= 9 ? 16D3 + 1 ? 16D3 =
5 ? 8D3 . Since he found the ratio of the volume of the cube to the inscribed sphere at 8 : 5 , the ratio of the area of a square to the inscribed circle is ? 8 : ? 5 . With this formula , Zhang was able to approximate pi as the square root of 10 , or 3 @.@ 162 . After the Han , Liu Hui approximated pi as 3 @.@ 14159 , while the mathematician Zu Chongzhi (429 ? 500 CE) approximated pi at 3 @.@ 141592 (or 355 ? 113) , the most accurate approximation the ancient Chinese would achieve .

= = = Musical tuning and theory = = =

Mathematics were also used in musical tuning and music theory . The 2nd @-@ century @-@ BCE Huainanzi , compiled by eight scholars under the patronage of King Liu An (179 ? 122 BCE) , outlined the use of twelve tones on a musical scale . Jing Fang (78 ? 37 BCE) , a mathematician and music theorist , expanded these to create a scale of 60 tones . While doing so , Jing Fang realized that 53 just fifths is approximate to 31 octaves . By calculating the difference at 177147 ? 176776 , Jing reached the same value of 53 equal temperament duly discovered by the German mathematician Nicholas Mercator (1620 ? 1687) (i.e. 353 / 284 , known as Mercator 's comma) . Later , the prince Zhu Zaiyu (1536 ? 1611 CE) in Ming China and Simon Stevin (1548 ? 1620 CE) of the Flemish Region in Europe would simultaneously (but separately) discover the mathematical formula for equal temperament .

= = = Astronomical observations = = =

The ancient Chinese made careful observations of heavenly bodies and phenomena since observations of the cosmos were used for astrology and prognostication . The astronomer Gan De (fl . 4th century BCE) from the State of Qi was the first in history to acknowledge sunspots as genuine solar phenomena (and not obstructing natural satellites as thought in the West after Einhard 's observation in 807 CE) , while the first precisely dated sunspot observation in China occurred on May 10 , 28 BCE during the reign of Emperor Cheng of Han (r . 33 ? 7 BCE) . Among the Mawangdui Silk Texts dated no later than 168 BCE (when they were sealed in a tomb at Mawangdui , Changsha , Hunan province) , the Miscellaneous Readings of Cosmic Patterns and Pneuma Images (Tianwen qixiang zazhan ??????) manuscript illustrates in writings and ink drawings roughly three @-@ hundred different climatic and astronomical features including clouds , mirages , rainbows , stars , constellations , and comets . Another silk text from the same site reports the times and locations of the rising and setting of planets in the night sky from the years 246 ? 177 BCE .
The Han @-@ era Chinese noted the passage of the same comet seen in Persia for the birth of Mithridates II of Parthia in 135 BCE , the same comet the Romans observed close to the assassination of Julius Caesar in 44 BCE , Halley 's comet in 12 BCE , the same comet noted by Roman historian Cassius Dio (c . 155 ? c . 229 CE) for 13 CE , and (what is now known to have been) a supernova in 185 CE . For various comets discussed in the Han @-@ era history books Records of the Grand Historian and Book of Han , details are given for their position in the sky and direction they were moving , the length of time they were visible , their color , and their size .
The Han @-@ era Chinese also made star catalogues , such as historian Sima Qian 's (145 ? 86 BCE) A Monograph on Celestial Officials (Tianguanshu ???) and Zhang Heng 's 2nd @-@ century @-@ CE star catalogue which featured roughly 2 @,@ 500 stars and 124 constellations . To create a three @-@ dimensional representation of such observations , Astronomer Geng Shouchang (???) provided his armillary sphere with an equatorial ring in 52 BCE . By 84 CE the elliptical ring was added to the armillary sphere , while Zhang Heng 's model of 125 CE added the celestial horizon ring and meridian ring .

= = = Han calendars = = =

The Han Chinese used astronomical studies mainly to construct and revise their calendar . In

contrast to the Julian calendar (46 BCE) and Gregorian calendar (1582 CE) of the West (but like the Hellenic calendars of Classical Greece) , the Chinese calendar is a lunisolar calendar , meaning that it uses the precise movements of the Sun and Moon as time @-@ markers throughout the year . In the 5th century BCE during the Spring and Autumn period , the Chinese established the Sifen calendar (????) , which measured the tropical year at 3651 ? 4 days (like the Julian calendar of Rome) . Emperor Wu replaced this with the new Taichu calendar (???) in 104 BCE which measured the tropical year at 365385 ? 1539 days and the lunar month at 2943 ? 81 days . Since the Taichu calendar had become inaccurate over two centuries , Emperor Zhang of Han (r . 75 ? 88 CE) halted its use and revived use of the Sifen calendar . Later , astronomer Guo Shoujing (1233 ? 1316 CE) would set the tropical year at 365 @.@ 2425 days for his Shoushi calendar (???) , the same value used in the Gregorian calendar . Besides the use of the calendar for regulating agricultural practices throughout the seasons , it was also used to mark important dates in the Sexagenary cycle ? constructed by celestial stems (gan ?) and Earthly Branches (zhi ?) , each of the latter associated with an animal of the Chinese zodiac .

= = = Astronomical theory = = =

Zhao Shaung 's 3rd @-@ century commentary in the Zhoubi suanjing describes two astronomical theories : in one , the heavens are shaped as a hemi @-@ spherical dome extending over the earth , while the other compares the earth to the central yolk of an egg , where the heavens are shaped as a celestial sphere around the earth . The latter astronomical theory was mentioned by Yang Xiong in his Model Sayings (Fayan ??) and expounded on by Zhang Heng in his Spiritual Constitution of the Universe (Lingxian ??) of 120 CE . Thus , the Han @-@ era Chinese believed in a geocentric model for the immediate solar system and greater universe , as opposed to a heliocentric model .

The Han @-@ era Chinese discussed the illumination and shapes of heavenly bodies : were they flat and circular , or were they rounded and spherical ? Jing Fang wrote in the 1st century BCE that Han astronomers believed the Sun , Moon , and planets were spherical like balls or crossbow bullets . He also wrote that the Moon and planets produce no light of their own , are viewable to people on Earth only because they are illuminated by the Sun , and those parts not illuminated by the Sun would be dark on the other side . For this , Jing compared the Moon to a mirror illuminating light . In the 2nd century CE , Zhang Heng drew a similar comparison to Jing 's by stating that the Sun is like fire and the Moon and planets are like water , since fire produces light and water reflects it . He also repeated Jing 's comment that the side of the moon not illuminated by the Sun was left in darkness . However , Zhang noted that sunlight did not always reach the Moon since the Earth obstructs the rays during a lunar eclipse . He also noted that a solar eclipse occurred when the Moon and Sun crossed paths to block sunlight from reaching earth .

In his Balanced Discourse (Lunheng) , Wang Chong (27 ? 100 CE) wrote that some Han thinkers believed that rain fell from the Heavens (i.e. where the stars were located) . Wang argued that , although rain fell from above , this common theory was false . He agreed with another theory that stated clouds were formed by the evaporation of water on earth , and that since clouds disperse rain , clouds and rain are in fact one and the same ; in essence , he accurately described the water cycle .

= = Structural engineering and public works = =

= = = Materials and construction = = =

Timber was the chief building material in Han architecture . It was used for grand palace halls , multi @-@ story towers , multi @-@ story residential halls , and humble abodes . However , due to wood 's rapid decay over time and susceptibility to fire , the oldest wooden buildings found in China (i.e. several temple halls of Mount Wutai) date no earlier than the Tang dynasty (618 ? 907 CE) .

Architectural historian Robert L. Thorp describes the scarcity of Han @-@ era archaeological remains , as well as the often unreliable Han @-@ era literary and artistic sources used by historians for clues about non @-@ existent Han architecture . What remains of Han @-@ dynasty architecture are ruins of brick and rammed earth walls (including aboveground city walls and underground tomb walls) , rammed earth platforms for terraced altars and halls , funerary stone or brick pillar @-@ gates , and scattered ceramic roof tiles that once adorned timber halls . Sections of the Han @-@ era rammed earth Great Wall still exist in Gansu province , along with the Han frontier ruins of thirty beacon towers and two fortified castles with crenellations . Han walls of frontier towns and forts in Inner Mongolia were typically constructed with stamped clay bricks instead of rammed earth .

Thatched or tiled roofs were supported by wooden pillars , since the addition of brick , rammed earth , or mud walls of these halls did not actually support the roof . Stone and plaster were also used for domestic architecture . Tiled eaves projecting outward were built to distance falling rainwater from the walls ; they were supported by dougong brackets that were sometimes elaborately decorated . Molded designs usually decorated the ends of roof tiles , as seen in artistic models of buildings and in surviving tile pieces .

= = = Courtyard homes = = =

Valuable clues about Han architecture can be found in Han artwork of ceramic models , paintings , and carved or stamped bricks discovered in tombs and other sites . The layout of Han tombs were also built like underground houses , comparable to the scenes of courtyard houses found on tomb bricks and in three @-@ dimensional models . Han homes had a courtyard area (and some had multiple courtyards) with halls that were slightly elevated above it and connected by stairways . Multi @-@ story buildings included the main colonnaded residence halls built around the courtyards as well as watchtowers . The halls were built with intersecting crossbeams and rafters that were usually carved with decorations ; stairways and walls were usually plastered over to produce a smooth surface and then painted .

= = = Chang 'an and Luoyang , the Han capitals = = =

The ruins of the walls of Han 's first capital Chang 'an still stand today at 12 m (39 ft) in height with a base width of 12 to 16 m (39 to 52 ft) . Modern archaeological surveys have proven that the eastern wall was 6 @,@ 000 m (20 @,@ 000 ft) long , the southern wall was 7 @,@ 600 m (24 @,@ 900 ft) long , the western wall was 4 @,@ 900 m (16 @,@ 100 ft) long , and the northern wall was 7 @,@ 200 (23 @,@ 622 ft) long . Overall the total length of walls equalled 25 @,@ 700 m (84 @,@ 300 ft) , and formed a roughly square layout (although the southern and northern walls had sections which zigzagged due to topographical concerns : rough terrain existed along the southern wall and the course of the Wei River obstructed the straight path of the northern wall) . The city 's moat was 8 m (26 ft) wide and 3 m (9 @.@ 8 ft) deep ; the remains of what were wooden bridges have been discovered along the moat . Chang 'an had twelve gatehouses leading into the city , three for each side of the wall , and acted as terminus points for the main avenues . Every gatehouse had three gateway entrances that were each 6 m (20 ft) wide ; Han @-@ era writers claimed that each gateway could accommodate the traffic of four horse @-@ drawn carriages at once . The drainage system included many drainholes that were dug under these gates and lined with bricks that form arches , where ceramic water pipes have been found that once connected to the ditches built alongside the major streets . Only some wall sections and platform foundations of the city 's once lavish imperial palaces remain . Likewise , the stone foundations of the armory were also discovered , but its wooden architecture had long since disappeared .

Some sections of the wall ruins of Han 's second capital Luoyang still stand at 10 m (33 ft) in height and 25 m (82 ft) in width at the base . The eastern wall was 3 @,@ 900 m (12 @,@ 800 ft) long , the western wall was 3 @,@ 400 m (11 @,@ 200 ft) long , and the northern wall was 2 @,@ 700 m (8 @,@ 900 ft) long , yet the southern wall was washed away when the Luo River changed

its course centuries ago ; by using the terminus points of the eastern and western walls , historians estimate that the southern wall was 2 @,@ 460 m (8 @,@ 070 ft) long . The overall walled enclosure formed a rectangular shape , yet with some disruptive curves due to topographical obstructions . Like Chang 'an , Luoyang had twelve gatehouses , three for each side of the wall , while each gatehouse had three gateway entrances which led to major avenues within the city . The rammed earth foundational platforms of religious altars and terraces still stand today outside of the walled perimeter of Luoyang , dedicated to the worship of deities and where state sacrifices were conducted . They were approached by long ramps and once had timber halls built on top with verandas on the lower levels .

= = = Underground tombs = = =

By the 1980s , over ten thousand brick @-@ and @-@ stone underground Han tombs had been discovered throughout China . Earlier Chinese tombs dating to the Warring States were often vertically dug pits lined with wooden walls . In digging the tomb sites , Han workers would first build vertical pits and then dig laterally , hence the name " horizontal pits " for Han tombs ; this method was also used for tomb sites dug into the sides of mountains . The walls of most Western Han tombs were built of large hollow bricks while the smaller , non @-@ hollow brick type that dominated Eastern Han tomb architecture (with some made out of stone) appeared in the late Western Han . The smaller brick type was better @-@ suited for Han tomb archways at entrances , vaulted chambers , and domed roofs . Underground vaults and domes did not require buttress supports since they were held in place by earthen pits . The use of brick vaults and domes in aboveground Han structures is unknown .

The layout of tombs dug into the sides of mountains typically had a front chamber , side chambers , and a rear chambers designed to imitate a complex of aboveground halls . The tomb of King Liu Sheng (d . 113 BCE) in Hebei province not only had a front hall with window drapes and grave goods , carriages and horses in the southern separate side chamber , and storage goods in the northern side chamber , but also the remains of real timber houses with tiled roofs erected within (along with a house made of stone slabs and two stone doors in the rear chamber) . Doors made completely out of stone were found in many Han tombs as well as tombs in later dynasties .

A total of twenty @-@ nine monumental brick or stone @-@ carved pillar @-@ gates (que) from the Han dynasty have survived and can be found in the aboveground areas around Han tomb and shrine sites . They often formed part of outer walls , usually flanking an entry but sometimes at the corners of walled enclosures . Although they lack wooden and ceramic components , they feature imitation roof tiles , eaves , porches , and balustrades .

= = = Boreholes and mining shafts = = =

On Han tomb brick reliefs of Sichuan province , scenes of borehole drilling for mining projects are shown . They show towering derricks lifting liquid brine through bamboo pipes to the surface so that the brine could be distilled in evaporation pans over the heat of furnaces and produce salt . The furnaces were heated by natural gas brought by bamboo pipes , yet gas brought up from 610 m (2 @,@ 000 ft) below the surface could cause an explosion if it was not properly mixed with oxygen first , so the Han @-@ era Chinese built underground carburetor chambers and siphoned some of the gas off with exhaust pipes . The drill bit for digging boreholes was operated by a team of men jumping on and off a beam while the boring tool was rotated by a draft animal , usually oxen or water buffaloes . Han boreholes dug for collecting brine could reach hundreds of meters (feet) beneath the Earth 's surface . Mining shafts dating to the Han dynasty have been found which reach depths of hundreds of meters (feet) beneath the earth , complete with spacious underground rooms structured by timber frames along with ladders and iron tools left behind .

= = = Ceramic model buildings = = =

There are Han @-@ era literary references to tall towers found in the capital cities ; they often served as watchtowers , astronomical observatories , and religious establishments meant to attract the favor of immortals . The court eunuchs Zhao Zhong and Zhang Rang discouraged the aloof Emperor Ling of Han (r . 168 ? 189 CE) from ascending to the top floors of tall towers (claiming it would cause bad luck) , in order to conceal from him the enormous palatial mansions the eunuchs built for themselves in Luoyang . It is not known for certain whether or not miniature ceramic models of residential towers and watchtowers found in Han @-@ dynasty tombs are completely faithful representations of such timber towers , yet they reveal vital clues about lost timber architecture .

There are only a handful of existing ceramic models of multi @-@ story towers from pre @-@ Han and Western Han eras ; the bulk of the hundreds of towers found so far were made during the Eastern Han period . Model towers could be fired as one piece in the kiln or assembled from several different ceramic pieces to create the whole . No one tower is a duplicate of the other , yet they share common features . They often had a walled courtyard at the bottom , a balcony with balustrades and windows for every floor , roof tiles capping and concealing the ceiling rafters , human figures peering out the windows or standing on the balconies , door knockers , and pets such as dogs in the bottom courtyard . Perhaps the most direct pieces of evidence to suggest that miniature ceramic tower models are faithful representations of real @-@ life Han timber towers are tile patterns . Artistic patterns found on the circular tiles that cap the eave @-@ ends on the miniature models are exact matches of patterns found on real @-@ life Han roof tiles excavated at sites such as the royal palaces in Chang 'an and Luoyang , and even the tiles of the original White Horse Temple . The ceramic model towers featured below come from tombs of the Han dynasty :

Besides towers , other ceramic models from the Han reveal a variety of building types . This includes multi @-@ story storehouses such as granaries , courtyard houses with multi @-@ story halls , kiosks , walled gate towers , mills , manufactories and workshops , animal pens , outhouses , and water wells . Even models of single @-@ story farmhouses show a great amount of detail , including tiled roofs , courtyards , steps leading to walkways , farmyards with troughs and basins , parapets , and privies . Models of granaries and storehouses had tiled rooftops , dougong brackets , windows , and stilt supports raising them above ground level . Han models of water wells sometimes feature tiny tiled roofs supported by beams that house the rope pulley used for lifting the bucket . The ceramic models featured below come from tombs of the Han dynasty :

= = = Roads , bridges , and canals = = =

In order to facilitate commerce and communication as well as speed the process of tax collection and movement of military troops , the Han government sponsored the building of new roads , bridges , and canal waterways . These include repairs and renovation work on the Dujiangyan Irrigation System of Sichuan and Zhengguo Canal of Shaanxi , both of which were built by the previous State of Qin . Accepting the proposal of Ni Kuan (zh : ??) , in 111 BCE Emperor Wu commissioned Er to lead the project of creating extensions to the Zhengguo Canal that could irrigate nearby terrain elevated above the main canal . Since a large amount of silt had built up over time at the bottom of the Zhengguo Canal (causing flooding) , in 95 BCE another project was initiated to tap irrigation waters from further up the Jing River , requiring the dredging of a new 100 km (62 mi) long canal following a contour line above the Zhengguo . The Han state also maintained a system of dikes to protect farmland from seasonal floods .

Roadways , wooden bridges , postal stations , and relay stations were occasionally repaired , while many new facilities such as these were established . As written by Han authors , roads built during the Han were tamped down with metal rammers , yet there is uncertainty over the materials used ; Joseph Needham speculates that they were rubble and gravel . The widths of roads ranged from narrow footpaths where only a single horse or oxen could pass at once to large highways that could accommodate the simultaneous passage of nine horse @-@ drawn chariots abreast . Fortified Han roadways were built as far west as Shanshan (Loulan) near the Lop Desert , while Han forces utilized routes that traversed north of the Taklamakan Desert towards Kashgar . A vast network of roads , fortified passes , and wooden bridges built over rushing torrents in steep gorges of the Qin

Mountains was consolidated during the Han , known as the gallery roads . During the reign of Emperor Wu , roads were built to connect newly conquered territories in what is now Yunnan in the far southwest as well as the Korean Peninsula in the far northeast .

One of the most common bridge @-@ types built during the Han was the wooden @-@ trestle beam bridge , described by literary sources and seen in reliefs carved on tomb bricks . Evidence for arch bridges is elusive : one outside of Chengdu 's south gate is claimed to date to the Han period , while that built by Ma Xian (??) (fl . 135 CE) was certainly a beam bridge . In artwork , a relief sculpture from a Han tomb in Sichuan province shows an arch bridge with a gradual curve , suggesting that it is segmental , although the use of such bridges are not entirely confirmed . Although there are rare references to simple suspension bridges in Han sources , these are only mentioned in connection with travels to foreign countries in the Himalaya , Hindukush and Afghanistan , demonstrating the antiquity of the invention there . Floating pontoon bridges made of boats secured by iron chains were built during the Han (some even spanning the Yellow River and Yangzi River) and were most often employed for military purposes since they could be easily assembled and then disassembled .

= = Medicine = =

Much of the beliefs held by Han @-@ era physicians are known to modern historians through such texts as the Yellow Emperor 's Inner Canon (Huangdi neijing) medical corpus , which was compiled from the 3rd to 2nd century BCE and was mentioned in the Book of Later Han . It is clear from this text and others that their metaphysical beliefs in the five phases and yin and yang dictated their medical decisions and assumptions . The Han @-@ era Chinese believed that each organ in the body was associated with one of the five phases (metal ? , wood ? , water ? , fire ? , earth ?) and had two circulatory qi channels (????) . If these channels were disrupted , Han medical texts suggest that one should consume an edible material associated with one of these phases that would counteract the organ 's prescribed phase and thus restore one 's health . For example , the Chinese believed that when the heart ? associated with the fire phase ? caused one to become sluggish , then one should eat sour food because it was associated with the wood phase (which promoted fire) . The Han Chinese also believed that by using pulse diagnosis , a physician could determine which organ of the body emitted " vital energy " (qi) and what qualities the latter had , in order to figure out the exact disorder the patient was suffering . Despite the influence of metaphysical theory on medicine , Han texts also give practical advice , such as the proper way to perform clinical lancing to remove an abscess . The Huangdi neijing noted the symptoms and reactions of people with various diseases of the liver , heart , spleen , lung , or kidneys in a 24 @-@ hour period , which was a recognition of circadian rhythm , although explained in terms of the five phases .

In his Essential Medical Treasures of the Golden Chamber (Jinkui yaolue) , Zhang Zhongjing (c . 150 ? c . 219 CE) was the first to suggest a regulated diet rich in certain vitamins could prevent different types of disease , an idea which led Hu Sihui (fl . 1314 ? 1330 CE) to prescribe a diet rich in Vitamin B1 as a treatment for beriberi . Zhang 's major work was the Treatise on Cold Injury and Miscellaneous Disorders (Shanghan zabing lun) . His contemporary and alleged associate Hua Tuo (d . 208 CE) was a physician who had studied the Huangdi neijing and became knowledgeable in Chinese herbology . Hua Tuo used anesthesia on patients during surgery and created an ointment that was meant to fully heal surgery wounds within a month . In one diagnosis of an ill woman , he deciphered that she bore a dead fetus within her womb which he then removed , curing her of her ailments .

Historical sources say that Hua Tuo rarely practiced moxibustion and acupuncture . The first mentioning of acupuncture in Chinese literature appeared in the Huangdi neijing . Acupuncture needles made of gold were found in the tomb of the Han King Liu Sheng (d . 113 BCE) . Some stone @-@ carved depictions of acupuncture date to the Eastern Han Era (25 ? 220 CE) . Hua Tuo also wrote about the allegedly life @-@ prolonging exercises of calisthenics . In the 2nd @-@ century @-@ BCE medical texts excavated from the tombs of Mawangdui , illustrated diagrams of calisthenic positions are accompanied by descriptive titles and captions . Vivienne Lo writes that the

modern physical exercises of taijiquan and qigong are derived from Han @-@ era calisthenics .

= = Cartography = =

Map @-@ making in China preceded the Han dynasty . Since two 4th @-@ century @-@ BCE silk maps from the State of Qin (found in Gansu , displaying the region about the Jialing River) show the measured distance between timber @-@ gathering sites , Mei @-@ ling Hsu argues that these are to be considered the first known economic maps (as they predate the maps of the Roman geographer Strabo , c . 64 BCE ? 24 CE) . Maps from the Han period have also been uncovered by modern archaeologists , such as those found with 2nd @-@ century @-@ BCE silk texts at Mawangdui . In contrast to the Qin maps , the Han maps found at Mawangdui employ a more diverse use of map symbols , cover a larger terrain , and display information on local populations and even pinpoint locations of military camps . One of the maps discovered at Mawangdui shows positions of Han military garrisons which were to attack Nanyue in 181 BCE .

In Chinese literature , the oldest reference to a map comes from the year 227 BCE , when the assassin Jing Ke was to present a map to Ying Zheng ?? , King of Qin (ruling later as Qin Shi Huang , r . 221 ? 210 BCE) on behalf of Crown Prince Dan of Yan . Instead of presenting the map , he pulled out a dagger from his scroll , yet was unable to kill Ying Zheng . The Rites of Zhou (Zhouli) , compiled during the Han and commented by Liu Xin in the 1st century CE , mentioned the use of maps for governmental provinces and districts , principalities , frontier boundaries , and locations of ores and minerals for mining facilities . The first Chinese gazetteer was written in 52 CE and included information on territorial divisions , the founding of cities , and local products and customs . Pei Xiu (224 ? 271 CE) was the first to describe in detail the use of a graduated scale and geometrically plotted reference grid . However , historians Howard Nelson , Robert Temple , and Rafe de Crespigny argue that there is enough literary evidence that Zhang Heng 's now lost work of 116 CE established the geometric reference grid in Chinese cartography (including a line from the Book of Later Han : " [Zhang Heng] cast a network of coordinates about heaven and earth , and reckoned on the basis of it ") . Although there is speculation fueled by the report in Sima 's Records of the Grand Historian that a gigantic raised @-@ relief map representing the Qin Empire is located within the tomb of Qin Shi Huang , it is known that small raised @-@ relief maps were created during the Han dynasty , such as one made out of rice by the military officer Ma Yuan (14 BCE ? 49 CE) .

= = Nautics and vehicles = =

In 1975 , an ancient shipyard discovered in Guangzhou is now dated to the late 3rd century BCE , made during either the Qin dynasty (221 ? 206 BCE) or early Western Han dynasty . It had three large platforms capable of building wooden ships that were 30 m (98 ft) long , 8 m (26 ft) wide , and had a weight capacity of 60 metric tons . Another Han shipyard in what is now Anhui province had a government @-@ operated maritime workshop where battle ships were assembled . The widespread use of iron tools during the Han dynasty was essential for crafting such vessels .

The southward expansion of the Han dynasty led to new trade routes and diplomatic contact with foreign kingdoms . In 111 BCE , Emperor Wu conquered the Kingdom of Nanyue in what is now modern northern Vietnam and Guangdong , Guangxi , Yunnan ; thereafter he opened up maritime trade to both Southeast Asia and the Indian Ocean , as foreign merchants brought lapis lazuli , pearls , jade , and glasswares to the Han Empire from this southern sea route . When a group of travelers from the Roman Empire (allegedly diplomats of Marcus Aurelius but most likely Roman merchants) came to the Han court in 166 CE , they allegedly came from this southern trade route . By at least the 1st century CE ? as proven by Eastern Han ceramic miniature models of ships found in various tombs ? the Chinese would have been able to brave distant waters with the new steering invention of the stern @-@ mounted rudder . This came to replace the less efficient steering oar . While ancient China was home to various ship designs , including the layered and fortified tower ship meant for calm waters of lakes and river , the junk design (jun ?) created by the 1st century

CE was China 's first seaworthy sailing ship . The typical junk has a square @-@ ended bow and stern , a flat @-@ bottomed hull or carvel @-@ shaped hull with no keel or sternpost , and solid transverse bulkheads in the place of structural ribs found in Western seacrafts . Since the Chinese junk lacked a sternpost , the rudder was attached to the back of the ship by use of either socket @-@ and @-@ jaw or block and tackle (which differed from the later European pintle and gudgeon design of the 12th century) . As written by a 3rd @-@ century author , junks had for @-@ and @-@ aft rigs and lug sails .

Although horse and ox @-@ drawn carts and spoke @-@ wheeled chariots had existed in China long before the Han dynasty , it was not until the 1st century BCE that literary evidence pointed to the invention of the wheelbarrow , while painted murals on Han tomb walls of the 2nd century CE show the wheelbarrow in use for hauling goods . While the ' throat @-@ and @-@ girth ' harness was still in use throughout much of the ancient world (placing an excessive amount of pressure on horses ' necks) , the Chinese were placing a wooden yoke across their horses ' chests with traces to the chariot shaft by the 4th century BCE in the State of Chu (as seen on a Chu lacquerware) . By Han times , the Chinese replaced this heavy yoke with a softer breast strap , as seen in Han stamped bricks and carved tomb reliefs . In the final stage of evolution , the modern horse collar was invented in China by the 5th century CE , during the Northern Wei period .

= = Weaponry and war machines = =

The pivot catapult , known as the traction trebuchet , had existed in China since the Warring States period (as evidenced by the Mozi) . It was regularly used in sieges during the Han dynasty , by both besiegers and the besieged . The most common projectile weapon used during the Han dynasty was the small handheld , trigger @-@ activated crossbow (and to a lesser extent , the repeating crossbow) , first invented in China during the 6th or 5th century BCE . Although the nomadic Xiongnu were able to twist their waists slightly while horse @-@ riding and shoot arrows at targets behind them , the official Chao Cuo (d . 154 BCE) deemed the Chinese crossbow superior to the Xiongnu bow .

The Han Chinese also employed chemical warfare . In quelling a peasant revolt near Guiyang in 178 CE , the imperial Han forces had horse @-@ drawn chariots carrying bellows that were used to pump powdered lime (calcium oxide) at the rebels , who were dispersed . In this same instance , they also lit incendiary rags tied to the tails of horses , so that the frightened horses would rush through the enemy lines and disrupt their formations .

To deter pursuits of marching infantry or riding cavalry , the Han Chinese made caltrops (barbed iron balls with sharp spikes sticking out in all directions) that could be scattered on the ground and pierce the feet or hooves of those who were unaware of them .