	T	24.50 gm	
		16 B.L. Śāṇa	1 Bhājanī Muṣṭi	47.3000 gm	U	47.30 gm	
	(iv) Heavy Assyrian System	1 Māṣa		1.1300 gm			
		1 Aṇḍaka		0.2825 gm	1 Aṇḍaka	0.279 gm	
		60 Aṇḍaka	1 Large Shekel	16.8000 gm	1 Shekel	16.75 gm	
		60 Large Shekel	1 Large Mina	1008.0000 gm	1 Mina	1005.00 gm	
		60 Large Mina	1 Talent	60480.00 gm	1 Talent	60303.00 gm	
		1 Talent		60480.00 gm	1 Talent	60303.00 gm	
		15 Mina		15120.00 gm	15 Mina	14933.00 gm	
		5 Mina		5040.00 gm	5 Mina	5043.00 gm	
		3 Mina		3024.00 gm	3 Mina	2865.00 gm	
		2 Mina		2016.00 gm	2 Mina	1962.00 gm	
		1 Mina		1008.00 gm	1 Mina	990.00 gm	
		2/3 Mina		672.00 gm	2/3 Mina	666.00 gm	
		1/4 Mina		252.00 gm	1/4 Mina	237.00 gm	
		1/5 Mina		201.00 gm	1/5 Mina	198.00 gm	
		1/6 Mina		168.00 gm	1/6 Mina	178.00 gm	
		1/8 Mina		126.00 gm	1/8 Mina	128.00 gm	
		3 Shekel		50.40 gm	3 Shekel	52.40 gm	
		2 Shekel		33.60 gm	2 Shekel	36.00 gm	
		1 Shekel	30 Aṇḍaka	8.40 gm			
		1 Talent		30240.00 gm	1 Talent	30240.00 gm	
		30 Mina		15120.00 gm	30 Mina	15120.00 gm	

Period	System	Based on Documental and Literary References			Based on Archaeological References		
		Weights & their Denominations	Designation	Weight	Symbol / Name	Weight	Remarks
	(v) Light Babylonian System	5 Mina		2520.00 gm	5 Mina	2520.00 gm	Mean Value of Shekel exactly tallies with that found by Marshall
		3 Mina		1512.00 gm	3 Mina	1512.00 gm	
		2 Mina		1008.00 gm	2 Mina	1003.00 gm	
		1 Mina		504.00 gm	1 Mina	504.00 gm	
		30 Shekel		252.00 gm	30 Shekel	252.00 gm	
		20 Shekel		168.00 gm	20 Shekel	168.00 gm	
		10 Shekel		84.00 gm	10 Shekel	84.00 gm	
		5 Shekel		42.00 gm	5 Shekel	42.00 gm	
		2 Shekel		16.80 gm	2 Shekel	16.80 gm	
		1 Shekel		8.40 gm	1 Shekel	8.40 gm	
		1/2 Shekel		4.20 gm	1/2 Shekel	4.20 gm	
		1/4 Shekel		2.10 gm	1/4 Shekel	2.10 gm	
		1/8 Shekel		1.05 gm	1/8 Shekel	1.05 gm	
800 to 500 B.C.	(vi) Kātyāyanī System or Viṃśatikā System	10 Kṛṣṇala 25 Kṛṣṇala 4 Pāda	1 Māṣa 1 Pāda 1 Pāṇitala Or Śatamāna	18.00 gm 45.60 gm 182.50 gm	Pāṇitala or Śatamāna	180.00 gt 177.30 gt	Bimbasāra Ajātaśatru
	(vii) South Indian System	4 Pāṇitala 20 Mañjadi	1 Bhājanī Muṣṭi 1 Vaidika Śāṇa or Kalañju	73.00 gt	Kalanju	73.00 gt	Nanda Dynasty
		10 Śana (Kalañju)	1 Bhājanī Muṣṭi or 40 Māṣa	730.00 gt			

Period	System	Based on Documental and Literary References			Based on Archaeological References		
		Weights & their Denominations	Designation	Weight	Symbol / Name	Weight	Remarks
400 B.C. and Onward	(viii) Dharna System	1 Māṣa 20 Sāmbya 10 Dharaṇa	1 Dharana 1 Ayamani Pala	17.50 gt 56.00 gt 560.00 gt	Dharṇa	56.00 gt	Maurya Dynasty
	(ix) Āyamānī System	1 Māṣa 4 Māṣa 4 Karṣa	1 Karṣa 1 Āyamānī Pala of 32 Māṣa	17.50 gt 140.00 gt	Kārṣāpaṇa	144.00 gt	
	(x) Vyâvahārikī System or Greek System	1 Māṣa 8 Drankṣaṇa 1 Dranksana	a 1 Vyâvaharikī pala of 30.4 Māṣa 3.8 Māṣa	17.50 gt 66.50 gt	Drachm	62.00 gt	
	(xi) Bhājanī System or Persian System	1 Masa 1 Karsa of Bhanani Pala of 28.8 Masa 1/6 Bhajani	7.2 Māṣa 4.8 Māṣa	18.00 gt 129.60 gt 86.40 gt	Kārṣāpaṇa Shekel Siglos	144.00 gt 130.00 gt 84.00 gt	
	(xii) Antaḥpura Bhājanī Systems or	1 Māṣa 1 Karṣa of Antaḥpura Bhājanī Pala		18.00 gt			

Period	System	Based on Documental and Literary References			Based on Archaeological References		
		Weights & their Denominations	Designation	Weight	Symbol / Name	Weight	Remarks
	(xiii) Avoirdupois or British System	1 Māṣa 40 Māṣa 10 Vaiṃśatikā Pala	 1 Vaiṃśika Pala 1 British Pound of 400 Māṣa	17.50 gt 700.00 gt 7000.00 gt	British Pound	7000.00 gt	
	(xiv) Apothecar-ies or Troy	1 Māṣa 32 Māṣa 10 Āyamānī Pala	 1 Āyamānī Pala 1 Troy Pound	18.00 gt 576.00 gt 5670.00 gt	Troy Pound	5760.00 gt	

Note : 1 -> Abbreviations : gm = Gramme, gt = Troy grain
: 2 -> Symbols A to U are in accordance with Marshall (1931)

or division). The Bhājanī lauha pala will be equal to 2.5 times Suvarṇa pala, i.e., .2.5 x 16 = 40 māṣa.

Heavy Assyrian and Babylonian Systems

It is well known that Heavy Assyrian and Babylonian unit of weight standards are sexagesimal systems where 60 large shekel is equal to one large mina and 60 large mina is equal to one talen. It is interesting to note that one lower member of this system is 'aṇḍaka' i.e. 60 aṇḍaka equals one large shekel showing 'aṇḍaka', which is one quarter of māṣa unit at the root of this Babylonian sexagesimal system.

Śatamāna System

800 to 500 BC in Northern India there was a system known as śatamāna equivalent to 100 kṛṣṇala (ratti) or 10 māṣa having a denomination as Pāda, a quarter of the śatamāna.

South Indian System

In South India there was a weight system in which twenty mañjadi was equal to the weight Kaḷañju, an equivalent of one śāṇa, or 4 māṣa, or one tenth of viṃśatikā or Bhājanī lauha pala belonging to the second system of Indus culture.

Dharaṇa System

Parallel to this system in 500 to 400 BC another system was prevailing in India. In this system 20 śāṃbya were equal to one dharaṇa, while 10 dharaṇa were equal to 1 Āyamānī pala.

Indo-Greek, Persian and Roman Systems

The other weight systems which have been described as Vyāvahārikī, Bhājanī and Antaḥpura bhājanī of weights 9.5, 9 and 8.5 dharaṇa respectively by Kauṭilya can also be well understood on the density ratio hypothesis. In fact these standards can be numerically obtained by considering the corresponding density ratios as 1.9, 1.8 and 1.7, which when multiplied by 5 yield 9.5, 9, and 8.5 respectively. As 1.8 is the actual ratio of densities of gold and silver and the bhājanī weight system is derived by this ratio it seems that the name Bhājanī is derived from bhajana- the division. The contemporary Greek, Persian and Roman weight systems as fixed by numismaticians seem to be Vyāvahārikī, Bhājanī and Antaḥpura bhājanī weight systems. These have been depicted in the Table-II.

The difference in density ratio (1.8 $\pm$ 0.1) may be accounted for purities of the metals in different parts of the world. The Indians have rounded it to two, though they were knowing the correct ratio as the name of the system. Bhājanī, itself suggests.

British and Troy Systems:

In western countries, before the advent of CGS or MKS system Avoirdupois pound or British pound, and Troy or Apothecaries pound were in use as the weight standards. Here it will be interesting to note that these weight units are simply 10 pala weights of Viṃśatikā and Āyamānī systems respectively.

Conclusion

These calculations, along with the archaeological data, not only confirm the Aryan unit of mass as māṣa, a scientifically based unit like gramme, but also indicate a probable adoption by the others with slight modifications, without mentioning māṣa, the Indian unit of mass.

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