Society of St. Francis Xavier, Pilar's
Fr. Conceicao Rodrigues College of Engineering
Fr. Agnel Technical Education Complex Bandstand
Bandra (West) Mumbai -400 050

SCIENCE, ENGINEERING AND TECHNOLOGY IN IKS: METALS AND METAL WORKING

ये धीवांनो रथका॒राः क॒र्मारा॒ ये मनी॒षिणः ।
उप॒स्तीन् प॑र्ण॒ मह्यं॒ त्वं सर्वा॑न् कृण्व॒भितो॒ जना॑न्॥६॥
[Atharvaveda, 3.5.6]

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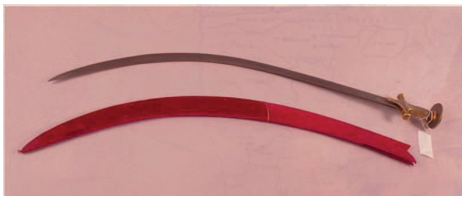
The Indian Science & Technology Heritage

This is a gold coin of the Gupta king Samudragupta (330–376 CE) kept at the British Museum. Samudragupta, with halo, standing facing left, wearing cap, decorated coat and trousers and earrings, holding a spear in left hand and making an offering with right hand over altar. In left field is a Garuda standard with ribbons and crescent above.

Stamping such coins with intricate details requires knowledge of mining, extraction of Gold and further metal forming techniques such as die casting.

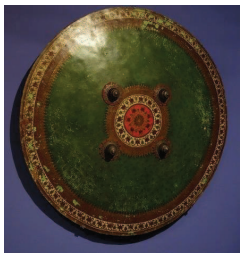
The Indian Science & Technology Heritage

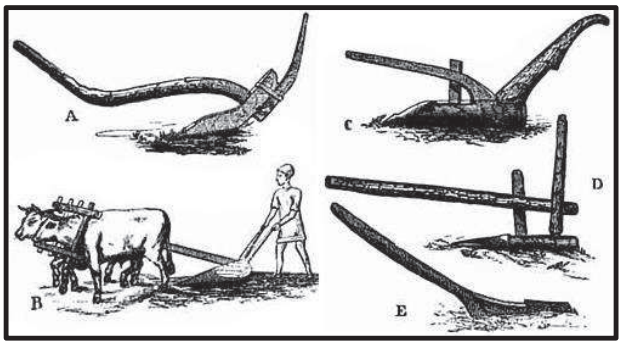


Famous Chola Era Idols.
Combination of five metals:

- Gold
- Silver
- Lead
- Copper
- Zinc

pañca-loha





Wootz Steel

Wootz steel is a crucible steel characterized by a pattern of bands and high carbon content. These bands are formed by sheets of microscopic carbides within a tempered martensite or pearlite matrix in higher-carbon steel, or by ferrite and pearlite banding in lower-carbon steels. It was a pioneering steel alloy developed in southern India in the mid-1st millennium BC and exported globally. It was used to manufacture '*Damascus Blades*'.

Sword of Tipu Sultan

With the advent of the ***carburisation*** of iron, a special type of high carbon steel was produced in India from as early as the fourth century BCE, known as wootz steel, used for military applications for producing tough swords, helmets, and armour.

The Indian Science & Technology Heritage

Andhra Pradesh Royal Earrings (1st Century BCE)

Evidence of the use of S & T in ancient times can be explored using any of the following three:

1. The archaeological evidence
2. Living examples of physical entities
3. Literary resources

> ***"There will never he another nation, which understood separate types of swords and their names, than the inhabitants of India……..***
> **- Al Biruni (973-1048 AD)**

S & T References in Ancient Indian Literature

Literary Sources for Science and Technology

Ṛgveda	Atharvaveda & Yajurveda	Chāndogya-upaniṣad, Taittirīya-brāhmaṇa	Rāmāyaṇa	Manusmṛti
• References to Iron, ironsmith and melting process in several passages • No mention of copper	• Mention of six metals (gold, silver, iron, tin, lead, copper) • Various technical occupational categories	• Mention of black metal and red metal	• Description of iron ores, metals and mines	• Mention of the use of household utensils made of copper, iron, bronze, brass, tin and lead and enjoins their purification with ashes, acid and water

S & T References in Ancient Indian Literature

Literary Sources for Science and Technology

Caraka and Suśruta Saṃhitās

- Description of surgical instruments
- Mention of six metals
- Alloys of copper (brass, zinc)
- Tools for surgical interventions

Arthaśāstra

- Primarily a book on statecraft and public administration
- Description of various warfare implements such as iron swords, arrows, axes, spades, etc.,
- Ores and mines of gold, silver, copper, iron, lead, tin and precious stones
- State functionaries such as superintendents of mines, ships and weaving
- Use of copper in making alloys and in gold and silver coins
- Goldsmith roles

Rasaratnākara of Nāgārjuna

- Reduction of metals
- Recipes for transmutation of base metals
- Yantras for carrying out several physio-chemical processes
- Alchemical processes and preparations of mercurial compounds

S & T References in Ancient Indian Literature

Literary Sources for Science and Technology

Bṛhat-saṃhitā of Varāhamihira

- Astronomy treatise
- Geological formations (rain, dust storm, water, etc.)
- Mining
- Earthquakes
- Yantras
- Medicine
- Botany
- Architecture (temple, idols, etc.)

Amara-kośa

- Technical terms
- Vocabulary

Yukti-kalpataru by Bhojarāja

- Architectural principles
- Ideas of different types of ships and shipbuilding

S & T References in Ancient Indian Literature

Literary Sources for Science and Technology

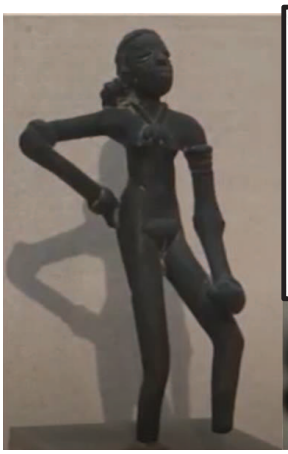
Samarāṅgaṇa-sūtradhāra of Mahārājādhirāja Bhojadeva	Mānasollāsa of king Sōmeśvara	Rasacintāmaṇi of Madanāntadeva
• Architectural principles • Different types of yantras (devices) • Ideas or aerial vehicles	• Process of making metal icons by the lost wax casting process	• Preparation of medicine • Information on chemistry and metallurgy • Production of zinc

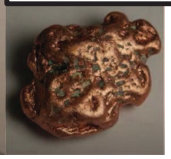
S & T References in Ancient Indian Literature

Literary Sources for Science and Technology

Rasaratna-samuccaya of Vāgbhaṭa
Contemporary method of production of zinc
Different categories of iron, mineral purification
Extraction of metals and mercury
Fuels, crucibles, furnaces
Metals, alloys and their properties
51 metallurgical implements
36 types of equipment
17 types of crucibles
9 types of furnaces
Pharmaceutical procedures of metals and minerals
Description of many herbo-metallic and mineral formulations

Mining and ore extraction



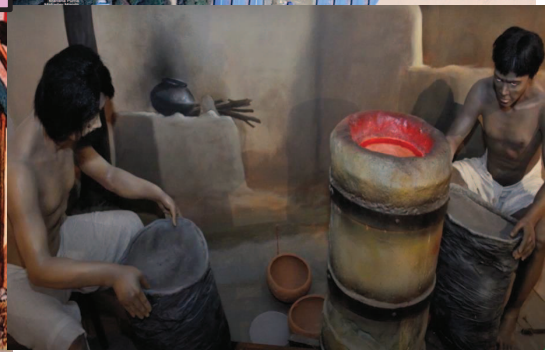


- In the Vedic texts, we find ample references to Gold, Silver, iron, copper, and their alloys.
- The Indian metal smiths were adept in alloy technology as they could produce alloys of controlled composition.

Statue of dancing girl made of Bronze (itself an alloy) found during Mohenzodaro times

- 1980- IIT Kanpur project on *recovery of Zinc from ancient slag*
- 1982- British Museum Research Lab- MS University Baroda- *discovery of Zinc distillation units, furnaces and retorts*

HINDUSTAN ZINC
Zinc & Silver of India



Modern parlance Dark Ages during which Indian were extracting metals

Ancient Mining and Ore Extraction Process

1. Fire setting - set fire and leave it for 3 days...
2. Quenching with water to create cracks in the rock
3. Extraction of the ore with hammering, chiselling and scrapping tools
4. Developed some more methods to further process the ore to get the molten metal
5. Underground excavations up to 500 feet are visible
6. Tunnels for improving the atmospheric condition at that level

Metals and Metalworking Technology

- The smelters and metalsmiths had gained a high degree of knowledge regarding furnace design, combustion of fuel, refractories, and skill in operating the furnaces at the desired temperature. They were also aware of the temperature specifications and other conditions required to carry out the process.

- The knowledge of the Indian metal smiths on Iron-Carbon alloy was clearly superior and ahead of the times. This is evident from their ability to produce the famous wootz steel, which was in demand in the West.

Metals and Metalworking Technology

- Indians were the *first to introduce Zinc to human civilisation and also to develop Cu-Zn alloys.*
- The Indian metal smiths were also adept in alloy technology as they could *produce alloys of controlled composition*.
- Indians developed good skills in designing and casting a variety of artefacts and deployed good moulding and diecasting methods. The available evidence suggests that they were casting small as well as large objects in the country.

Gold Extraction Process
Zinc Production
Copper Mining and Extraction Process
Copper Alloys
Mercury
Lead and Silver

Gold Extraction Process

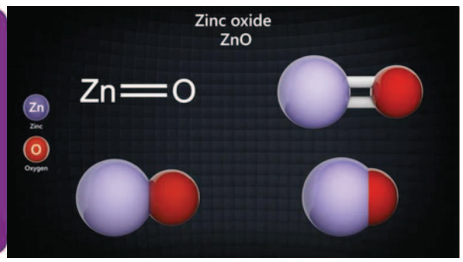
The process for the extraction of gold in ancient times has been analysed and documented by *Bharat Gold Mines Ltd.*

The main purpose of the extraction of gold was to make ornaments and coins. It was also used as **'Suvarṇa Bhasma'** in Āyurvedic preparations.

Kolar Gold Fields (K.G.F.)

Kolar Gold Fields (K.G.F.) is a mining location in the Kolar district of Karnataka, India.

Zinc Production

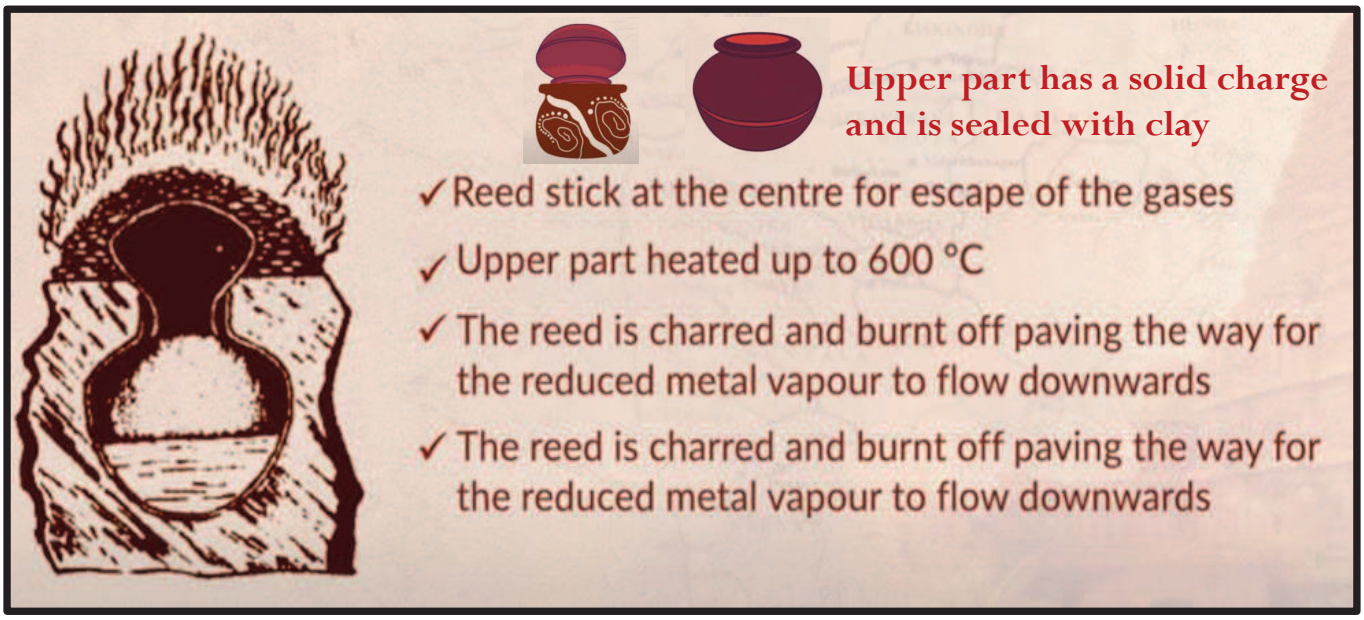


- ✓ Ancient Indians adopted a novel technique of *downward drift reduction distillation process* for Zinc production, which is a precursor to the modern processes adopted all over the world.
- ✓ The distillation apparatus found near the ancient Takṣaśilā (Needham) was unique and much advanced.

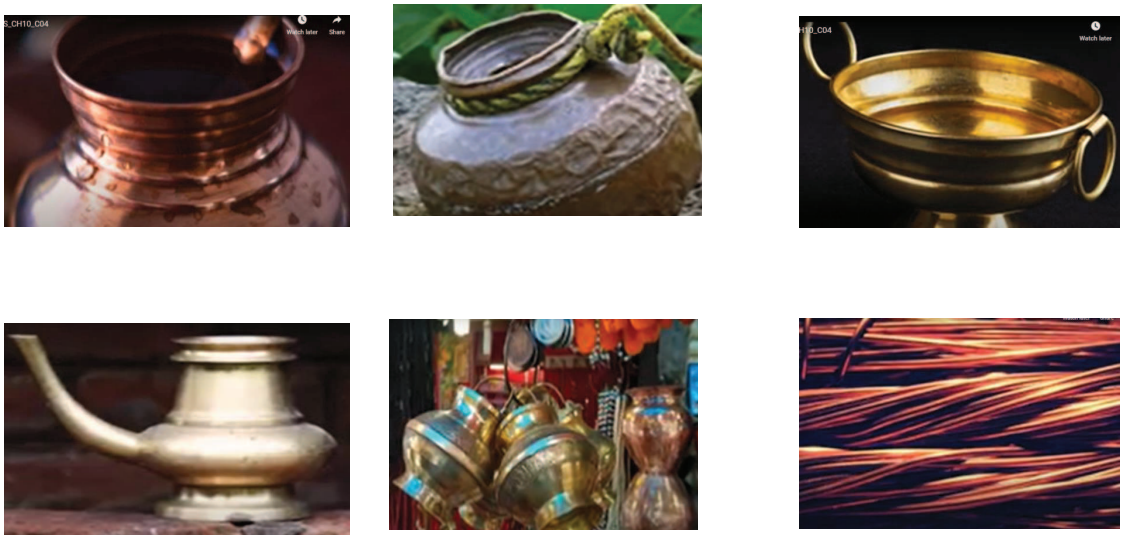
The principle of the downward drift distillation process can be explained in simple terms using the description of a yantra available in *Rasa-Ratna-Samuccaya (RRS)* for extraction of Zinc, Mercury, etc.

A Simple Illustration of the Yantra Used for Downward Drift Distillation Process

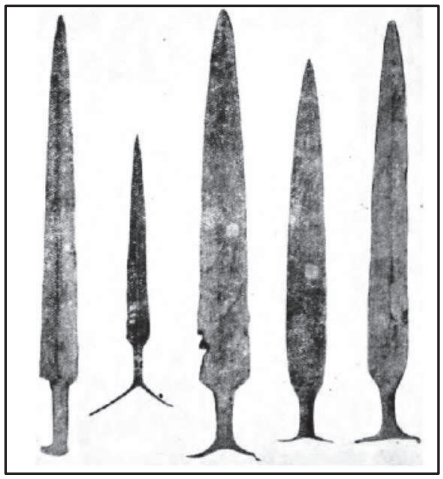
Zinc Production



Copper and Its Alloys



Copper in Ancient Times



Prehistoric Copper Swords
Discovered at Fatehgarh

Copper Statue of Buddha
Discovered at Sultangunj

- The Chinese traveller Hiuen Tsang has written that Indians knew the method of preparing brass from a mixture of Copper and Calamine.
- Rasa-ratna-samuccaya gives a vivid account of the processes of extraction of copper and its use in the preparation of various Āyurvedic formulations.

Copper Mining and Extraction Process

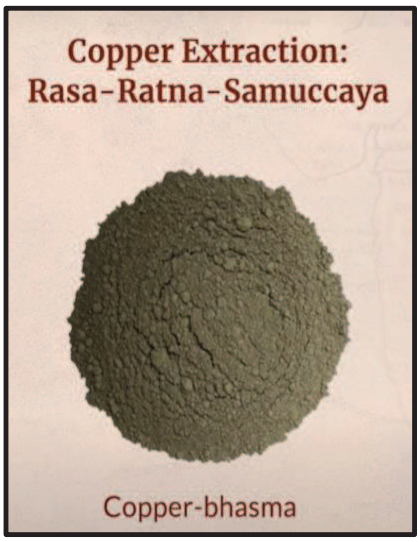
Varieties of Copper

Red	Black
High-purity (99.5%) Very ductile	Contains copper-oxides and other impurities such as Pb, Sn, Zn etc. Making it hard and brittle.

- During roasting Cu and Fe get converted into citrates
- Roasted ore mixed with 25% Borax (flux) and more lemon juice
- Mixture pressed into balls
- Dried in sunlight
- Melted at 1250 C in a 4 stage process
- Sulphide free copper is extracted

Copper Mining and Extraction Process

Extraction of Copper for Āyurvedic Purposes



RRS has mentioned many processes for obtaining pure copper from ***chalcopyrite*** by smelting small charges in crucibles.
In Āyurveda, copper in the powder form **(bhasma)** is used for therapeutic formulations.

Another process mentioned in the RRS is based on the precipitation of Cu from blue, vitriol solution (CuSO4) by the process of cementation. In this process, concentrated CuSO4 solution was kept in an iron bowl, where on the surface a copper layer was formed following the reaction given below:

$$CuSO_4 + Fe = FeSO_4 + Cu$$

Copper Alloys

Brass Objects in Ancient India

Date and Site	*Archaeological Specimen*
~ 1500 BCE Lothal	No. 4189 Copper Object
Harappan Rosdi	Chisel, Celtrod, Bangle
4th Century BCE, Takṣaśilā	Vase Bm
2nd Century BCE, Takṣaśilā	Bangle
2nd Century CE, Gujarat	Female Figure Carrying Flower-Container Indo-Parthian
5th Century CE	Gāndhāra Buddha
6th Century CE, Akota	Ambikā
7th Century CE, Mahudi	Ṛśabhanātha
8th Century CE, Kashmir	Śiva
9th Century CE, Nalanda	Buddha
11th Century CE, W. Tibet	Mañjuśri
Gujarat 1350 CE	Ambikā
~ 1480 CE	Model Temple with Four Doors 10 × 24.5 cm
~ 1485 CE	Viṣṇu-Nārāyaṇa
Rajasthan 15th–16th Centuries CE	Rajput Prince on Horse
Gujarat 1554 CE	Kal Bhairava

Mercury

$$HgS + O_2 \longrightarrow Hg + SO_2$$
$$3HgS + 2CaO \longrightarrow 2Cas + 3Hg + SO_2$$

- The technique of amalgamation and gilding of Mercury was known to the Indian craftsmen from the very early times.
- Geographically Rajasthan stands out as a major mining province dating back to about 1000 BCE.

Lead and Silver

PbS can be converted into PbO through a simple process of *roasting* and further reduced to molten lead at 500°C.

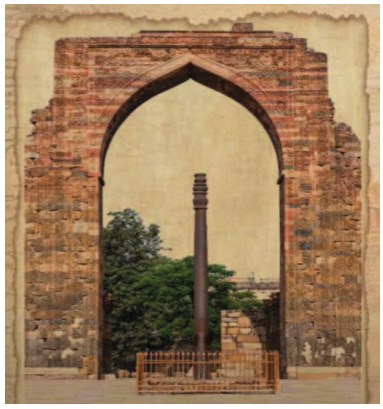
Kauṭilya's Arthaśāstra describes Silver–Copper alloys and the techniques applied for minting silver coins of a definite weight. The study of the punch marks on ancient coins indicates a high level of craftsmanship in the preparation of punching dies.

Iron and steel in India

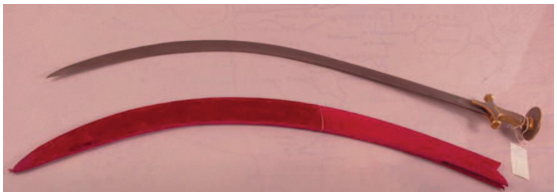
- Indians manufactured massive iron objects during the Christian era, which were much ahead of the times.
- The Suśruta saṁhitā has mentioned the fabrication of more than 100 surgical tools made of iron-carbon alloys and the process of heat treatment to obtain a razor-sharp edge.

The Thanjavur Cannon

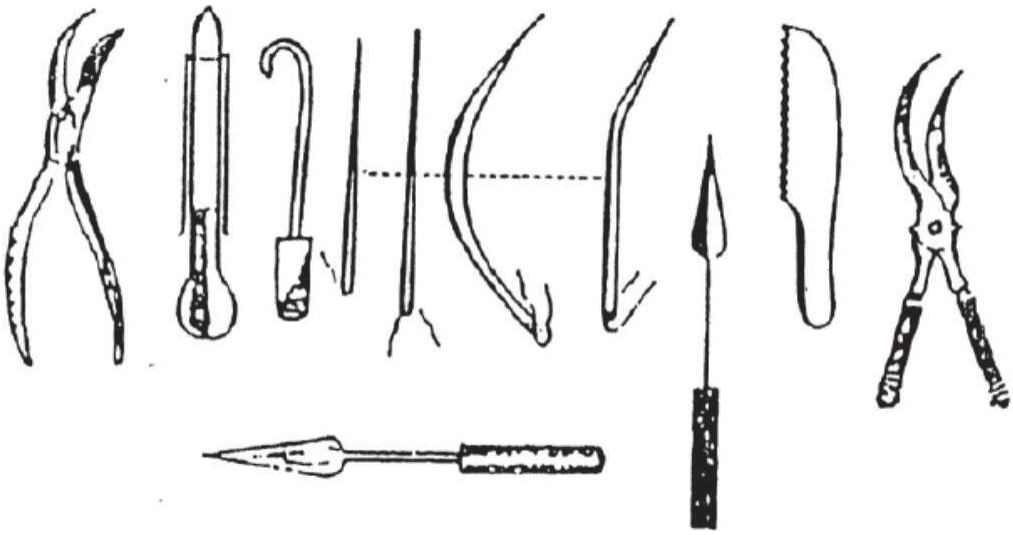
The Delhi Iron Pillar



Iron Pillor at Kutub Minar

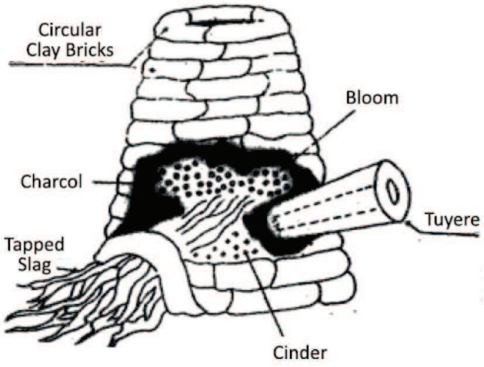


Ashoka pillar at Vaishali, Bihar



A Sample Set of Tools Designed by Suśruta Using Fe-C Alloy

Smelting of Iron



Sketch of a Reconstructed Furnace (700 BCE)

People Involved in Smelting:
Asuras: Eastern Part of India
Agarias: Iron ore to wrought iron
Loharins: Wrought iron to various tools and objects

Classification of Fe-C Steel Alloys as per Rasa-ratna-samuccaya

Type of Iron	*Name*	*Properties*
Kānta-loha (Soft Iron)	Bhrāmaka	Very soft, magnetic iron
	Cumbaka	Mildly magnetic, sticks to iron pieces
	Karṣaka	Attracts iron objects
	Drāvaka	Strong magnetic iron
	Romaka	Permanent magnet, develops magnetic field around it
Tīkṣṇa-loha (Carbon Steel)	Khara	Develops good cutting edge, breaks on bonding
	Sāra	Softer iron, it has fibrous fracture
	Hṛnnāla	Hard and tough, has fibrous fracture
	Tārāvaṭṭa	Develops good cutting edge
	Vājira	Good hardening and tempering property, bluish in colour, hard cutting edge
	Kāla	Develops hard cutting edge after tempering
Muṇḍa-loha (Cast Iron)	Mṛdu	Soft, brittle, low melting point
	Kuṇṭha	Grey iron
	Kadāra	White cast iron

सामान्याद् द्विगुणश्चोक्तं कलिर्दशगुणस्ततः । कलेः शतगुणं भद्रं भद्राद्वज्रं सहस्रधा ॥ 85.31
वज्रात् षष्टिगुणः पाण्डिर्निरविर्दशभिर्गुणैः । ततः कोटिसहस्रेण ह्ययस्कान्तः प्रशस्यते ॥ 85.32

sāmānyād dviguṇañcoktaṃ kalirdaśaguṇastataḥ | kaleḥ śataguṇaṃ bhadraṃ bhadrādvajraṃ sahasradhā || 85.31
vajrāt ṣaṣṭiguṇaḥ pāṇḍirniravirdaśabhirguṇaiḥ | tataḥ koṭisahasreṇa hyayaskāntaḥ praśasyate || 85.32

Yuktikalpataru an 11th century CE work mentions the relative properties of **iron-carbon alloys** produced in different regions of India and provides a comparative metric for their relative superiority as given below:

- **Krauñca**—iron is supposed to be two times better than Sāmānya (probably Muṇḍa-loha).
- **Kaliṅga** (Odisha)—8 times better than Crouñca iron.
- **Bhadra**—100 times better than Kaliṅga iron.
- **Vajra**—1000 times better than Bhadra iron.
- **Pāṇḍi**—6 times better than Vajra iron.
- **Niravi**—10 times better than Pāṇḍi iron.
- **Kānta**—Ten billion times as good as Niravi iron.

Extraction of Iron from Biotite by Āyurvedic Method

The suggested liquids used for purification of biotite are:

1. Kāñjī (Acidic fermentative liquid)
2. Triphalā (Decoction of a mixture of Terminienelia chebula, Terminalia belerica, and Emblica Officinalis)
3. Cow's urine
4. Cow's milk

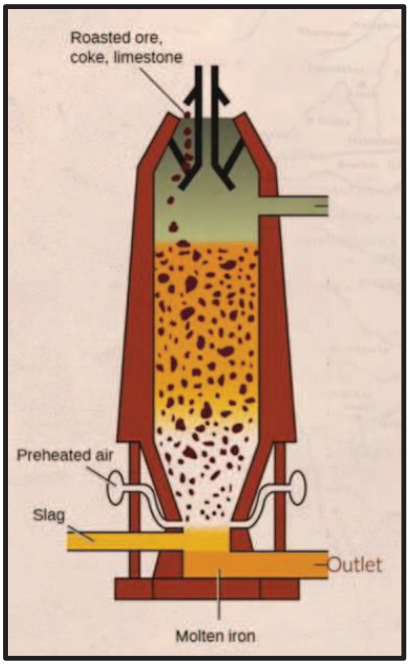
Varāhamihira (550 CE) in Bṛhat-saṃhitā discussed the following processes for **carburisation** and hardening of iron swords in Chapter 50 (verses 23–26):

- Make a paste of the gelatin from the sheep's horn and excreta of pigeon and mouse with the juice of the plant Arka (Caletropis Gigantica) and smear this to the steel after rubbing it with sesame oil. After heating the sword to red hot condition, sprinkle on it any of the following: water, milk of horse, camel or goat, ghee, blood, fat, or bile. Then sharpen the edge.
- Plunge the steel, red hot into a solution of plantain ashes in whey, keep it for twenty hours, and then sharpen the edge.

Manufacture of Steel

Steel may be prepared in two ways:

- firstly, by removing part of the carbon of cast iron before it is converted into wrought iron; or
- secondly, by carburising wrought iron or making it combine with the requisite quantity of carbon. The second process is called the *process of cementation*.



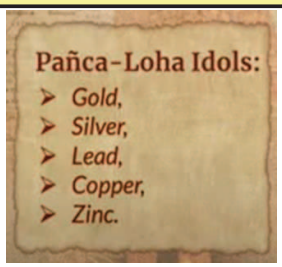
- Varāhamihira (550 CE) in Bṛhat-saṃhitā discussed the processes for carburisation and hardening of iron swords.
- The European method of cementation using charcoal used to take six or seven days, and even fourteen to twenty days, while the Indian process takes only four to six hours.

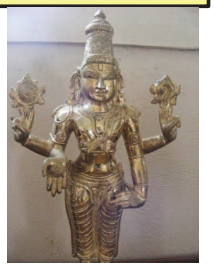
Lost wax casting of idols and artefacts

The beautiful idols and icons made during the Chola era were produced using bronze using this technique.

A 11th Century CE Bronze Idol of Śiva–Pārvatī

In this process, a pattern of the desired shape is made out of *beeswax* first (therefore the process is known as *Madhūcchiṣṭa Vidhānam*—meaning process using remains of beehives).

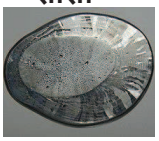




पंचधातु:

सोना 

चाँदी 

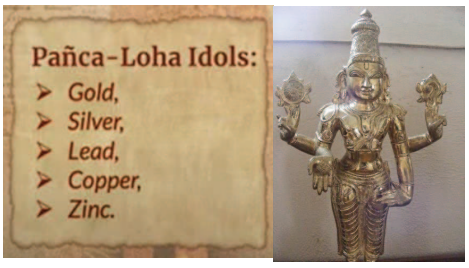
सीसा 

ताँबा 

जस्ता 

'kansa (bronze: alloy of Copper (Cu) 80%-95% , and Tin (Sn) 5%-15%)
'peetal (Brass: alloy of Copper (Cu) and Zinc (Zn).)'
'tamba (Copper: naturally product metal)'

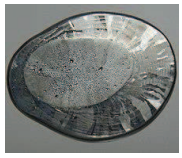
Lost wax casting of idols and artefacts



पंचधातु:

सोना 

चाँदी 

सीसा 

ताँबा 

जस्ता 

'kansa'
(bronze: alloy of Copper (Cu) 80%-95% , and Tin (Sn) 5%-15%)

'peetal'
(Brass: alloy of Copper (Cu) and Zinc (Zn).)

'tamba'
(Copper: naturally product metal)

Lost wax Metal casting Process

Literary Sources

- Viṣṇu-saṃhitā (part of Viṣṇu-purāṇa):
  - Chapter 14, mentions the need to make a wax model first before making a metal replica
- Mānasāra:
  - Chapter 68, details on Madhūcchiṣṭa Vidhānam
- Manasollāsa and Abhilāṣita-cintāmaṇi:
  - Detailed account of the method of preparation of wax pattern and slurry coating

Apparatuses used for extraction of metallic components

Metal working Engineers and Metalsmiths:

- Mining the Ore
- Extracting the Ore
- Shaping the metal

Ayurvedic Practitioners:

- Extracted metals
- Prepared therapeutic formulations using the powder form of the metals (bhasma)

Alchemists:

- Extracting metals
- Alchemical preparations

Apparatuses used for extraction of metallic components

- **Dolā-yantra** uses a suspension mechanism using which the ingredient to be subjected to some treatment is kept in a piece of cloth, tied, and suspended using a rod.
- **Svedanī-yantra** is used for steaming purposes.
- **Pātana-yantra** is used whenever a sublimation or distillation process is involved.
- **Dekī-yantra** is used for distillation of substances such as mercury.
- **Vālukā-yantra** is a type of sand bath for heating substances uniformly and for usually a long time.
- **Dhūpa-yantra** is used for fumigation purposes.

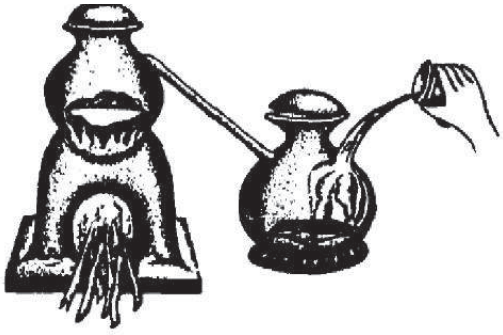
Mūṣā-Yantra:

It is a crucible, known is the frequently used apparatus. It serves as a generic container for a variety of operations

- Yuktikalpataru an 11th century CE work mentions the relative properties of iron-carbon alloys produced in different regions of India.
- The alchemist, the Āyurvedic expert, and the metalworking engineer seem to be benefiting from each other's know-how.

Dolā-yantra uses a suspension mechanism using which the ingredient to be subjected to some treatment is kept in a piece of cloth, tied, and suspended using a rod.

Svedanī-yantra
(used for steaming purposes:
Substance is steamed by boiling the water)

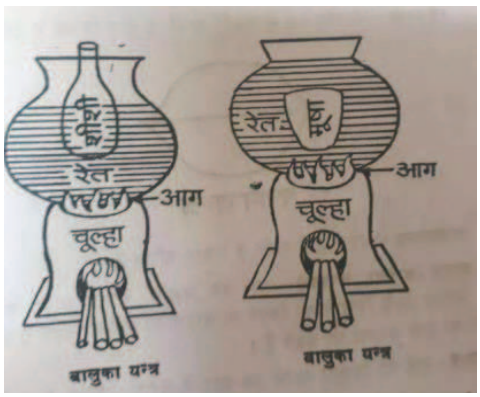


Pātana-yantra is used whenever a sublimation or distillation process is involved.

- ✓ For the downward distillation process, the vapour passes through a pipe into another pot kept alongside.
- ✓ The second pot is cooled with water and the vapour condenses into liquid and is collected in the second pot.

Dhūpa-yantra is used for fumigation purposes.

Dekī-yantra is used for distillation of substances such as mercury.



Vālukā-yantra is a type of sand bath for heating substances uniformly and for usually a long time

Rasa-ratna-samuccaya:

- Metallurgical tools (upakaraṇas)-51
- Equipment (yantras)-36
- Crucibles-17
- Furnaces-9

ಆಭಾರ ಶುಕ್ರಿಯಾಧನ್ಯವಾದ ತುಹಾಡಾ ಧಂಗವಾದ ನಂಡ್ರಿಧನ್ಯವಾದಾಲು
ಧನ್ಯವಾದಮಂತಿ धन्यवाद ಆಭಾರ ಶುಕ್ರಿಯಾಧನ್ಯವಾದ ತುಹಾಡಾ ಧಂಗವಾದ
ನಂಡ್ರಿ ಧನ್ಯವಾದಾಲು ಧನ್ಯವಾದ ಮಂತಿಆಭಾರ ಶುಕ್ರಿಯಾಧನ್ಯವಾದ ತುಹಾಡಾ
ಧಂಗವಾದ ನಂಡ್ರಿಧನ್ಯವಾದ ಧನ್ಯವಾದಮಂತಿಆಭಾರ ಶುಕ್ರಿ
ધન્યવાદ ತುಹಾಡಾ ಧಂಗವಾದ ನಂಡ್ರಿಧನ್ಯವಾದಾಲು ಧನ್ಯವಾದಮಂತಿ
ಆಭಾರ ಶುಕ್ರಿಯಾ ತುಹಾಡಾ ಧಂಗವಾದ धन्यवाद
ನಂಡ್ರಿಧನ್ಯವಾದಾಲು धन्यवाद ಧನ್ಯವಾದಮಂತಿ ಆಭಾರ ಶುಕ್ರಿ
ધન્યવાદ ತುಹಾಡಾ ಧಂಗವಾದ ನಂಡ್ರಿಧನ್ಯವಾದಾಲು ಧನ್ಯವಾದಮಂತಿ
धन्यवाद ಧನ್ಯವಾದಮಂತಿ ಆಭಾರ ಶುಕ್ರಿಯಾಧನ್ಯವಾದ ತುಹಾಡಾ ಧಂಗವಾದ
ನಂಡ್ರಿಧನ್ಯವಾದಾಲು ಧನ್ಯವಾದಮಂತಿ ಆಭಾರ ધન્યવાદ ತುಹಾಡಾ ಧಂಗವಾದ
ನಂಡ್ರಿಧನ್ಯವಾದಾಲು धन्यवाद ತುಹಾಡಾ ಧಂಗವಾದ
ನಂಡ್ರಿಧನ್ಯವಾದಾಲು

धन्यवाद

Thank you