Knowledge

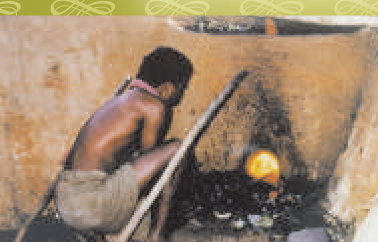
TRADITIONS & PRACTICES OF INDIA

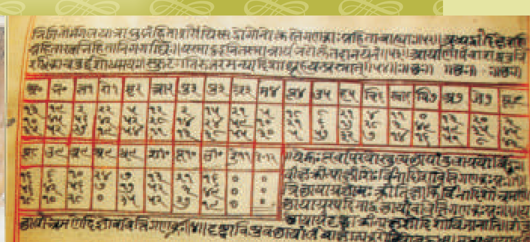
Textbook for Class XI

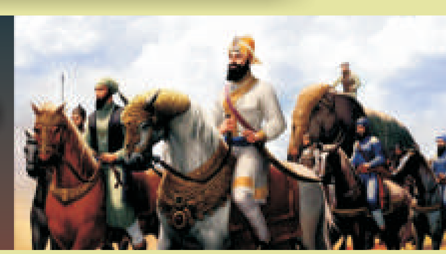
Statue of Kannagi, Chennai

Module 8

Metallurgy in India







CENTRAL BOARD OF SECONDARY EDUCATION

Shiksha Kendra, 2, Community Centre, Preet Vihar,
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अब परिणामों के भय से
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बदले शिक्षा का स्वरूप
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बेहतर शिक्षा से बदले देश, ऐसे इसे अपनाए
शिक्षक, शिक्षा और शिक्षित
बस आगे बढते जाएँ
बस आगे बढते जाएँ
बस आगे बढते जाएँ.........

CBSE
CONTINUOUS AND COMPREHENSIVE EVALUATION
KNOW - AS YOU GROW

Knowledge TRADITIONS & PRACTICES OF INDIA

Textbook for Class XI

Module 8

Metallurgy in India

CENTRAL BOARD OF SECONDARY EDUCATION
Shiksha Kendra, 2, Community Centre, Preet Vihar, Delhi-110 092 India

Preface

India has a rich tradition of intellectual inquiry and a textual heritage that goes back to several hundreds of years. India was magnificently advanced in knowledge traditions and practices during the ancient and medieval times. The intellectual achievements of Indian thought are found across several fields of study in ancient Indian texts ranging from the Vedas and the Upanishads to a whole range of scriptural, philosophical, scientific, technical and artistic sources.

As knowledge of India's traditions and practices has become restricted to a few erudite scholars who have worked in isolation, CBSE seeks to introduce a course in which an effort is made to make it common knowledge once again. Moreover, during its academic interactions and debates at key meetings with scholars and experts, it was decided that CBSE may introduce a course titled 'Knowledge Traditions and Practices of India' as a new Elective for classes XI - XII from the year 2012-13. It has been felt that there are many advantages of introducing such a course in our education system. As such in India, there is a wide variety and multiplicity of thoughts, languages, lifestyles and scientific, artistic and philosophical perceptions. The rich classical and regional languages of India, which are repositories of much of the ancient wisdom, emerge from the large stock of the shared wealth of a collective folklore imagination. A few advantages given below are self explanatory.

- India is a land of knowledge and traditions and through this course the students will become aware of our ancient land and culture.
- Learning about any culture particularly one's own culture - whatever it may be - builds immense pride and self-esteem. That builds a community and communities build harmony.
- The students will be learning from the rich knowledge and culture and will get an objective insight into the traditions and practices of India. They will delve deeply to ascertain how these teachings may inform and benefit them in future.
- The textbook has extracts and translations that will develop better appreciation and understanding of not only the knowledge, traditions and practices of India but also contemporary questions and issues that are a part of every discipline and field in some form or another.

This course once adopted in schools across India can become central to student learning: each student brings a unique culture, tradition and practice to the classroom. The content is devised in a way that the educator becomes knowledgeable about his/her students' distinctive cultural background. This can be translated into effective instruction and can enrich the curriculum thereby benefitting one and all. This insight has close approximation with the pedagogy of CCE.

The course is designed in a way that it embodies various disciplines and fields of study ranging from Language and Grammar, Literature, Fine Arts, Agriculture, Trade and Commerce, Philosophy and Yoga to Mathematics, Astronomy, Chemistry, Metallurgy, Medicine and Surgery, Life Sciences, Environment and Cosmology. This can serve as a good foundation for excellence in any discipline pursued by the student in her/his academic, personal and professional life.

This book aims at providing a broad overview of Indian thought in a multidisciplinary and interdisciplinary mode. It does not seek to impart masses of data, but highlights concepts and major achievements while engaging the student with a sense of exploration and discovery. There is an introduction of topics so that students who take this are prepared for a related field in higher studies in the universities.

The examination reforms brought in by CBSE have strengthened the Continuous and Comprehensive Evaluation System. It has to be ascertained that the teaching and learning methodology of CCE is adopted by the affiliated schools when they adopt this course. The contents have to cultivate critical appreciation of the thought and provide insights relevant for promoting cognitive ability, health and well-being, good governance, aesthetic appreciation, value education and appropriate worldview.

This document has been prepared by a special committee of convenors and material developers under the direction of Dr. Sadhana Parashar, Director (Academic & Training) and co-ordinated by Mrs. Neelima Sharma, Consultant, CBSE.

The Board owes a wealth of gratitude to Professor Jagbir Singh, Professor Kapil Kapoor, Professor Michel Danino, and all those who contributed to the extensive work of conceptualizing and developing the contents. I sincerely hope that our affiliated schools will adopt this new initiative of the Board and assist us in our endeavour to nurture our intellectual heritage.

Vineet Joshi
Chairman

Convenor's Note by Professor Jagbir Singh

In 2012, CBSE decided to introduce an Elective Course 'Knowledge Traditions and Practices of India' for classes XI and XII and an Advisory Committee was constituted to reflect on the themes and possible content of the proposed course. Subsequently Module-Preparation Committees were constituted to prepare ten modules for the first year of the programme to include the following Astronomy, Ayurveda (Medicine and Surgery), Chemistry, Drama, Environment, Literature, Mathematics, Metallurgy, Music and Philosophy.

Each module has;

I. A Survey article

ii. Extracts from primary texts

iii. Suitably interspersed activities to enable interactive study and class work

iv. Appropriate visuals to engender reading interest, and

v. Further e- and hard copy readings.

Each module in the course has kept in mind what would be a viable amount of reading and workload, given all that the class IX students have to do in the given amount of time, and controlled the word-length and also provided, where needed, choices in the reading materials.

Each Module consists of:

I. A Survey Essay (about 1500-2000 words) that introduces and shows the growth of ideas, texts and thinkers and gives examples of actual practice and production.

ii. A survey-related selection of extracts (in all about 2000 words) from primary sources (in English translation, though for first hand recognition, in some cases, where feasible, the extracts are also reproduced in the original language and script).

iii. Three kinds of interactive work are incorporated, both in the survey article and the extracts - comprehension questions, individual and collective activities and projects (that connect the reading material and the student to the actual practice and the environment).

iv. Visuals of thinkers, texts, concepts (as in Mathematics), practices.

v. Internet audiovisual resources in the form of URLs.

vi. List of further questions, and readings.

The objective of each module, as of the whole course, is to re-connect the young minds with the large body of intellectual activity that has always happened in India and, more importantly, to enable them (i) to relate the knowledge available to the contemporary life, theories and practices, (ii) to develop, wherever feasible, a comparative view on a level ground of the contemporary Western ideas and the Indian theories and practices, and (iii) to extend their horizons beyond what is presented or is available and contemplate on possible new meanings, extensions and uses of the ideas - in other words to make them think.

We have taken care to be objective and factual and have carefully eschewed any needless claims or comparisons with western thought. Such things are best left to the readers' judgement.

This pedagogical approach clearly approximates CBSE's now established activity-oriented interactive work inviting the students' critical responses.

It is proposed to upload the first year's modular programme to be downloaded and used by schools, teachers and students.

As a first exercise, we are aware that the content selection, a major difficult task, can be critically reviewed from several standpoints. We do not claim perfection and invite suggestions and concrete proposals to develop the content. We are eagerly looking forward to receiving the feedback from both teachers and students. That would help us refining the content choice, the length and the activities. We will also thankfully acknowledge any inadvertent errors that are pointed out by readers.

The finalisation of this course is thus envisaged as a collective exercise and only over a period of time, the Course will mature. We know that perfection belongs only to God.

If our students enjoy reading these materials, that would be our true reward.

Prof. Jagbir Singh
Convenor

Acknowledgement

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Content of Module 8

Metallurgy in India: A Survey

Technology is today defined as applied science, but early humans developed technologies — such as stone-working, agriculture, animal husbandry, pottery, metallurgy, textile manufacture, bead-making, wood-carving, cart-making, boat-making and sailing — with hardly any science to back them up. If we define technology as a human way of altering the surrounding world, we find that the first stone tools in the Indian subcontinent go back more than two million years! Jumping across ages, the 'neolithic revolution' of some 10,000 years ago saw the development in agriculture in parts of the Indus and the Ganges valleys, which in turn triggered the need for pots, water management, metal tools, transport, etc.

Agriculture apart, metallurgy brought about important changes in human society, as it gave rise to a whole new range of weapons, tools and implements. Some of these had been made in stone earlier, it is true, but the result was coarser as well as heavier. Metal, precious or not, is also a prime material for ornaments, and thus enriches cultural life.

What changes did agriculture bring to early human societies?

Metallurgy may be defined as the extraction, purification, alloying and application of metals. Today, some eighty-six metals are known, but most of them were discovered in the last two centuries. The 'seven metals of antiquity', as they are sometimes called, were, more or less in order of discovery: gold, copper, silver, lead, tin, iron and mercury. For over 7,000 years, India has had a high tradition of metallurgical skills; let us see some of its landmarks.

What properties made these 'seven metals' more popular than others in antiquity?

Metallurgy before and during the Harappan Civilization

The first evidence of metal in the Indian subcontinent comes from Mehrgarh in Baluchistan, where a small copper bead was dated to about 6000 BCE; it is however thought to have been native copper, not the smelted metal extracted from ore. The growth of copper metallurgy had to wait for another 1,500 years; that was the time when village communities were developing trade networks and technologies which would allow them, centuries later, to create the Harappan cities.

Archaeological excavations have shown that Harappan metal smiths obtained copper ore (either directly or through local communities) from the Aravalli hills, Baluchistan or beyond. They soon discovered that adding tin to copper produced bronze, a metal harder than copper yet easier to cast, and also more resistant to corrosion. Whether deliberately added or already present in the ore, various 'impurities' (such as nickel, arsenic or lead) enabled the Harappans to harden bronze further, to the point where bronze chisels could be used to dress stones! The alloying ranges have been found to be 1%–12% in tin, 1%–7% in arsenic, 1%–9% in nickel and 1%–32% in lead. Shaping copper or bronze involved techniques of fabrication such as forging, sinking, raising, cold work, annealing, riveting, lapping and joining.

Among the metal artefacts produced by the Harappans, let us mention spearheads, arrowheads, axes, chisels, sickles, blades (for knives as well as razors), needles, hooks, and vessels such as jars, pots and pans, besides objects of toiletry such as bronze mirrors; those were slightly oval, with their face raised, and one side was highly polished. The Harappan craftsmen also invented the true saw, with teeth and the adjoining part of the blade set alternatively from side to side, a type of saw unknown elsewhere until Roman times.

Why is the true saw an advance over the earlier saws (with a single row of teeth)?

Besides, many bronze figurines or humans (the well-known ‘Dancing Girl’, for instance) and animals (rams, deer, bulls...) have been unearthed from Harappan sites. Those figurines were cast by the lost-wax process: the initial model was made of wax, then thickly coated with clay; once fired (which caused the wax to melt away or be ‘lost’), the clay hardened into a mould, into which molten bronze was later poured.

The ‘Dancing Girl’ (Mohenjo-daro), made by the lost-wax process; a bronze foot and anklet from Mohenjo-daro; and a bronze figurine of a bull (Kalibangan). (Courtesy: ASI)

Harappans also used gold and silver (as well as their joint alloy, electrum) to produce a wide variety of ornaments such as pendants, bangles, beads, rings or necklace parts, which were usually found hidden away in hoards such as ceramic or bronze pots. While gold was probably panned from the Indus waters, silver was perhaps extracted from galena, or native lead sulphide.

After the Harappans

During and after the Harappan civilization, a 'Copper Hoard' culture of still unclear authorship produced massive quantities of copper tools in central and northern India. Later, in the classical age, copper-bronze smiths supplied countless pieces of art. Let us mention the huge bronze statue of the Buddha made between 500 and 700 CE in Sultanganj (Bhagalpur district, Bihar, now at the Birmingham Museum); at 2.3 m high, 1 m wide, and weighing over 500 kg, it was made by the same lost-wax technique that Harappans used three millenniums earlier.

So were thousands of statues made later (and up to this day) in Tamil Nadu, such as the beautiful Nataraja statues of the Chola period, among other famous bronzes. Of course, all kinds of bronze objects of daily use have continued to be produced; for instance, highly polished bronze mirrors are still made in Kerala today, just as they were in Harappan times.

Why was bronze particularly suited to the making of such statues?

A colossal bronze statue of the Buddha, Sultanganj. (Courtesy: Wikipedia)

Magnificent Chola bronze statues: Mahālakṣmī and Naṭarāja. (Courtesy: Michel Danino)

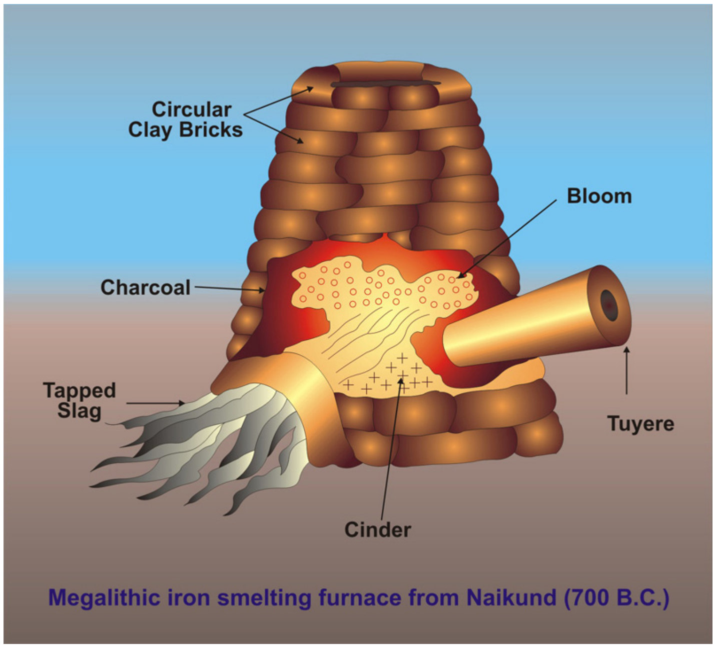
Iron Metallurgy

While the Indus civilization belonged to the Bronze Age, its successor, the Ganges civilization, which emerged in the first millennium BCE, belonged to the Iron Age. But recent excavations in central parts of the Ganges valley and in the eastern Vindhya hills have shown that iron was produced there possibly as early as in 1800 BCE. Its use appears to have become widespread from about 1000 BCE, and we find in late Vedic texts mentions of a 'dark metal' (*kṛṣṇāyas*), while earliest texts (such as the Rig-Veda) only spoke of *ayas,* which, it is now accepted, referred to copper or bronze.

What advantages did people find in iron over copper / bronze?

Whether other parts of India learned iron technology from the Gangetic region or came up with it independently is not easy to figure out. What seems clear, however, is

that the beginnings of copper-bronze and iron technologies in India correspond broadly with those in Asia Minor (modern Turkey) and the Caucasus, but were an independent development, not an import.



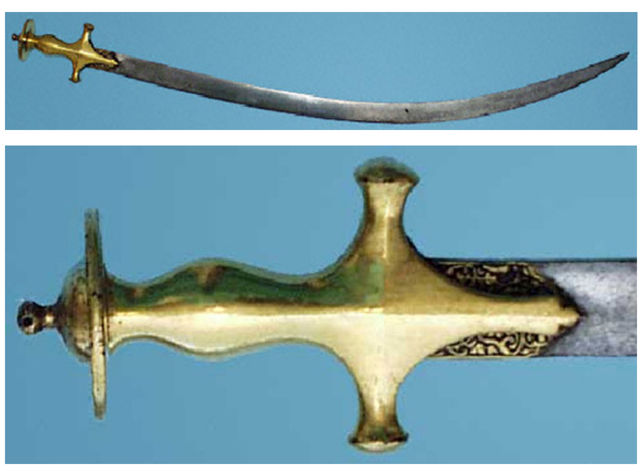
A typical iron-smelting furnace in the first millennium BCE.
(Courtesy: National Science Centre, New Delhi)

Wootz Steel

Instead, India was a major innovator in the field, producing two highly advanced types of iron.

The first, wootz steel, produced in south India from about 300 BCE, was iron carburized under controlled conditions. Exported from the Deccan all the way to Syria, it was shaped there into 'Damascus swords' renowned for their sharpness and toughness. But it is likely that the term 'Damascus' derived not from Syria's capital city, but from the 'damask' or wavy pattern characteristic of the surface of those swords. In any case, this Indian steel was called 'the wonder material of the Orient'. A Roman historian, Quintius Curtius, recorded that among the gifts which Alexander the Great received from Porus of Taxila (in 326 BCE), there was some two-and-a-half tons of wootz steel — it was evidently more highly prized than gold or jewels! Later, the Arabs fashioned it into swords and other weapons, and during the Crusades, Europeans were overawed by the superior Damascus swords. It remained a favoured metal for weapons through the Moghul era, when wootz swords, knives and armours were artistically embellished with carvings and inlays of brass, silver and gold. In the armouries of Golconda and Hyderabad's Nizams, Tipu Sultan, Ranjit Singh, the Rajputs and the Marathas, wootz weapons had pride of place.

Wootz steel is primarily iron containing a high proportion of carbon (1.0 – 1.9%). Thus the term wootz (an English rendering of '*ukku*', a Kannada word for steel) applies to a high-carbon alloy produced by crucible process. The basic process consisted in first preparing sponge (or porous) iron; it was then hammered while hot to expel slag, broken up, then sealed with wood chips or charcoal in closed crucibles (clay containers) that were heated, causing the iron to absorb appreciable amounts of carbon; the crucibles were then cooled, with solidified ingot of wootz steel remaining.



A typical sword made of wootz steel (about 18th century); the hilt is of iron and coated with a thick layer of gold. (Courtesy: R. Balasubramaniam)

Right from the 17th century, several European travellers documented India's iron- and steel-making furnaces (Francis Buchanan's accounts of south India are an important source of information as regards wootz). From the 18th century, savants in England (Pearson, Stodart and Faraday), France and Italy tried to master the secrets of wootz; the French Jean-Robert Bréant, conducting over 300 experiments by adding various metals to steel, understood the role of the high carbon proportion in wootz, and was the first European who successfully produced steel blades comparable to the Indian ones. Together, such researches contributed to the understanding of the role of carbon in steel and to new techniques in steel-making.

The Delhi Iron Pillar

The Delhi Iron Pillar, with a close-up of the inscription. (Courtesy: R. Balasubramaniam)

The second advanced iron is the one used in the famous 1,600-year-old Delhi Iron Pillar, which, at a height of 7.67 m, consists of about six tons of wrought iron. It was initially erected 'by Chandra as a standard of Vishnu at Vishnupadagiri', according to a six-line Sanskrit inscription on its surface. 'Vishnupadagiri' has been identified with modern Udayagiri near Sanchi in Madhya Pradesh, and 'Chandra' with the Gupta emperor, Chandragupta II Vikramaditya (375–414 CE). In 1233, the pillar was brought to its current location in the courtyard of the Quwwat-ul Islam mosque in New Delhi's Qutub complex, where millions continue to come and see this 'rustless wonder'.

But why is it rustless, or, more precisely, rust-resistant? Here again, numerous experts, both Indian and Western, tried to grasp the secret of the pillar's manufacture. Only recently have its rust-resistant properties been fully explained (notably by R. Balasubramaniam). They are chiefly due to the presence of phosphorus in the iron: this element, together with iron and oxygen from the air, contributes to the formation of a thin protective passive coating on the surface, which gets reconstituted if damaged by scratching. It goes to the credit of Indian blacksmiths that through patient trial and error they were able to select the right type of iron ore and process it in the right way for such monumental pillars.

Other Iron Pillars and Beams

There are a few more such pillars in India, for instance at Dhar (Madhya Pradesh) and Kodachadri Hill (coastal Karnataka). Besides, the same technology was used to manufacture huge iron beams used in some temples of Odisha, such as Jagannath of Puri (12^{th} century). The iron beams at Konarak's famous sun temple are of even larger dimensions. Chemical analysis of one of the beams confirmed that it was wrought iron of a phosphoric nature (99.64% Fe, 0.15% P, traces of C, traces of S and no manganese).

Zinc

Indian metallurgists were familiar several other metals, of which zinc deserves a special mention because, having a low boiling point (907°C), it tends to vaporize while its ore is smelted. Zinc, a silvery-white metal, is precious in combination with copper, resulting in brass of superior quality. Sometimes part of copper ore, pure zinc could be produced only after a sophisticated 'downward' distillation technique in which the vapour was captured and condensed in a lower container. This technique, which was also applied to mercury, is described in Sanskrit texts such as the 14th-century *Rasaratnasamuccaya*.

Zinc metallurgy at Zawar mines. (Courtesy: National Science Centre, New Delhi)

There is archaeological evidence of zinc production at Rajasthan's mines at Zawar from the 6th or 5th century BCE. The technique must have been refined further over the centuries. India was, in any case, the first country to master zinc distillation, and it is estimated that between 50,000 and 100,000 tons of zinc was smelted at Zawar from the 13th to the 18th century CE! British chroniclers record continuing production there as late as in 1760; indeed, there is documentary evidence to show that an Englishman learned the technique of downward distillation there in the 17th century and took it to England — a case of technology transfer which parallels that of wootz steel.

Social Context

We should finally note that most of India's metal production was controlled by specific social groups, including so-called tribes, most of them from the lower rungs of Indian society.

An underground furnace at Ghatgaon (Madhya Pradesh), with a tribal smelting iron ore.
(Courtesy: A.V. Balasubramaniam)




For instance, the Agarias of Uttar Pradesh and Madhya Pradesh are reputed iron smiths, and there are still such communities scattered across Jharkhand, Bihar, West-Bengal, Kerala and Tamil Nadu.

Together, they contributed substantially to India's wealth, since India was for a long time a major exporter of iron. In the late 1600s, shipments of tens of thousands of wootz ingots would leave the Coromandel Coast for Persia every year. India's iron and steel industry was intensive till the 18th century and declined only when the British started selling their own products in India while imposing high duties on Indian products. Industrially produced iron and steel unavoidably put a final stop to most of India's traditional production.

***

Match the following

Agarias	lost-wax bronze casting
Dancing Girl	iron beams
wootz steel	phosphorus
Jagannath temple (Puri)	iron smiths
rust-resistance pillars	Zawar
zinc extraction	sharp swords

Comprehension Questions

1. Could the Harappans have developed their urban civilization without copper / bronze metallurgy? Justify your answer.
2. Spell out two chief qualities of bronze.

3. What are the basic processes in the manufacture of wootz implements?
4. Why were most of India's metallurgical practices the prerogative of lower sections of the society, such as rural and tribal communities? Why does it make more difficult to document their achievements?

Project ideas

- Compare and contrast the different methods used in ancient times and today to extract gold and silver.
- Collect pictures and documents on bronze metallurgy in India. Explain the technical, social and artistic impact of bronze in Indian history. Make a PowerPoint presentation.
- Watch a few videos on lost-wax bronze casting (see Internet Resources below) and make a PowerPoint presentation summarizing the process. Show the similarity between the casting of the 'Dancing Girl' of Mohenjo-daro and recent bronzes of south India.
- Document the rise of a few Iron Age cultures outside India, and the role played by iron metallurgy. Include a timeline of such cultures and compare with the Indian dates.
- Find out ten weapons used by warriors in ancient and medieval India. Collect the specific qualities of such weapons.

Activities & exercises

- Make a timeline of the evolution of early technologies in India from about 10000 BCE to and including the Ganges civilization.
- The inscription on the Delhi Iron Pillar says it was manufactured by one 'Vishnu'. With what emperor has he been identified? Re-create the historical context.

- Collect information on three rust-resistant pillars (besides Delhi's) which were erected in India, including their historical background. If you live not too far from one of these iron pillars, try to visit it, photograph it, and study its appearance.
- Spell out in detail the successive steps in the distillation of zinc.

Further Reading

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8. Sharada Srinivasan & Srinivasa Ranganatha, *India's Legendary Wootz Steel: An Advanced Material of the Ancient World*, NIAS & IISc, Bangalore, 2004, available online at http://met.iisc.ernet.in/~rangu/text.pdf
9. Vibha Tripathi, *The Age of Iron in South Asia: Legacy and Tradition*, Aryan Books International, New Delhi, 2001
10. Vibha Tripathi, *History of Iron Technology in India: From Beginning To Pre-Modern Times,* Rupa & Infinity Foundation, New Delhi, 2008

Internet Resources (all URLs accessed in May 2012)

- BBC TV series 'What the Ancients Did for Us: India' (especially for the section on lost-wax bronze casting):
  www.youtube.com/watch?v=LWRhsenRZUI
- Lost-wax bronze casting at Swamimalai, Tamil Nadu:

www.youtube.com/watch?v=Xrire4qPFpY

- An article on India's metallurgical heritage:
  www.tf.uni-kiel.de/matwis/amat/def_en/articles/metallurg_heritage_india/metallurgical_heritage_india.html
- Text of a book on wootz steel:
  http://met.iisc.ernet.in/~rangu/text.pdf
- An article on a cannon of Thanjavur, Tamil Nadu:
  http://home.iitk.ac.in/~bala/journalpaper/journal/journalpaper_40.pdf
- A paper by Dr. Rakesh Tewari on recent findings on the origins of iron metallurgy in the Ganges valley:
  www.antiquity.ac.uk/projgall/tewari298/tewari.pdf
- A general introduction to ancient metallurgy (deficient as far as India is concerned):
  http://weber.ucsd.edu/~dkjordan/arch/metallurgy.html
- A short history of metals (deficient as far as India is concerned):
  http://neon.mems.cmu.edu/cramb/Processing/history.html
- Metallurgy in ancient China:
  www.joanpacos.com/asianart/articles/metalwork/art_li_mat.html,
  www.csun.edu/~bavarian/ancient_chinese_metallurgy.htm
- Metallurgy in ancient Egypt:
  www.aldokkan.com/science/metallurgy.htm
- Steel in Ancient Greece and Rome (note the part on wootz):
  www.tf.uni-kiel.de/matwis/amat/def_en/articles/steel_greece_rome/steel_in_ancient_greece_an.html

Primary Texts on Metallurgy in India: A Selection

Note: Many texts of chemistry refer to the working of metals, especially precious ones (a few extracts are below), but it should be kept in mind that some of India's greatest metallurgical advances — such as wootz steel or rust-resistant iron — do not figure in any known texts; they were the work of communities of craftsmen who perfected such practices from generation to generation, but did not generally leave written testimonies behind.

Rig-Veda (tr. adapted from R.T.H. Griffith)

[From a hymn in praise of the celestial horse:] His horns are made of gold, his feet of bronze ... (1.163.9)

Brahmaṇaspati forged the gods with blast and smelting, like a metal-smith; Existence, in an earlier age of Gods, from Non-existence sprang. (10.72.2)

Note: There are many more such references in the Vedas to metal and metal-working, often used as a metaphor as in the above verse. The word for metal was *ayas,* which in the *Rig-Veda*, refers to copper or bronze, not to iron. In later literature, terms like *kṛṣṇāyas, kālāyasa* or *śyāmāyas*, i.e., 'dark metal', came into use, which clearly referred to iron; *loha* (literally, 'red') or *lohāyas* initially referred to copper, but later became a generic term for metal, and often came to mean iron.

***

Early texts: various terms about metals

Pāṇini's ***Aṣṭādhyāyī***: bellows (*bhastra,* 7.3.47), hammer (*ayoghana,* 3.3.82), pincer (4.4.18), hook (*kuṭilikā,* 4.4.18)

Samyutta Nikaya (a Buddhist text): village of iron workers (*lohar-gama*)

Dighanikaya (a Buddhist text): iron smith (*karmkara*)

Amarakośa (a Sanskrit dictionary): sharp (*tikṣṇa*), shining (*tejas*)

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Arthaśāstra (tr. R.P. Kangle)

Note: Kauṭilya's famous treatise of governance and administration, the *Arthaśāstra,* dates back to Mauryan times, a few centuries BCE. The following passage, from a long chapter on the 'department of mines', reveals an intimate knowledge of the different types of metal ores and the ways to test and purify different metals, or to create alloys.

> The Director of Mines, being conversant with the sciences of [metal] veins in the earth and metallurgy, the art of smelting and the art of colouring gems, or having the assistance of experts in these, and fully equipped with workmen skilled in the work and with implements, should inspect an old mine by the marks of dross, crucibles, coal and ashes, or a new mine, where there are ores in the earth, in rocks or in liquid form, with excessive colour and heaviness and with a strong smell and taste. ...
>
> Ores in earth or rocks, which are yellow or copper-coloured or reddish-yellow, which, when broken, show blue lines or are the colour of the *mudga* or *māṣa* bean or *kṛsara*, which are variegated with spots or lumps as of curds, which are of the colour of turmeric or myrobalan or lotus-leaf or moss or

liver or spleen or saffron, which, when broken, show lines, spots or *svastikas* of fine sand, which are possessed of pebbles and are lustrous, which, when heated, do not break and yield plenty of foam and smoke, are gold-ores, to be used for insertion, as transmuters of copper and silver. ...

Ore from rocks or a region of the earth, which is heavy, unctuous and soft [and which is] tawny, green, reddish or red is copper ore.

That which is crow-black or of the colour of the dove or yellow pigment or studded with white lines [and] smelling like raw flesh, is lead-ore.

That which is grey like saline earth or of the colour of a baked lump of earth is tin-ore.

That which is made up mostly of smooth stones, is whitish-red or of the colour of *sinduvāra*-flower is iron-ore. (2.12.1–15)

Of the best [varieties of gold], the pale-yellow and the white are impure. He [the Superintendent of Gold] should cause that because of which it is impure to be removed by means of lead four times that quantity. If it becomes brittle by the admixture of lead, he should cause it to be smelted with dried lumps of cow-dung. If it is brittle because of [its own] roughness, he should cause it to be infused in sesame oil and cow-dung. Gold produced from the mines, becoming brittle by the admixture of lead, he should turn into leaves by heating and cause them to be pounded on wooden anvils, or should cause it to be infused in the pulp of the bulbous roots of the *kadalī* and the *vajra* plants. (2.13.5-9)

Three parts of ornamental gold, strengthened with thirty-two parts of white silver, it becomes white-red. It makes copper yellow. Making the ornamental gold bright, he should give one-third part colouring; it becomes

yellowish red. [With] two parts of white silver, one part of ornamental gold produces the colour of the *mudga* bean. When smeared with half a part of black iron, it becomes black. Ornamental gold twice smeared with an enveloping liquid gets the colour of the parrot's feather. In undertaking these works, he should take a test regarding the various colours. And he should be conversant with the treatment of iron and copper. (2.13.51-58)

The Goldsmith should cause the gold and silver work of the citizens and the country people to be carried out by workshop artisans. ... In the case of gold and silver, a loss of one *kākaṇī* in a *suvarṇa* may be allowed [this is equivalent to $1/64^{th}$ of 1.5%] (2.14.1, 8)

***

Varāhamihira (b. ~ 485 CE), *Khaḍgalakṣaṇam* (tr. Vibha Tripathi)

Make a paste of gelatin from the sheep's horn and pigeon and mouse meat with the juice of the plant *arka* [*Calotropis gigantea*] and apply this to the steel after rubbing it with sesame oil. Heat the sword in the fire and when it is red hot sprinkle water on it or milk of mare (camel or goat) or ghee (clarified butter) or blood or fat or bile. Then sharpen the edge on the lathe. ... Also plunge the red hot steel into a solution of plantain ashes in whey kept standing for twenty hours, then sharpen on the lathe. (29.23-26)

Note: Here, Varāhamihira explains the process of carburization and hardening of iron swords. Carburization is the controlled addition of carbon to iron, so as to turn it into steel; it is usually done by adding organic substances, whether vegetal or animal, in the course of the smelting. (Carburization was essential in the preparation of wootz steel, too.)

Nāgārjuna (7th or 8th century CE), *Rasendramaṅgalam* (tr. H.S. Sharma)

> It is not a matter of surprise that the copper becomes white like the moon or conch shell. Melt copper with the help of commonly available alkali, i.e., borax and subject it into the milk of sheep and its ghee. On its melting add sixteenth part of orpiment [arsenic trisulphide] in it. The copper will be converted into whiteness.
>
> Hence take the copper duly extracted from bronze or take as such and melt it with the help of borax six times to it. Pour into juice of *sinduvāra*; for fifty times repeat the process then melt in the same way, pour seven times into juice of *kūṣmāṇḍa* [*Benincasa cerifera*]. There is no doubt that the blackishness of copper vanishes on these [fifty-seven] immersions.
>
> To purify silver, brass, copper and bronze, the alkali borax mixed with five types of salts and rubbed with juice of lemon very well, then coated with the paste of same drugs and subjected to fire in a pit of individual metal is the process. Repeat the same for seven times. (1.56-61)

Note: The technical literature has several works authored by Nāgārjuna, but there were probably several Nāgārjunas too, many of them chemists and physicians. Here, a process for whitening copper is described. It would be interesting to try and put such recipes to test so as to assess their value.

***

Vāgbhaṭa (13th century), *Rasaratnasamuccaya* (tr. INSA)

Note: The following is a systematic exposition of the principal metals in a well-known text of alchemy. Each metal's properties and medicinal uses are clearly brought out, although, of course, within the alchemical framework of the times.

Classification of metals

In nature there are four *śuddha lohas* (native metals) viz., *suvarṇa* (gold), *rajata* (silver), *tāmra* (copper) and *loha* (iron). In addition there are two *pūtilohas* — *nāga* (lead) and *vaṅga* (tin) and three *miśra loha* (alloys) *viz., pittala* (brass), *kāṃsya* (bell metal) and *varta loha* (an alloy made of five metals). The term *loha* is derived from the root *luh* which means *karṣaṇa* (to be extracted).

❖ *Survarṇa* (gold)

Varieties:

- *Prākṛta* (native), *sahaja* (natural), *vahni sambhūta* (born out of fire / produced by pyrometallurgy), *khani sambhūta* (obtained from a mine) and *rasendra vedha sañjāta* (produced by transmutation through mercury) are the five types of gold.

Description of different types of *suvarṇa* (gold):

- *Prākṛta suvarṇa:* That which is produced by *rajoguṇa* and which pervades the entire globe (world) is known as *Prākṛta.* It is claimed to be difficult to obtain, even for the gods.
- *Sahaja suvarṇa:* That (the gold) which enveloped Lord Brahmā in the form of a *jarāyu* at the time of his birth and which was converted into a divine mountain (*meru parvata*) in due course, is known as *sahaja suvarṇa.*
- *Vahni sambhūta suvarṇa:* That which was obtained from the vomited material of god Agni after he swallowed an unbearable essence (semen) of Lord Śiva is *vahni sambhūta suvarṇa*.

These three varieties of gold are claimed to be divine and are said to be accomplished with all the sixteen colours. Mere wearing of these makes the body free from senility and mortality.

- *Khanija suvarṇa:* The gold obtained from the mines and / or available as deposits on the mountains is *khanija*. It is said to be accomplished with fourteen colours and its ingestion is claimed to cure all the diseases.
- *Rasendra vedhaja suvarṇa:* The gold produced by the process of mercurial transmutation is known as *rasendra vedhaja*. It is considered to be the best rejuvenating agent *(rasāyana)* and sacred.

Pharmaco-therapeutic properties of gold:

- Gold grants longevity, wealth, brightness, intelligence and memory.
- It destroys all the diseases, proves virtuous, prevents invasion of *bhūtas* (bacteria), imparts immense sexual vigour (pleasure), induces happiness and strength.
- Gold and silver both may cure diseases, prevent old age, destroy *pramehas*, impart strength to debilitated persons, increase grasping power and improve vigour and vitality.
- Gold is further claimed to be unctuous (*snigdha*), and brain stimulant *(medhya)*.
- It destroys toxins and the diseases, acts as nourishing (agent) *bṛṃhaṇa)*, is considered best aphrodisiac *(agrya vṛṣya)* and alleviates phthisis *(yakṣmā)*, insanity *(unmāda)* and other bodily diseases.
- Gold also improves retention power of mind, intellect, memory and happiness of a person, relieves diseases caused by all the three *doṣas*,

stimulates taste / desire to take food, improves digestion, alleviates pain / unhappiness and proves sweet after digestion *madhura vipāka*. (1–10)

❖ *Rajata* (silver)

Varieties:

- *Sahaja* (natural), *khani sañjāta* (obtained from mine) and *kṛtrima* (artificial) are the three varieties of silver. A preceding one is relatively better in qualities than the succeeding one.

Description of each variety:

- *Sahaja rajata* — Silver obtained from the Kailāśa group of mountains is *sahaja* (native). Mere touch of this is considered sufficient to destroy the diseases in human beings.
- *Khanija rajata* — Silver obtained from the mines of the Himālaya group of mountains is known as *khanija*. It is considered the best rejuvenating agent *(rasāyana)*.
- *Kṛtrima rajata* — Tin applied to *Śri Rāmapādukā* and transformed into silver is known as *pādarūpya*. It is *kṛtrima* (artificial) and is claimed to cure all the diseases.

Qualities of superior silver:

- The silver which is compact, heavy, clear, soft, *śaṅkha*-like in colour, smooth, free from fissures, and white on cutting and heating is considered to be of superior quality.

Qualities of inferior silver:

- The silver exhibiting red, yellow or black colours on heating, rough, full of fissure, light, thick, and hard to touch is said to be of inferior quality and is not recommended for use.

Pharmaco-therapeutic properties of silver:

- Silver is sweet *(madhura)* and astringent *(kaṣāya)* in taste *(rasa)*, sweet *(madhura)* in digestion *(vipāka)*, cool *(śīta)* in potency *(vīrya)*, unctuous *(sara* and *snigdha*) in properties *(guṇas)* and very much anti-obese *(paramalekhana*), strengthening *(balya)*, checks ageing process *(sthira vayaskara)*, brain tonic *(medhya)* and stimulating digestive fire *(jaṭharāgni dīpana)* in actions *(karmas).*
- As regards its action on *doṣas* it destroys *vāta kapha* diseases *(vāta kapha hara).*
- Silver is further claimed to be cool in potency *(śīta vīrya)*, sour and astringent in taste *(kaṣāyāmlarasa)*, light *(laghu)*, unctuous *(snigdha)* and remover of *vāta (vātahara).*
- If used by the *rasāyana* method it destroys all the diseases. (22– 29)

❖ *Tāmra* (copper)

Varieties:

- *Mleccha* and *nepālaka* are the two varieties of *tāmra*, (copper), out of which the *nepālaka* is considered the better. The copper obtained from the mines other than those of Nepal is known as *mleccha.*

Qualities of *mleccha tāmra*:

- The copper with white, black and red shades, very hard and remaining black even after repeated washing is considered the *mleccha tāmraka.*

Qualities of *nepāla tāmra*:

- The copper which is very brilliant, soft, red, resistant to strong hammering, heavy, not producing bad effects and possessing all the best qualities / properties is considered the *nepāla tāmra*.

Qualities of inferior *tāmra*:

- That which is pale and blackish red in colour, light, possesses rough surface, fissures, and layers is inferior and is not considered suitable for being used in *rasa karmas*.

Pharmaco-therapeutic properties of *tāmra*:

- Copper *(tāmra)* is bitter *(tikta)* and astringent *(kaṣāya)* in taste *(rasa)*, sweet after digestion *(madhura* in *vipāka)* and hot in potency *(uṣṇa* in *vīrya)*.
- It is associated with sour taste *(amla rasa)* also. It destroys *pitta* and *kapha doṣas.*
- It is indicated in pain in abdomen *(jaṭhara ruk)*, leprosy *(kuṣṭha)*, symptoms of indigestion (*āma doṣa)* and worms *(kṛmiroga)*.
- It causes vomiting and purging both and thus cleans the body from both upper and lower passages.
- It is further claimed to remove poisonous effect *(viṣa)*, liver disorders *(yakṛt)* and obesity *(sthaulya)*.
- It improves appetite and proves good for piles *(arśas),* wasting diseases *(kṣaya)* and anaemia *(pāṇḍu roga)*.
- It is good for eyes *(netra)* and is claimed to be the best emaciating/anti-obese agent *(lekhana)*. (42–46)

❖ *Loha* (iron)

Varieties:

- *Muṇḍa, tīkṣṇa* and *kānta* are the three main varieties of iron.

Sub-varieties:

- *Mṛdu, kuṇṭha* and *kaḍāra* are the three sub-varieties of *muṇḍa loha.*
- *Khara, sāra, hṛnnāla, tārāvaṭṭa, vājira* and *kāla-loha* are the six sub-varieties of *tīkṣṇa* loha.
- *Bhrāmaka, cumbaka, karṣaka, drāvaka* and *romaka* are the five sub-varieties of *kānta loha*.

Varieties of *muṇḍa loha*:

- *Mṛdu muṇḍa loha:* That which melts quickly, does not contain fissures and has a smooth surface is considered as *mṛdu muṇḍa loha*. It is the best of all the three varieties of *muṇḍa.*
- *Kuṇṭha muṇḍa loha:* That which expands with great difficulty on hammering is known as *kuṇṭha muṇḍa loha*. It is considered medium.
- *Kaḍāra muṇḍa loha:* That which breaks on hammering and looks black is *kaḍāra muṇḍa loha.*

Pharmaco-therapeutic properties of *muṇḍa loha*:

- In comparison to other varieties *mṛdu muṇḍa loha* is soft.
- It destroys *kapha, vāta, śūla, mūla roga, āma doṣa, meha, kāmalā* and *pāṇḍu.* It also cures *gulma*, *āmavāta, udaraśūla* and *śopha.*
- It is stomachic, increases *rakta dhātu* (blood) and cleans the *koṣṭha* / *mahāsrotas.* (69-74)

❖ *Vaṅga* (tin)

Varieties:

- *Khuraka* and *miśraka* are the two types of *vaṅga*. Of the two *khuraka* is better in properties, while *miśraka* is considered inferior.

Physical properties:

- Whiteness, softness, brilliancy, quick melting, heaviness and devoid of cracking sound (tin-cry) are the qualities of *khura vaṅga* while *miśraka* is claimed to be blackish white in colour.

Pharmaco-therapeutic properties of *vaṅga*:

- *Vaṅga* is bitter *(tikta)* in taste *(rasa)*, hot *(uṣṇa)* and rough *(rūkṣa)* in properties *(guṇa)*, causes slight *vātakopana* and destroys *meha, śleṣma roga, meda* and *kṛmirogas*. (153–155)

❖ *Nāga / śīśa* (lead)

Physical properties of lead:

- The superior variety of lead should be heavy, externally black, produce foul smell, melt quickly and on fracture should appear shining black. The lead without these properties is impure and not recommended for use.

Pharmaco-therapeutic properties of lead:

- *Śiśaka* is very hot *(atiuṣṇa)* in *vīrya*, onctuous *(snigdha)* in *guṇa* and bitter *(tikta)* in *rasa*.
- It is claimed to destroy *vāta and kapha doṣas* and to possess stomachic effect (*dīpana karma*).

- It is indicated for removing the *toyadoṣa* of *prameha* and also *āmavāta*. (170–171)

❖ *Pittala* (brass)

Varieties:

- *Pittala* is of two types, *rītikā* and *kākatuṇḍī*. That which turns into copper-like colour when heated and dipped in *Kāññjika* is *rītikā*, while that which turns black is known as *kākatuṇḍī*.

Physical properties of superior *pittala*:

- Heaviness, softness, yellowness, strong, resistibility to hammering (malleable) and brilliancy are the properties of superior *rītī*.

Physical properties of inferior *pittala*:

- That which is pale yellow, hard, rough with spots, irresistible to hammering (non-malleable), foul smelling and light in weight is inferior *rītī* and is not considered good for internal use.

Pharmaco-therapeutic properties of *pittala*:

- *Rītī* is *tikta* in *rasa, rūkṣa* in *guṇa*, destroys intestinal worms, *raktapittta* and *kuṣṭa rogas* (skin diseases due to worms in infection). When used with other drugs it becomes *uṣṇa* in *vīrya* otherwise it is *śita* in *vīrya.*

- *Kākatuṇḍī* is *tikta* in *rasa, uṣṇa* and non-unctuous in *guṇa,* destroys *kapha* and *pitta doṣas,* cures *yakṛt* and *plīha roga* and is said to be *śitavīrya*. (191–196)

***

Comprehension

On the basis of your reading of the texts, complete the following table:

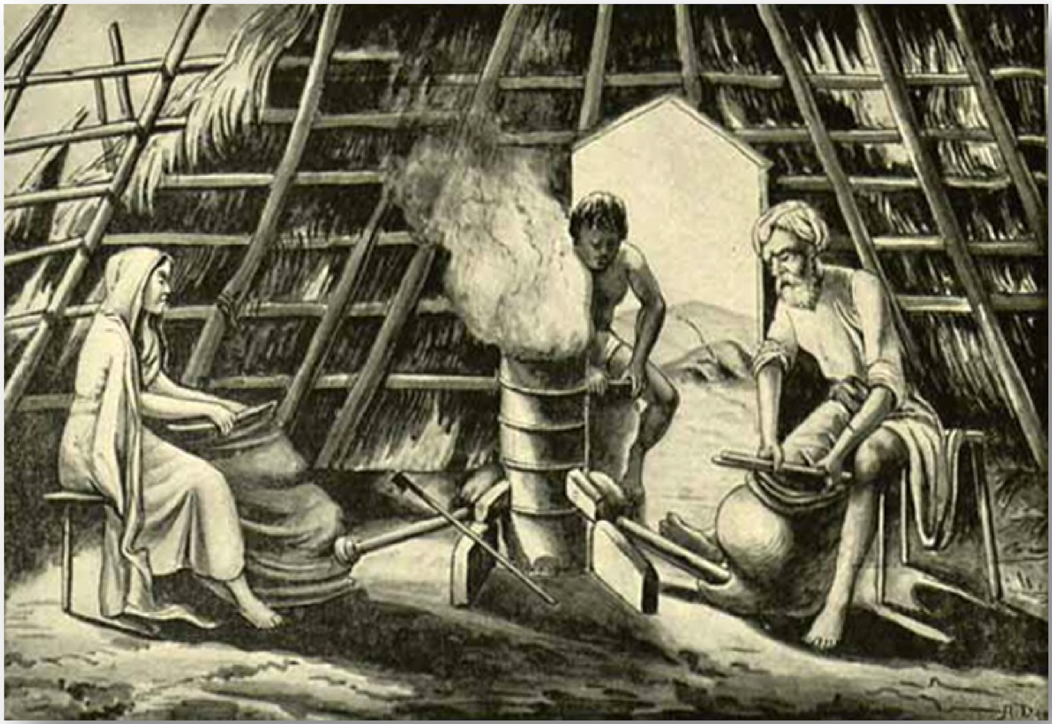
Astronomer	Period	Finding	Relevance
Kauṭilya			
Varāhamihira			

1. Summarize the duties of the Director of Mines given by Kauṭilya, as well as the expertise he is expected to have. Do you find this expertise adequate for his responsibilities?

2. Note the properties attributed to various metals by Vāgbhaṭa; make an exhaustive list of those properties.

3. What uses of metals is Vāgbhaṭa's alchemical text concentrating on?

4. The above texts describe several processes by which a metal is treated with an organic substance, such as a plant extract. Select one of those processes which, in your opinion, would be easily testable in a modern laboratory.



Copper-smelting furnace at Khetri, Rajasthan
(from a geological report of the 19th century)

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