



# Technology & its History

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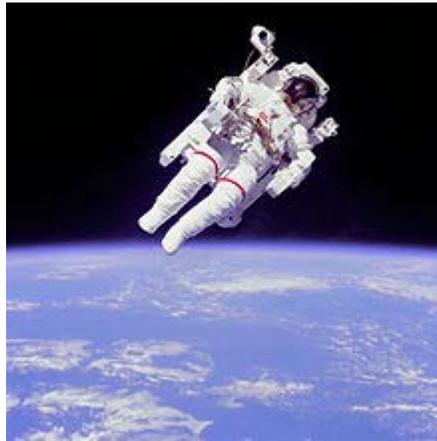
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## Chapter-1

# Introduction to Technology



By the mid 20th century, humans had achieved a mastery of technology sufficient to leave the atmosphere of the Earth for the first time and explore space.

**Technology** is the creation, usage and knowledge of tools, techniques, crafts, systems or methods of organization as means in order to solve a problem or serve some purpose or end. The word *technology* comes from Greek *τεχνολογία* (*technología*); from *τέχνη* (*téchnē*), meaning "art, skill, craft", and *-λογία* (*-logía*), meaning "study of-". The term can either be applied generally or to specific areas: examples include *construction technology*, *medical technology*, and *information technology*.

Technologies significantly affect human as well as other animal species' ability to control and adapt to their natural environments. The human species' use of technology began with the conversion of natural resources into simple tools. The prehistorical discovery of the ability to control fire increased the available sources of food and the invention of the wheel helped humans in travelling in and controlling their environment. Recent technological developments, including the printing press, the telephone, and the Internet, have lessened physical barriers to communication and allowed humans to interact freely on a global scale. However, not all technology has been used for peaceful purposes; the development of weapons of ever-increasing destructive power has progressed throughout history, from clubs to nuclear weapons.

Technology has affected society and its surroundings in a number of ways. In many societies, technology has helped develop more advanced economies (including today's global economy) and has allowed the rise of a leisure class. Many technological processes produce unwanted by-products, known as pollution, and deplete natural resources, to the detriment of the Earth and its environment. Various implementations of technology influence the values of a society and new technology often raises new ethical questions. Examples include the rise of the notion of efficiency in terms of human productivity, a term originally applied only to machines, and the challenge of traditional norms.

Philosophical debates have arisen over the present and future use of technology in society, with disagreements over whether technology improves the human condition or worsens it. Neo-Luddism, anarcho-primitivism, and similar movements criticise the pervasiveness of technology in the modern world, opining that it harms the environment and alienates people; proponents of ideologies such as transhumanism and techno-progressivism view continued technological progress as beneficial to society and the human condition. Indeed, until recently, it was believed that the development of technology was restricted only to human beings, but recent scientific studies indicate that other primates and certain dolphin communities have developed simple tools and learned to pass their knowledge to other generations.

## Definition and usage



The invention of the printing press made it possible for scientists and politicians to communicate their ideas with ease, leading to the Age of Enlightenment; an example of technology as a cultural force.

The use of the term *technology* has changed significantly over the last 200 years. Before the 20th century, the term was uncommon in English, and usually referred to the description or study of the useful arts. The term was often connected to technical

education, as in the Massachusetts Institute of Technology (chartered in 1861). "Technology" rose to prominence in the 20th century in connection with the second industrial revolution. The meanings of technology changed in the early 20th century when American social scientists, beginning with Thorstein Veblen, translated ideas from the German concept of *Technik* into "technology." In German and other European languages, a distinction exists between *Technik* and *Technologie* that is absent in English, as both terms are usually translated as "technology." By the 1930s, "technology" referred not to the study of the industrial arts, but to the industrial arts themselves. In 1937, the American sociologist Read Bain wrote that "technology includes all tools, machines, utensils, weapons, instruments, housing, clothing, communicating and transporting devices and the skills by which we produce and use them." Bain's definition remains common among scholars today, especially social scientists. But equally prominent is the definition of technology as applied science, especially among scientists and engineers, although most social scientists who study technology reject this definition. More recently, scholars have borrowed from European philosophers of "technique" to extend the meaning of technology to various forms of instrumental reason, as in Foucault's work on technologies of the self ("techniques de soi").

Dictionaries and scholars have offered a variety of definitions. The Merriam-Webster dictionary offers a definition of the term: "the practical application of knowledge especially in a particular area" and "a capability given by the practical application of knowledge". Ursula Franklin, in her 1989 "Real World of Technology" lecture, gave another definition of the concept; it is "practice, the way we do things around here". The term is often used to imply a specific field of technology, or to refer to high technology or just consumer electronics, rather than technology as a whole. Bernard Stiegler, in *Technics and Time, 1*, defines technology in two ways: as "the pursuit of life by means other than life", and as "organized inorganic matter."

Technology can be most broadly defined as the entities, both material and immaterial, created by the application of mental and physical effort in order to achieve some value. In this usage, technology refers to tools and machines that may be used to solve real-world problems. It is a far-reaching term that may include simple tools, such as a crowbar or wooden spoon, or more complex machines, such as a space station or particle accelerator. Tools and machines need not be material; virtual technology, such as computer software and business methods, fall under this definition of technology.

The word "technology" can also be used to refer to a collection of techniques. In this context, it is the current state of humanity's knowledge of how to combine resources to produce desired products, to solve problems, fulfill needs, or satisfy wants; it includes technical methods, skills, processes, techniques, tools and raw materials. When combined with another term, such as "medical technology" or "space technology", it refers to the state of the respective field's knowledge and tools. "State-of-the-art technology" refers to the high technology available to humanity in any field.

Technology can be viewed as an activity that forms or changes culture. Additionally, technology is the application of math, science, and the arts for the benefit of life as it is

known. A modern example is the rise of communication technology, which has lessened barriers to human interaction and, as a result, has helped spawn new subcultures; the rise of cyberculture has, at its basis, the development of the Internet and the computer. Not all technology enhances culture in a creative way; technology can also help facilitate political oppression and war via tools such as guns. As a cultural activity, technology predates both science and engineering, each of which formalize some aspects of technological endeavor.

## Science, engineering and technology

The distinction between science, engineering and technology is not always clear. Science is the reasoned investigation or study of phenomena, aimed at discovering enduring principles among elements of the phenomenal world by employing formal techniques such as the scientific method. Technologies are not usually exclusively products of science, because they have to satisfy requirements such as utility, usability and safety.

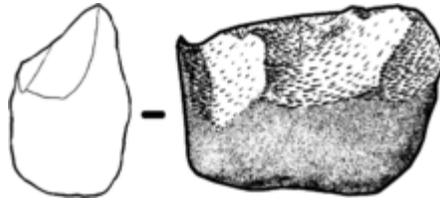
Engineering is the goal-oriented process of designing and making tools and systems to exploit natural phenomena for practical human means, often (but not always) using results and techniques from science. The development of technology may draw upon many fields of knowledge, including scientific, engineering, mathematical, linguistic, and historical knowledge, to achieve some practical result.

Technology is often a consequence of science and engineering — although technology as a human activity precedes the two fields. For example, science might study the flow of electrons in electrical conductors, by using already-existing tools and knowledge. This new-found knowledge may then be used by engineers to create new tools and machines, such as semiconductors, computers, and other forms of advanced technology. In this sense, scientists and engineers may both be considered technologists; the three fields are often considered as one for the purposes of research and reference.

The exact relations between science and technology in particular have been debated by scientists, historians, and policymakers in the late 20th century, in part because the debate can inform the funding of basic and applied science. In the immediate wake of World War II, for example, in the United States it was widely considered that technology was simply "applied science" and that to fund basic science was to reap technological results in due time. An articulation of this philosophy could be found explicitly in Vannevar Bush's treatise on postwar science policy, *Science—The Endless Frontier*: "New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature... This essential new knowledge can be obtained only through basic scientific research." In the late-1960s, however, this view came under direct attack, leading towards initiatives to fund science for specific tasks (initiatives resisted by the scientific community). The issue remains contentious—though most analysts resist the model that technology simply is a result of scientific research.

# History

## Paleolithic (2.5 million – 10,000 BC)



A primitive chopper

The use of tools by early humans was partly a process of discovery, partly of evolution. Early humans evolved from a species of foraging hominids which were already bipedal, with a brain mass approximately one third that of modern humans. Tool use remained relatively unchanged for most of early human history, but approximately 50,000 years ago, a complex set of behaviors and tool use emerged, believed by many archaeologists to be connected to the emergence of fully modern language.

## Stone tools



Hand axes from the Acheulian period



A Clovis point, made via pressure flaking

Human ancestors have been using stone and other tools since long before the emergence of *Homo sapiens* approximately 200,000 years ago. The earliest methods of stone tool making, known as the Oldowan "industry", date back to at least 2.3 million years ago, with the earliest direct evidence of tool usage found in Ethiopia within the Great Rift Valley, dating back to 2.5 million years ago. This era of stone tool use is called the *Paleolithic*, or "Old stone age", and spans all of human history up to the development of agriculture approximately 12,000 years ago.

To make a stone tool, a "core" of hard stone with specific flaking properties (such as flint) was struck with a hammerstone. This flaking produced a sharp edge on the core stone as well as on the flakes, either of which could be used as tools, primarily in the form of choppers or scrapers. These tools greatly aided the early humans in their hunter-gatherer lifestyle to perform a variety of tasks including butchering carcasses (and breaking bones to get at the marrow); chopping wood; cracking open nuts; skinning an animal for its hide; and even forming other tools out of softer materials such as bone and wood.

The earliest stone tools were crude, being little more than a fractured rock. In the Acheulian era, beginning approximately 1.65 million years ago, methods of working these stone into specific shapes, such as hand axes emerged. The Middle Paleolithic, approximately 300,000 years ago, saw the introduction of the prepared-core technique, where multiple blades could be rapidly formed from a single core stone. The Upper Paleolithic, beginning approximately 40,000 years ago, saw the introduction of pressure flaking, where a wood, bone, or antler punch could be used to shape a stone very finely.

## **Fire**

The discovery and utilization of fire, a simple energy source with many profound uses, was a turning point in the technological evolution of humankind. The exact date of its discovery is not known; evidence of burnt animal bones at the Cradle of Humankind

suggests that the domestication of fire occurred before 1,000,000 BC; scholarly consensus indicates that Homo erectus had controlled fire by between 500,000 BC and 400,000 BC. Fire, fueled with wood and charcoal, allowed early humans to cook their food to increase its digestibility, improving its nutrient value and broadening the number of foods that could be eaten.

### **Clothing and shelter**

Other technological advances made during the Paleolithic era were clothing and shelter; the adoption of both technologies cannot be dated exactly, but they were a key to humanity's progress. As the Paleolithic era progressed, dwellings became more sophisticated and more elaborate; as early as 380,000 BC, humans were constructing temporary wood huts. Clothing, adapted from the fur and hides of hunted animals, helped humanity expand into colder regions; humans began to migrate out of Africa by 200,000 BC and into other continents, such as Eurasia.

### **Neolithic through Classical Antiquity (10,000BC – 300AD)**



An array of Neolithic artifacts, including bracelets, axe heads, chisels, and polishing tools.

Man's technological ascent began in earnest in what is known as the Neolithic period ("New stone age"). The invention of polished stone axes was a major advance because it allowed forest clearance on a large scale to create farms. The discovery of agriculture allowed for the feeding of larger populations, and the transition to a sedentist lifestyle increased the number of children that could be simultaneously raised, as young children no longer needed to be carried, as was the case with the nomadic lifestyle. Additionally, children could contribute labor to the raising of crops more readily than they could to the hunter-gatherer lifestyle.

With this increase in population and availability of labor came an increase in labor specialization. What triggered the progression from early Neolithic villages to the first cities, such as Uruk, and the first civilizations, such as Sumer, is not specifically known; however, the emergence of increasingly hierarchical social structures, the specialization of labor, trade and war amongst adjacent cultures, and the need for collective action to overcome environmental challenges, such as the building of dikes and reservoirs, are all thought to have played a role.

## **Metal tools**

Continuing improvements led to the furnace and bellows and provided the ability to smelt and forge native metals (naturally occurring in relatively pure form). Gold, copper, silver, and lead, were such early metals. The advantages of copper tools over stone, bone, and wooden tools were quickly apparent to early humans, and native copper was probably used from near the beginning of Neolithic times (about 8000 BC). Native copper does not naturally occur in large amounts, but copper ores are quite common and some of them produce metal easily when burned in wood or charcoal fires. Eventually, the working of metals led to the discovery of alloys such as bronze and brass (about 4000 BC). The first uses of iron alloys such as steel dates to around 1400 BC.

## **Energy and Transport**



The wheel was invented circa 4000 BC.

Meanwhile, humans were learning to harness other forms of energy. The earliest known use of wind power is the sailboat. The earliest record of a ship under sail is shown on an Egyptian pot dating back to 3200 BC. From prehistoric times, Egyptians probably used the power of the Nile annual floods to irrigate their lands, gradually learning to regulate much of it through purposely built irrigation channels and 'catch' basins. Similarly, the early peoples of Mesopotamia, the Sumerians, learned to use the Tigris and Euphrates rivers for much the same purposes. But more extensive use of wind and water (and even human) power required another invention.

According to archaeologists, the wheel was invented around 4000 B.C. probably independently and nearly-simultaneously in Mesopotamia (in present-day Iraq), the Northern Caucasus (Maykop culture) and Central Europe. Estimates on when this may have occurred range from 5500 to 3000 B.C., with most experts putting it closer to 4000 B.C. The oldest artifacts with drawings that depict wheeled carts date from about 3000 B.C.; however, the wheel may have been in use for millennia before these drawings were made. There is also evidence from the same period of time that wheels were used for the production of pottery. (Note that the original potter's wheel was probably not a wheel, but rather an irregularly shaped slab of flat wood with a small hollowed or pierced area near the center and mounted on a peg driven into the earth. It would have been rotated by

repeated tugs by the potter or his assistant.) More recently, the oldest-known wooden wheel in the world was found in the Ljubljana marshes of Slovenia.

The invention of the wheel revolutionized activities as disparate as transportation, war, and the production of pottery (for which it may have been first used). It didn't take long to discover that wheeled wagons could be used to carry heavy loads and fast (rotary) potters' wheels enabled early mass production of pottery. But it was the use of the wheel as a transformer of energy (through water wheels, windmills, and even treadmills) that revolutionized the application of nonhuman power sources.

## **Medieval and Modern history (300 AD —)**

Innovations continued through the Middle Ages with new innovations such as silk, the horse collar and horseshoes in the first few hundred years after the fall of the Roman Empire. Medieval technology saw the use of simple machines (such as the lever, the screw, and the pulley) being combined to form more complicated tools, such as the wheelbarrow, windmills and clocks. The Renaissance brought forth many of these innovations, including the printing press (which facilitated the greater communication of knowledge), and technology became increasingly associated with science, beginning a cycle of mutual advancement. The advancements in technology in this era allowed a more steady supply of food, followed by the wider availability of consumer goods.

Starting in the United Kingdom in the 18th century, the Industrial Revolution was a period of great technological discovery, particularly in the areas of agriculture, manufacturing, mining, metallurgy and transport, driven by the discovery of steam power. Technology later took another step with the harnessing of electricity to create such innovations as the electric motor, light bulb and countless others. Scientific advancement and the discovery of new concepts later allowed for powered flight, and advancements in medicine, chemistry, physics and engineering. The rise in technology has led to the construction of skyscrapers and large cities whose inhabitants rely on automobiles or other powered transit for transportation. Communication was also improved with the invention of the telegraph, telephone, radio and television.

The second half of the 20th century brought a host of new innovations. In physics, the discovery of nuclear fission has led to both nuclear weapons and nuclear energy. Computers were also invented and later miniaturized utilizing transistors and integrated circuits. These advancements subsequently led to the creation of the Internet. Humans have also been able to explore space with satellites (later used for telecommunication) and in manned missions going all the way to the moon. In medicine, this era brought innovations such as open-heart surgery and later stem cell therapy along with new medications and treatments. Complex manufacturing and construction techniques and organizations are needed to construct and maintain these new technologies, and entire industries have arisen to support and develop succeeding generations of increasingly more complex tools. Modern technology increasingly relies on training and education — their designers, builders, maintainers, and users often require sophisticated general and specific training. Moreover, these technologies have become so complex that entire fields

have been created to support them, including engineering, medicine, and computer science, and other fields have been made more complex, such as construction, transportation and architecture.

## Technology and philosophy

### Technicism

Generally, technicism is a reliance or confidence in technology as a benefactor of society. Taken to extreme, technicism is the belief that humanity will ultimately be able to control the entirety of existence using technology. In other words, human beings will someday be able to master all problems and possibly even control the future using technology. Some, such as Stephen V. Monsma, connect these ideas to the abdication of religion as a higher moral authority.

### Optimism

Optimistic assumptions are made by proponents of ideologies such as transhumanism and singularitarianism, which view technological development as generally having beneficial effects for the society and the human condition. In these ideologies, technological development is morally good. Some critics see these ideologies as examples of scientism and techno-utopianism and fear the notion of human enhancement and technological singularity which they support. Some have described Karl Marx as a techno-optimist.

### Skepticism and Critics of Technology

On the somewhat skeptical side are certain philosophers like Herbert Marcuse and John Zerzan, who believe that technological societies are inherently flawed. They suggest that the inevitable result of such a society is to become evermore technological at the cost of freedom and psychological health.

Many, such as the Luddites and prominent philosopher Martin Heidegger, hold serious, although not entirely deterministic reservations, about technology. According to Heidegger scholars Hubert Dreyfus and Charles Spinosa, "Heidegger does not oppose technology. He hopes to reveal the essence of technology in a way that 'in no way confines us to a stultified compulsion to push on blindly with technology or, what comes to the same thing, to rebel helplessly against it.' Indeed, he promises that 'when we once open ourselves expressly to the essence of technology, we find ourselves unexpectedly taken into a freeing claim.'" What this entails is a more complex relationship to technology than either techno-optimists or techno-pessimists tend to allow.

Some of the most poignant criticisms of technology are found in what are now considered to be dystopian literary classics, for example Aldous Huxley's *Brave New World* and other writings, Anthony Burgess's *A Clockwork Orange*, and George Orwell's *Nineteen Eighty-Four*. And, in *Faust* by Goethe, Faust's selling his soul to the devil in return for power over the physical world, is also often interpreted as a metaphor for the adoption of

industrial technology. More recently, modern works of science fiction, such as those by Philip K. Dick and William Gibson, and films (e.g. Blade Runner, Ghost in the Shell) project highly ambivalent or cautionary attitudes toward technology's impact on human society and identity.

The late cultural critic Neil Postman distinguished tool-using societies from technological societies and, finally, what he called "technopolies," that is, societies that are dominated by the ideology of technological and scientific progress, to the exclusion or harm of other cultural practices, values and world-views.

Darin Barney has written about technology's impact on practices of citizenship and democratic culture, suggesting that technology can be construed as (1) an object of political debate, (2) a means or medium of discussion, and (3) a setting for democratic deliberation and citizenship. As a setting for democratic culture, Barney suggests that technology tends to make ethical questions, including the question of what a good life consists in, nearly impossible, because they already give an answer to the question: a good life is one that includes the use of more and more technology.

Nikolas Kompridis has also written about the dangers of new technology, such as genetic engineering, nanotechnology, synthetic biology and robotics. He warns that these technologies introduce unprecedented new challenges to human beings, including the possibility of the permanent alteration of our biological nature. These concerns are shared by other philosophers, scientists and public intellectuals who have written about similar issues (e.g. Francis Fukuyama, Jürgen Habermas, William Joy, and Michael Sandel).

Another prominent critic of technology is Hubert Dreyfus, who has published books *On the Internet* and *What Computers Still Can't Do*.

Another, more infamous anti-technological treatise is *Industrial Society and Its Future*, written by Theodore Kaczynski (aka The Unabomber) and printed in several major newspapers (and later books) as part of an effort to end his bombing campaign of the techno-industrial infrastructure.

### **Appropriate technology**

The notion of appropriate technology, however, was developed in the 20th century to describe situations where it was not desirable to use very new technologies or those that required access to some centralized infrastructure or parts or skills imported from elsewhere. The eco-village movement emerged in part due to this concern.

## **Technology and competitiveness**

In 1983 a classified program was initiated in the US intelligence community to reverse the US declining economic and military competitiveness. The program, Project Socrates, used all source intelligence to review competitiveness worldwide for all forms of competition to determine the source of the US decline. What Project Socrates determined

was that technology exploitation is the foundation of all competitive advantage and that the source of the US declining competitiveness was the fact that decision-making through the US both in the private and public sectors had switched from decision making that was based on technology exploitation (i.e., technology-based planning) to decision making that was based on money exploitation (i.e., economic-based planning) at the end of World War II.

Technology is properly defined as any application of science to accomplish a function. The science can be leading edge or well established and the function can have high visibility or be significantly more mundane but it is all technology, and its exploitation is the foundation of all competitive advantage.

Technology-based planning is what was used to build the US industrial giants before WWII (e.g., Dow, DuPont, GM) and it what was used to transform the US into a superpower. It was not economic-based planning.

Project Socrates determined that to rebuild US competitiveness, decision making through out the US had to readopt technology-based planning. Project Socrates also determined that countries like China and India had continued executing technology-based (while the US took its detour into economic-based) planning, and as a result had considerable advanced the process and were using it to build themselves into superpowers. To rebuild US competitiveness the US decision-makers needed adopt a form of technology-based planning that was far more advanced than that used by China and India.

Project Socrates determined that technology-based planning makes an evolutionary leap forward every few hundred years and the next evolutionary leap, the Automated Innovation Revolution, was poised to occur. In the Automated Innovation Revolution the process for determining how to acquire and utilize technology for a competitive advantage (which includes R&D) is automated so that it can be executed with unprecedented speed, efficiency and agility.

Project Socrates developed the means for automated innovation so that the US could lead the Automated Innovation Revolution in order to rebuild and maintain the country's economic competitiveness for many generations.

## Other animal species



This adult gorilla uses a branch as a walking stick to gauge the water's depth; an example of technology usage by primates.

The use of basic technology is also a feature of other animal species apart from humans. These include primates such as chimpanzees, some dolphin communities, and crows. Considering a more generic perspective of technology as ethology of active environmental conditioning and control, we can also refer to animal examples such as beavers and their dams, or bees and their honeycombs.

The ability to make and use tools was once considered a defining characteristic of the genus *Homo*. However, the discovery of tool construction among chimpanzees and related primates has discarded the notion of the use of technology as unique to humans. For example, researchers have observed wild chimpanzees utilising tools for foraging: some of the tools used include leaf sponges, termite fishing probes, pestles and levers. West African chimpanzees also use stone hammers and anvils for cracking nuts, as do capuchin monkeys of Boa Vista, Brazil.

## Future technology

Theories of technology often attempt to predict the future of technology based on the high technology and science of the time.

## Chapter-2

# History of Technology



The wheel was invented circa 4000 BC, and has become one of the world's most famous, and most useful technologies. This wheel is on display in The National Museum of Iran, in Tehran.

The **history of technology** is the history of the invention of tools and techniques, and is similar in many ways to the history of humanity. Background knowledge has enabled people to create new things, and conversely, many scientific endeavors have become possible through technologies which assist humans to travel to places we could not otherwise go, and probe the nature of the universe in more detail than our natural senses allow.

*Technological artifacts* are products of an economy, a force for economic growth, and a large part of everyday life. Technological innovations affect, and are affected by, a society's cultural traditions. They also are a means to develop and project military power.

## Measuring technological progress

Many sociologists and anthropologists have created social theories dealing with social and cultural evolution. Some, like Lewis H. Morgan, Leslie White, and Gerhard Lenski, declare technological progress to be the primary factor driving the development of human civilization. Morgan's concept of three major stages of social evolution (savagery, barbarism, and civilization) can be divided by technological milestones, like fire, the bow, and pottery in the savage era, domestication of animals, agriculture, and metalworking in the barbarian era and the alphabet and writing in the civilization era.

Instead of specific inventions, White decided that the measure by which to judge the evolution of culture was energy. For White "the primary function of culture" is to "harness and control energy." White differentiates between five stages of human development: In the first, people use energy of their own muscles. In the second, they use energy of domesticated animals. In the third, they use the energy of plants (agricultural revolution). In the fourth, they learn to use the energy of natural resources: coal, oil, gas. In the fifth, they harness nuclear energy. White introduced a formula  $P=E*T$ , where E is a measure of energy consumed, and T is the measure of efficiency of technical factors utilizing the energy. In his own words, "culture evolves as the amount of energy harnessed per capita per year is increased, or as the efficiency of the instrumental means of putting the energy to work is increased". Russian astronomer, Nikolai Kardashev, extrapolated his theory creating the Kardashev scale, which categorizes the energy use of advanced civilizations.

Lenski takes a more modern approach and focuses on information. The more information and knowledge (especially allowing the shaping of natural environment) a given society has, the more advanced it is. He identifies four stages of human development, based on advances in the history of communication. In the first stage, information is passed by genes. In the second, when humans gain sentience, they can learn and pass information through by experience. In the third, the humans start using signs and develop logic. In the fourth, they can create symbols, develop language and writing. Advancements in the technology of communication translates into advancements in the economic system and political system, distribution of wealth, social inequality and other spheres of social life. He also differentiates societies based on their level of technology, communication and economy:

- hunters and gatherers,
- simple agricultural,
- advanced agricultural,
- industrial,
- special (such as fishing societies).

Finally, from the late 1970s sociologists and anthropologists like Alvin Toffler (author of *Future Shock*), Daniel Bell and John Naisbitt have approached the theories of post-industrial societies, arguing that the current era of industrial society is coming to an end, and services and information are becoming more important than industry and goods.

Some of the more extreme visions of the post-industrial society, especially in fiction, are strikingly similar to the visions of near and post-Singularity societies.

## By period and geography

### Early technology



Agriculture preceded writing in the history of technology.

- Olduvai stone technology (Olduwan) 2.5 million years ago (scrapers; to butcher dead animals)
- Acheulean stone technology 1.6 million years ago (hand axe)
- Fire creation and manipulation, used since the Paleolithic, possibly by Homo erectus as early as 1.5 Million years ago
- (Homo sapiens sapiens - modern human anatomy arises, around 200,000 years ago.)
- Clothing possibly 100,000 years ago.
- Stone tools, used by Homo floresiensis, possibly 100,000 years ago.
- Ceramics ca. 25,000 BC
- Domestication of Animals, ca. 15,000 BC
- Bow, sling ca. 9th millennium BC
- Microliths ca. 9th millennium BC

- Copper ca. 8000 BC
- Agriculture and Plough ca. 8000 BC
- Wheel ca. 4000 BC
- Gnomon ca. 4000 BC
- Writing systems ca. 3500 BC
- Bronze ca. 3300 BC
- Salt
- Chariot ca. 2000 BC
- Iron ca. 1500 BC
- Sundial ca. 800 BC
- Glass ca. 500 BC
- Catapult ca. 400 BC
- Horseshoe ca. 300 BC
- Stirrup first few centuries AD

### Stone Age



A variety of stone tools

During the **Stone Age**, all humans had a lifestyle which involved limited use of tools and few, if any, permanent settlements. The first major technologies, then, were tied to survival, hunting, and food preparation in this environment. Fire, stone tools and weapons, and clothing were technological developments of major importance during this period. Stone Age cultures developed music, and engaged in organized warfare. A subset of Stone Age humans developed ocean-worthy outrigger canoe ship technology, leading to an eastward migration across the Malay archipelago, across the Indian ocean to Madagascar and also across the Pacific Ocean, which required knowledge of the ocean currents, weather patterns, sailing, celestial navigation, and star maps. The early Stone Age is described as Epipaleolithic or Mesolithic. The former is generally used to describe the early Stone Age in areas with limited glacial impact. The later Stone Age, during which the rudiments of agricultural technology were developed, is called the Neolithic period. During this period, polished stone tools were made from a variety of hard rocks

such as flint, jade, jadeite and greenstone, largely by working exposures as quarries, but later the valuable rocks were pursued by tunnelling underground, the first steps in mining technology. The polished axes were used for forest clearance and the establishment of crop farming, and were so effective as to remain in use when bronze and iron appeared.

Although Paleolithic cultures left no written records, the shift from nomadic life to settlement and agriculture can be inferred from a range of archaeological evidence. Such evidence includes ancient tools, cave paintings, and other prehistoric art, such as the Venus of Willendorf. Human remains also provide direct evidence, both through the examination of bones, and the study of mummies. Though concrete evidence is limited, scientists and historians have been able to form significant inferences about the lifestyle and culture of various prehistoric peoples, and the role technology played in their lives.

### **Copper and Bronze Age**

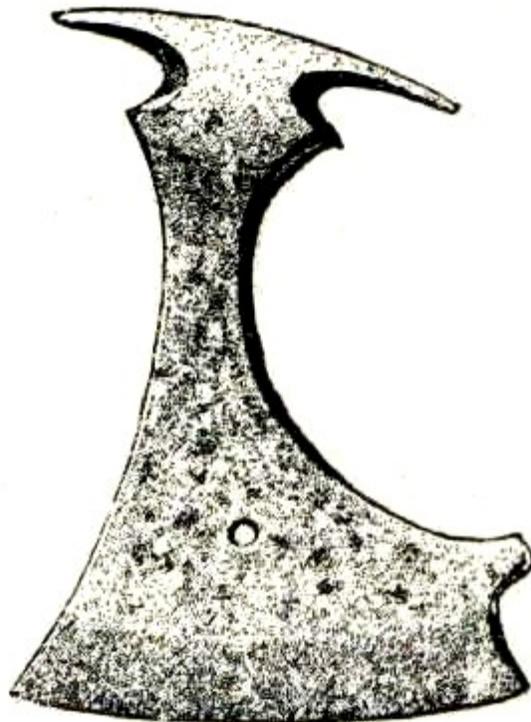


A late Bronze Age sword or dagger blade

The Stone Age developed into the **Bronze Age** after the Neolithic Revolution. The Neolithic Revolution involved radical changes in agricultural technology which included development of agriculture, animal domestication, and the adoption of permanent settlements. These combined factors made possible the development of metal smelting, with copper and later bronze, an alloy of tin and copper, being the materials of choice, although polished stone tools continued to be used for a considerable time owing to their abundance compared with the less common metals (especially tin).

This technological trend apparently began in the Fertile Crescent, and spread outward over time. These developments were not, and still are not, universal. The Three-age system does not accurately describe the technology history of groups outside of Eurasia, and does not apply at all in the case of some isolated populations, such as the Spinifex People, the Sentinelese, and various Amazonian tribes, which still make use of Stone Age technology, and have not developed agricultural or metal technology.

### **Iron Age**



An axehead made of iron, dating from Swedish Iron Age.

The **Iron Age** involved the adoption of iron smelting technology. It generally replaced bronze, and made it possible to produce tools which were stronger and cheaper to make than bronze equivalents. In many Eurasian cultures, the Iron Age was the last major step before the development of written language, though again this was not universally the case. It was not possible to mass manufacture steel because high furnace temperatures

were needed, but steel could be produced by forging bloomery iron to reduce the carbon content in a controllable way. Iron ores were much more widespread than either copper or tin. In Europe, large hill forts were built either as a refuge in time of war, or sometimes as permanent settlements. In some cases, existing forts from the Bronze Age were expanded and enlarged. The pace of land clearance using the more effective iron axes increased, providing more farmland to support the growing population.

By 1000 BC – 500 BC, the Germanic tribes had a Bronze Age civilization, while the Celts were in the Iron Age by the time of the Hallstatt culture. Their cultures collided with the military and agricultural practices of the Romans, leading those Europeans who were conquered to adopt Roman technological advances.

## **Ancient civilizations**

It was the growth of the ancient civilizations which produced the greatest advances in technology and engineering, advances which stimulated other societies to adopt new ways of living and governance.

The Egyptians invented and used many simple machines, such as the ramp to aid construction processes. The Indus Valley Civilization, situated in a resource-rich area, is notable for its early application of city planning and sanitation technologies. Ancient India was also at the forefront of seafaring technology—a panel found at Mohenjodaro, depicts a sailing craft. Indian construction and architecture, called 'Vaastu Shastra', suggests a thorough understanding of materials engineering, hydrology, and sanitation.

The Chinese were responsible for numerous technology discoveries and developments. Major technological contributions from China include early seismological detectors, matches, paper, cast iron, the iron plough, the multi-tube seed drill, the suspension bridge, the parachute, natural gas as fuel, the magnetic compass, the raised-relief map, the propeller, the crossbow, the South Pointing Chariot, and gun powder.

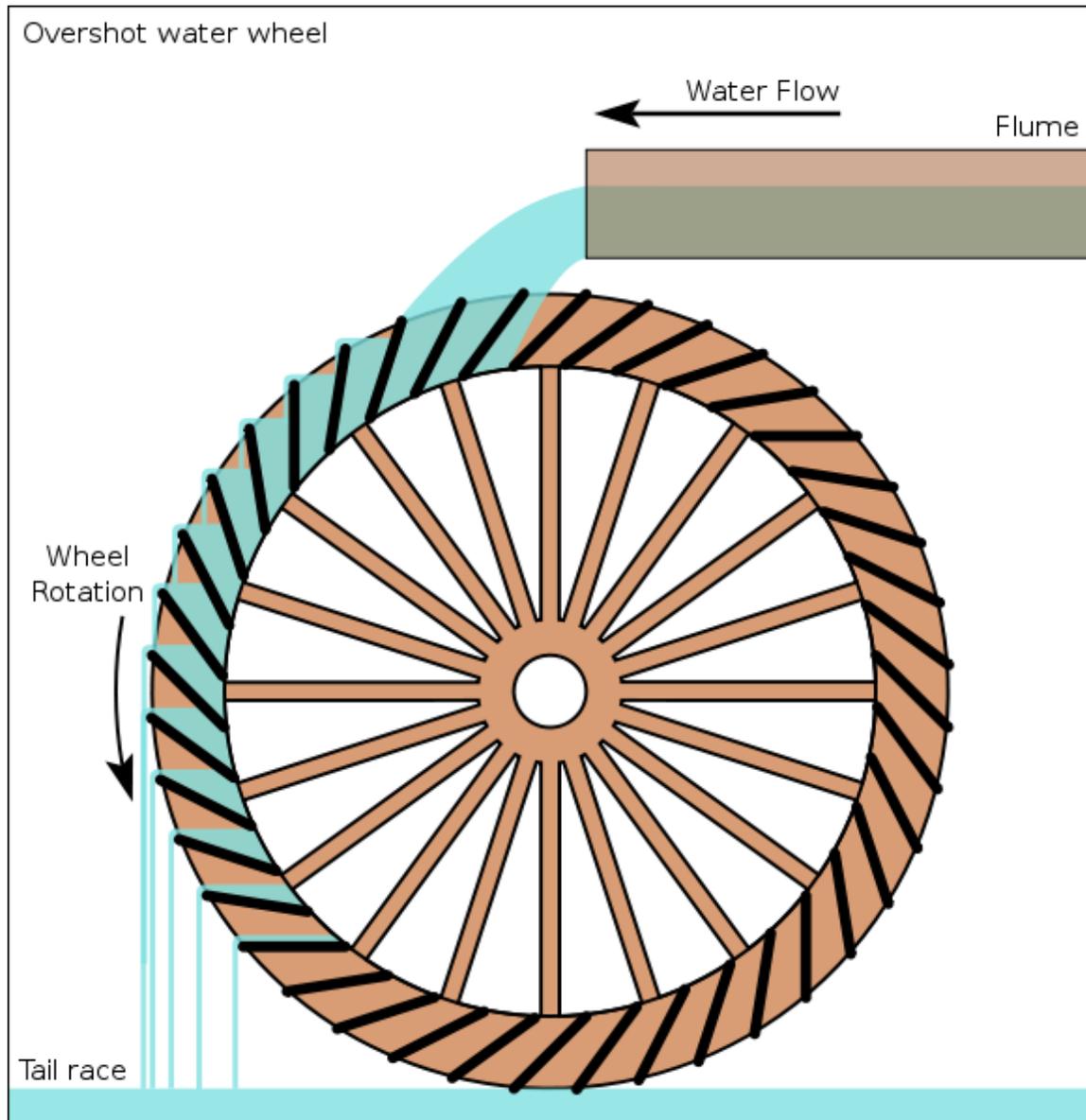


An illustration of the aeolipile, the earliest steam-powered device

Greek and Hellenistic engineers invented many technologies and improved upon pre-existing technologies. Particularly the Hellenistic period saw a sharp rise in technological inventiveness, fostered by a climate of openness to new ideas, royal patronage, the blossom of a mechanistic philosophy and the establishment of the Library of Alexandria and its close association with the adjacent museion. In contrast to the typically anonymous inventor of earlier ages, ingenious minds such as Archimedes, Philo of Byzantium, Heron and Ctesibius now remained known by name to posterity.

Ancient Greek innovations were particularly pronounced in mechanical technology, including the ground-breaking invention of the watermill which constituted the first human-devised motive force not to rely on muscle labour (besides the sail). Apart from

their pioneer use of waterpower, Greek inventors were also the first to experiment with wind power and even created the earliest steam engine (the aeolipile), opening up entirely new possibilities in harnessing natural forces whose full potential came only to be exploited in the industrial revolution. Of particular importance for the operation of mechanical devices became the newly devised right-angled gear and the screw.



The compartmented water-wheel, here its overshot version, was invented in Hellenistic times

Ancient agriculture, as in any period prior to the modern age the primary mode of production and subsistence, and its irrigation methods were considerably advanced by the invention and widespread application of a number of previously unknown water-lifting devices, such as the vertical water-wheel, the compartmented wheel, the water turbine,

Archimedes screw, the bucket-chain and pot-garland, the force pump, the suction pump, the double-action piston pump and quite possibly the chain pump.

In music, water organ, invented by Ctesibius and subsequently improved, constituted the earliest instance of a keyboard instrument. In time-keeping, the introduction of the inflow clepsydra and its mechanization by the dial and pointer, the application of a feedback system and the escapement mechanism far superseded the earlier outflow clepsydra.

The famous Antikythera mechanism, a kind of analogous computer working with a differential gear, and the astrolabe show great refinement in the astronomical science.

Greek engineers were also the first to devise automaton such as vending machines, suspended ink pots, automatic washstands and doors, primarily as toys, which however featured many new useful mechanisms such as the cam and gimbals.

In other fields, ancient Greek inventions include the catapult and the gastraphetes crossbow in warfare, hollow bronze-casting in metallurgy, the dioptra for surveying, in infrastructure the lighthouse, central heating, the tunnel excavated from both ends by scientific calculations, the ship trackway, the dry dock and plumbing. In horizontal vertical and transport great progress resulted from the invention of the crane, the winch, the wheelbarrow and the odometer.

Further newly created techniques and items were spiral staircases, the chain drive, sliding calipers and showers.



Pont du Gard in France, a Roman aqueduct

The Romans developed an intensive and sophisticated agriculture, expanded upon existing iron working technology, created laws providing for individual ownership, advanced stone masonry technology, advanced road-building (exceeded only in the 19th century), military engineering, civil engineering, spinning and weaving and several different machines like the Gallic reaper that helped to increase productivity in many sectors of the Roman economy. Roman engineers were the first to build monumental arches, amphitheatres, aqueducts, public baths, true arch bridges, harbours, reservoirs and dams, vaults and domes on a very large scale across their Empire. Notable Roman inventions include the book (Codex), glass blowing and concrete. Because Rome was located on a volcanic peninsula, with sand which contained suitable crystalline grains, the concrete which the Romans formulated was especially durable. Some of their buildings have lasted 2000 years, to the present day.

The engineering skills of the Inca and the Mayans were great, even by today's standards. An example is the use of pieces weighing in upwards of one ton in their stonework placed together so that not even a blade can fit in-between the cracks. The villages used irrigation canals and drainage systems, making agriculture very efficient. While some claim that the Incas were the first inventors of hydroponics, their agricultural technology was still soil based, if advanced. Though the Maya civilization had no metallurgy or wheel technology, they developed complex writing and astrological systems, and created

sculptural works in stone and flint. Like the Inca, the Maya also had command of fairly advanced agricultural and construction technology. Throughout this time period much of this construction, was made only by women, as men of the Maya civilization believed that females were responsible for the creation of new things. The main contribution of the Aztec rule was a system of communications between the conquered cities. In Mesoamerica, without draft animals for transport (nor, as a result, wheeled vehicles), the roads were designed for travel on foot, just like the Inca and Mayan civilizations.

## Medieval and Modern technologies

### Medieval Europe



Medieval counterweight trebuchet (reconstruction)

European technology in the Middle Ages may be best described as a symbiosis of *traditio et innovatio*. While medieval technology has been long depicted as a step backwards in the evolution of Western technology, sometimes willfully so by modern authors intent on denouncing the church as antagonistic to scientific progress, a generation of medievalists around the American historian of science Lynn White stressed from the 1940s onwards the innovative character of many medieval techniques. Genuine medieval contributions include for example mechanical clocks, spectacles and vertical windmills. Medieval ingenuity was also displayed in the invention of seemingly inconspicuous items like the

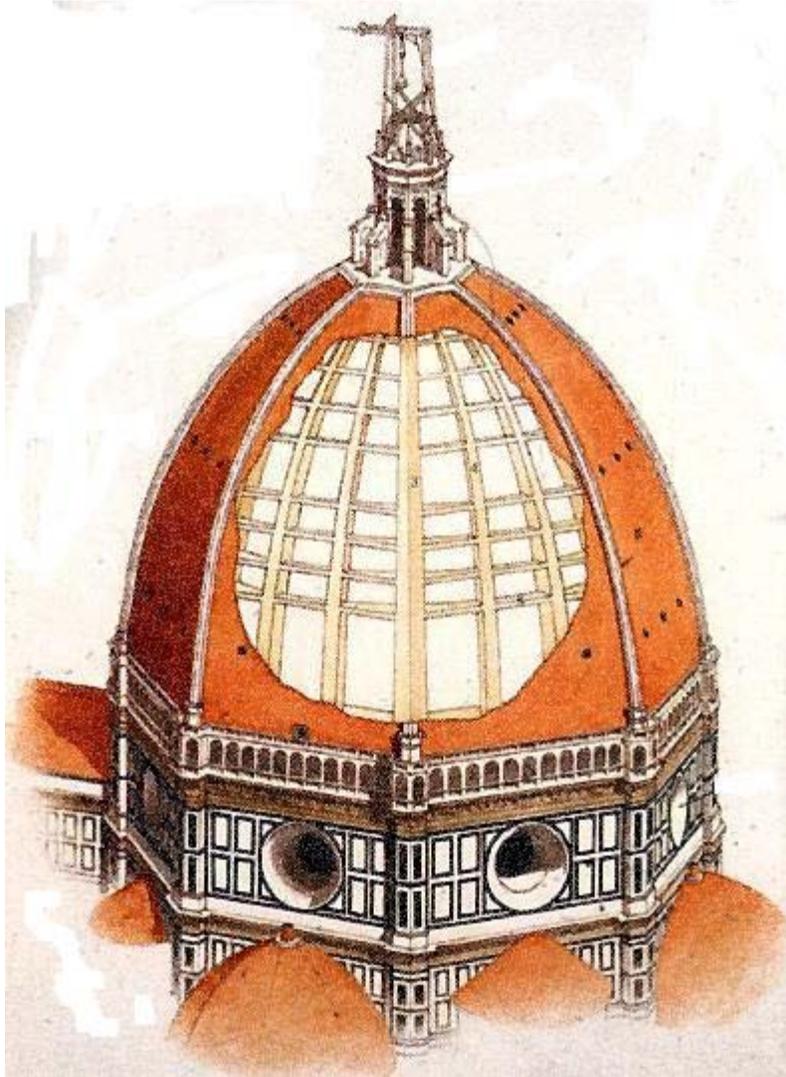
watermark or the functional button. In navigation, the foundation to the subsequent age of exploration was laid by the introduction of pintle-and-gudgeon rudders, lateen sails, the dry compass the horseshoe and the astrolabe.

Significant advances were also made in military technology with the development of plate armour, steel crossbows, counterweight trebuchets and cannon. Perhaps best known are the Middle Ages for their architectural heritage: While the invention of the rib vault and pointed arch gave rise to the high rising Gothic style, the ubiquitous medieval fortifications gave the era the almost proverbial title of the 'age of castles'.

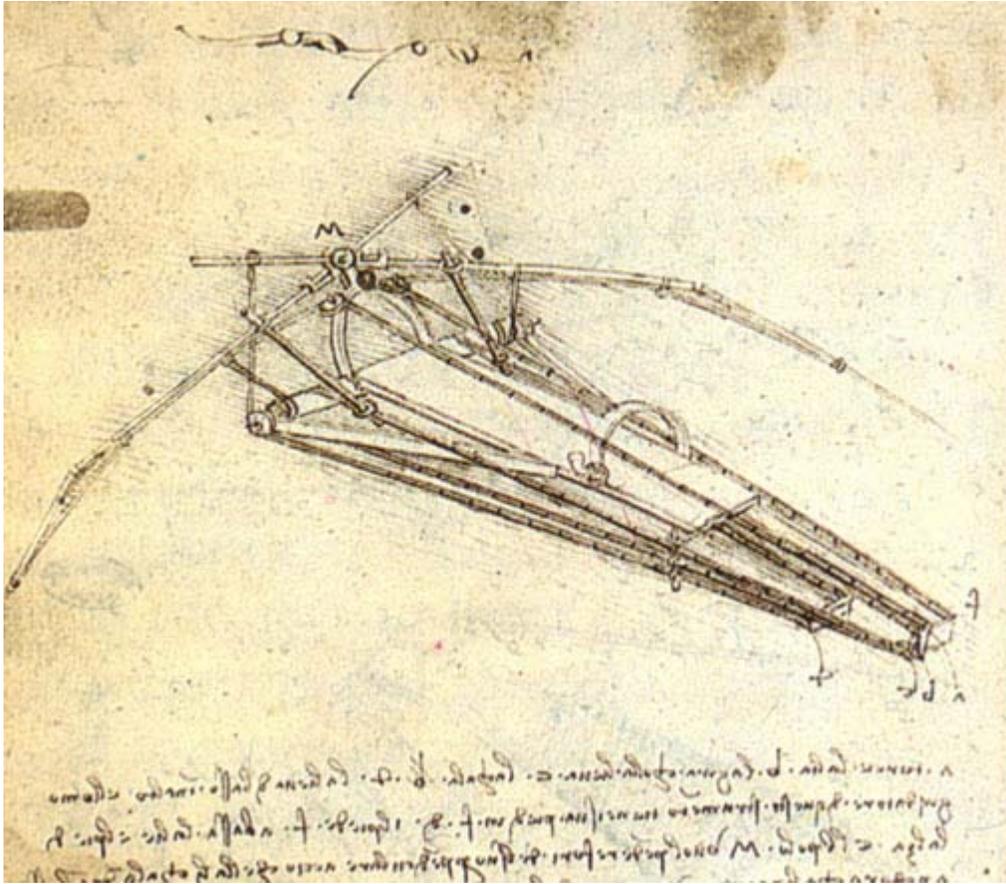
**Inexpensive paper: a revolution in the diffusion of knowledge**

Paper making, a second century Chinese technology, was carried to the Middle East when a group of Chinese paper makers were captured in the 8th century. Paper making technology was spread to Mediterranean by the Muslim conquests. A paper mill was established in Sicily in the 12th century. The spinning wheel increased the productivity of thread making by a factor of greater than 10. Lynn White credited the spinning wheel with increasing the supply of rags, which led to cheap paper, which was a factor in the development of printing.

## Renaissance



Dome of Florence Cathedral



Design for a flying machine (c.1488) by da Vinci

### **Age of Exploration**

The sailing ship (Nau or Carrack) enabled the Age of Exploration with the European colonization of the Americas, epitomized by Francis Bacon's *The New Atlantis*. Pioneers like Vasco de Gama, Cabral, Magellan and Christopher Columbus explored the world in search of new trade routes for their goods and contacts with Africa, India and China which shortened the journey compared with traditional routes overland. They also re-discovered the Americas while doing so. They produced new maps and charts which enabled following mariners to explore further with greater confidence. Navigation was generally difficult however owing to the problem of longitude and the absence of accurate chronometers. European powers rediscovered the idea of the civil code, lost since the time of the Ancient Greeks.

## 19th century



The preserved *Rocket*

The 19th century saw astonishing developments in transportation, construction, and communication technologies originating in Europe, especially in Britain. The Steam Engine which had existed since the early 18th century, was practically applied to both steamboat and railway transportation. The first purpose built railway line opened between Manchester and Liverpool in 1825, the Rocket locomotive of Robert Stephenson being one of the first working locomotives used on the line. Telegraphy also developed into a practical technology in the 19th century to help run the railways safely.

Other technologies were explored for the first time, including the Incandescent light bulb. The Portsmouth Block Mills was where manufacture of ships' pulley blocks by all-metal machines first took place and instigated the age of mass production. Machine tools used by engineers to manufacture other machines began in the first decade of the century, notably by Richard Roberts and Joseph Whitworth. Steamships were eventually completely iron-clad, and played a role in the opening of Japan and China to trade with the West. The Second Industrial Revolution at the end of the 19th century saw rapid development of chemical, electrical, petroleum, and steel technologies connected with highly structured technology research.

The period from last third of the 19th century until WW1 is sometimes referred to as the **Second Industrial Revolution**:

## 20th century



Landing on the Moon

20th Century technology developed rapidly. Communication technology, transportation technology, broad teaching and implementation of scientific method, and increased research spending all contributed to the advancement of modern science and technology. Due to the scientific gains directly tied to military research and development, technologies including electronic computing might have developed as rapidly as they did in part due to war. Radio, radar, and early sound recording were key technologies which paved the way for the telephone, fax machine, and magnetic storage of data. Energy and engine technology improvements were also vast, including nuclear power, developed

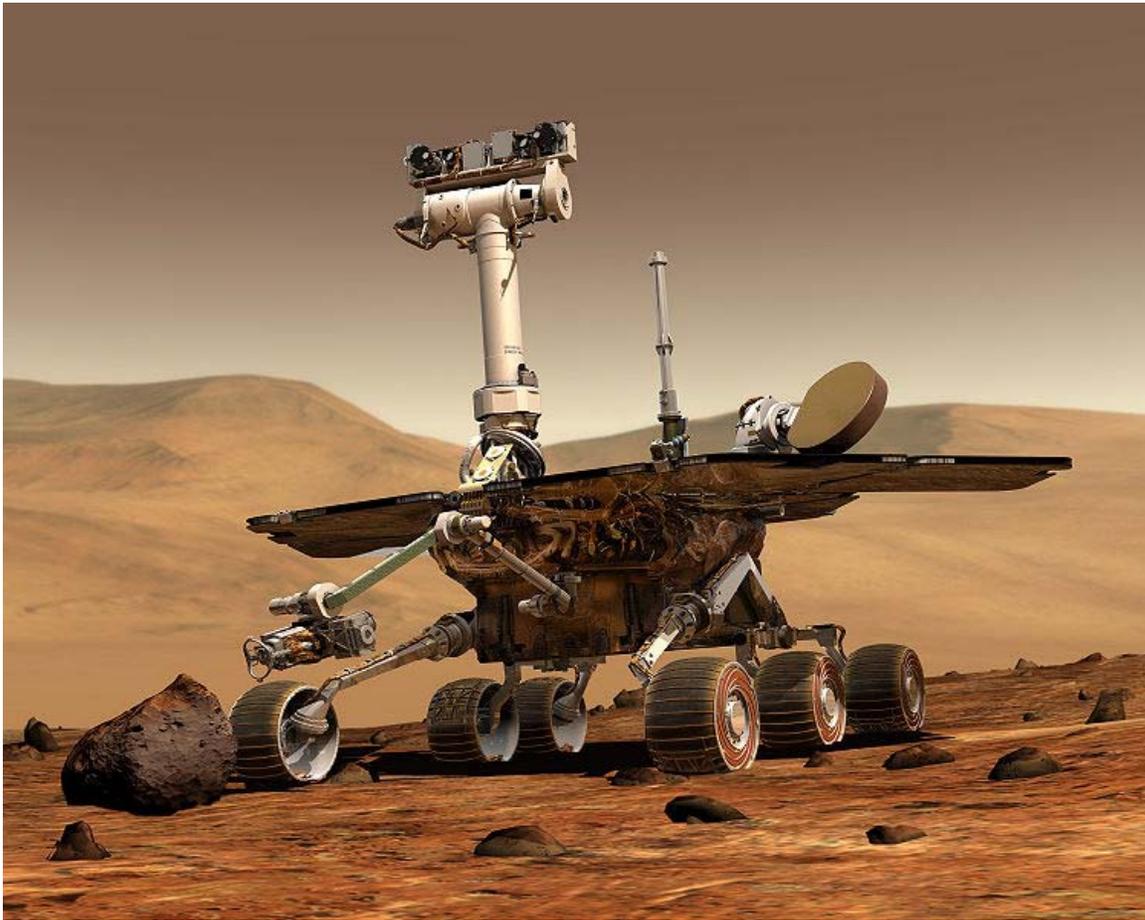
after the Manhattan project. Transport by rocketry: most work occurred in the U.S. (Goddard), Russia (Tsiolkovsky) and Germany (Oberth). Making use of computers and advanced research labs, modern scientists have recombinant DNA.

The National Academy of Engineering, by expert vote, established the following ranking of the most important technological developments of the 20th century:

1. Electrification
2. Automobile
3. Airplane
4. Water supply and Distribution
5. Electronics
6. Radio and Television
7. Mechanized agriculture
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear technologies
20. Materials science

Absent from the above list is the systematic method of mass production which contributed to almost all of the above technologies.

## 21st century



The Mars Exploration Rovers have provided huge amounts of information by functioning well beyond NASA's original lifespan estimates.

In the early 21st century, the main technology being developed is electronics. Broadband Internet access became commonplace in developed countries, as did connecting home computers with music libraries and mobile phones. However, the technologies developed are insignificant compared to the *great innovations* that were developed during the Second Industrial Revolution.

Biotechnology is a relatively new field that holds yet unknown possibilities.

Research is ongoing into quantum computers, nanotechnology, bioengineering, nuclear fusion, advanced materials (e.g., graphene), the scramjet (along with railguns and high-energy beams for military uses), superconductivity, the memristor, and green technologies such as alternative fuels (e.g., fuel cells, plugin hybrid cars) and more efficient LEDs and solar cells.

The understanding of particle physics is also expected to expand through particle accelerator projects, such as the Large Hadron Collider – the largest science project in the

world and neutrino detectors such as the ANTARES. Theoretical physics currently investigates quantum gravity proposals such as M-theory, superstring theory, and loop quantum gravity.

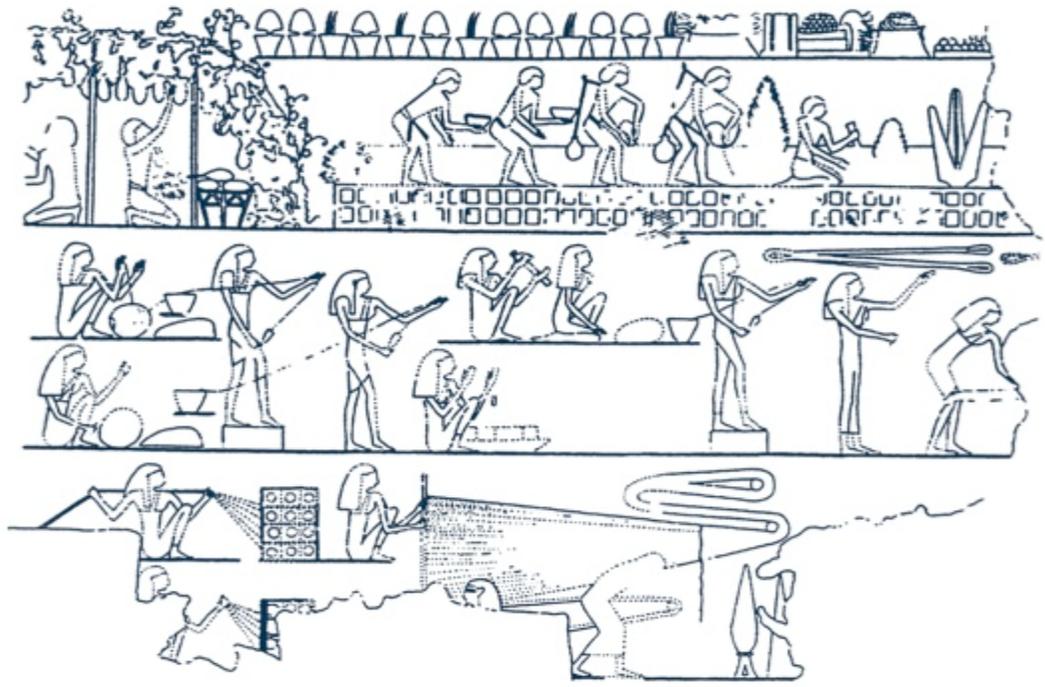
Spacecraft designs are also being developed, i.a. under the Project Constellation. The James Webb Space Telescope will try to identify early galaxies as well as the exact location of the Solar System within our galaxy, using the infrared spectrum. The finished International Space Station will provide an intermediate platform for space missions and zero gravity experiments. Despite challenges and criticism, NASA and ESA plan a manned mission to Mars in the 2030s.

## Chapter-3

# Ancient Technology

## Ancient Egyptian technology

The characteristics of **ancient Egyptian technology** are indicated by a set of artifacts and customs that lasted for thousands of years. The Egyptians invented and used many basic machines, such as the ramp and the lever, to aid construction processes. They used rope trusses to stiffen the beam of ships. Egyptian paper, made from papyrus, and pottery was mass produced and exported throughout the Mediterranean basin. The wheel, however, did not arrive until foreign invaders introduced the chariot in the 16th century B.C. The Egyptians also played an important role in developing Mediterranean maritime technology including ships and lighthouses.

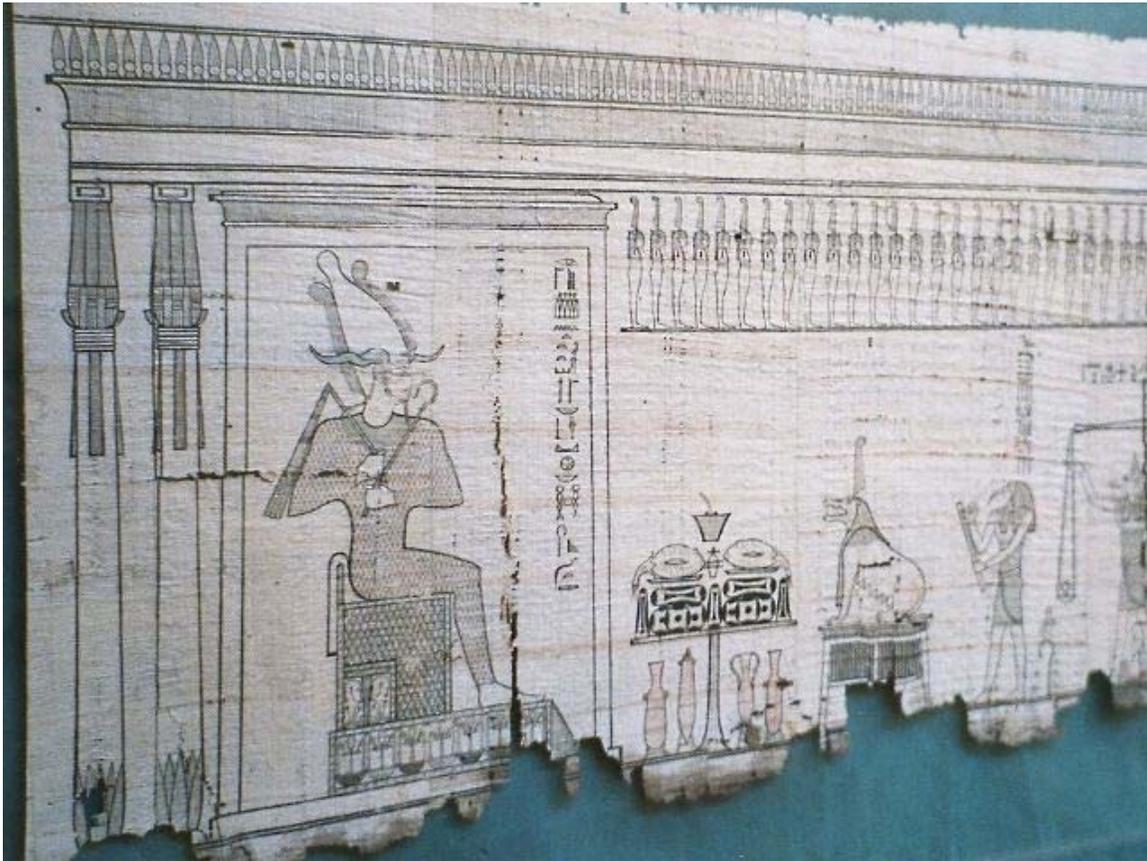


Ancient Egyptian depiction of women engaged in mechanical rope making, the first graphic evidence of the craft, shown in the two lower rows of the illustration

## Technology in Dynastic Egypt

Significant advances in ancient Egypt during the dynastic period include astronomy, mathematics, and medicine. Their geometry was a necessary outgrowth of surveying to preserve the layout and ownership of farmland, which was flooded annually by the Nile river. The 3,4,5 right triangle and other rules of thumb served to represent rectilinear structures, and the post and lintel architecture of Egypt. Egypt also was a center of alchemy research for much of the western world.

### Paper and writing



A section of the Egyptian Book of the Dead, which is written and drawn on papyrus

The word *paper* comes from the Greek term for the ancient Egyptian writing material called papyrus, which was formed from beaten strips of papyrus plants. Papyrus was produced as early as 3000 B.C. in Egypt, and sold to ancient Greece and Rome. The establishment of the Library of Alexandria limited the supply of papyrus for others. As a result, according to the Roman historian Pliny (Natural History records, xiii.21), parchment was invented under the patronage of Eumenes II of Pergamon to build his rival library at Pergamon.

Egyptian hieroglyphs, a phonetic writing system, served as the basis for the Phoenician alphabet from which later alphabets were derived. With this ability, writing and record keeping, the Egyptians developed one of the—if not *the*—first decimal system.

The city of Alexandria retained preeminence for its records and scrolls with its library. That ancient library was damaged by fire when it fell under Roman rule, and was destroyed completely by 642 CE. With it, a huge amount of antique literature, history, and knowledge was lost.

## **Structures and construction**

### **Buildings**

Many temples from Ancient Egypt are still standing today. Some are in ruin from wear and tear, while others have been lost entirely. The Egyptian structures are among the largest constructions ever conceived and built by humans. They constitute one of the most potent and enduring symbols of Ancient Egyptian civilization. Temples and tombs built by a pharaoh famous for her projects, Hatshepsut, were massive and included many colossal statues of her. Pharaoh Tutankamun's rock-cut tomb in the Valley of the Kings was full of jewellery and antiques. In some late myths, Ptah was identified as the primordial mound and had called creation into being, he was considered the deity of craftsmen, and in particular, of stone-based crafts. Imhotep, who was included in the Egyptian pantheon, was the first documented engineer.



The Lighthouse of Alexandria on the island of Pharos.

In Hellenistic Egypt, lighthouse technology was developed, the most famous example being the Lighthouse of Alexandria. Alexandria was a port for the ships that traded the goods manufactured in Egypt or imported into Egypt. A giant cantilevered hoist lifted cargo to and from ships. The lighthouse itself was designed by Sostratus of Cnidus and built in the 3rd century B.C. (between 285 and 247 B.C.) on the island of Pharos in Alexandria, Egypt, which has since become a peninsula. This lighthouse was renowned in its time and knowledge of it was never lost. A 2006 drawing of it created from the study of many references, is shown at the right.

## Monuments

The Nile valley has been the site of one of the most influential civilizations in the world with its architectural monuments, which include the pyramids of Giza and the Great Sphinx—among the largest and most famous buildings in the world.



Giza Plateau, Cairo. Khafre's pyramid in the background

The most famous pyramids are the Egyptian pyramids—huge structures built of brick or stone, some of which are among the largest constructions by humans. Pyramids functioned as tombs for pharaohs. In Ancient Egypt, a pyramid was referred to as *mer*, literally "place of ascendance." The Great Pyramid of Giza is the largest in Egypt and one of the largest in the world. The base is over thirteen acres in area. It is one of the Seven Wonders of the World, and the only one of the seven to survive into modern times. The Ancient Egyptians capped the peaks of their pyramids with gold and covered their faces with polished white limestone, although many of the stones used for the finishing purpose have fallen or been removed for use on other structures over the millennia.

The Red Pyramid of Egypt (c.26th century BC), named for the light crimson hue of its exposed granite surfaces, is the third largest of Egyptian pyramids. Menkaure's Pyramid, likely dating to the same era, was constructed of limestone and granite blocks. The Great Pyramid of Giza (c. 2580 BC) contains a huge granite sarcophagus fashioned of "Red

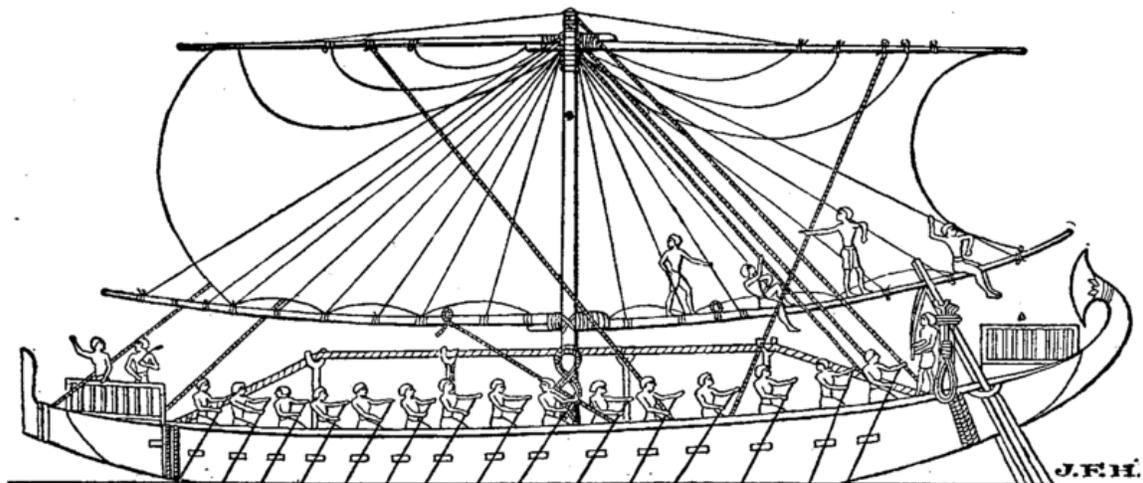
Aswan Granite." The mostly ruined Black Pyramid dating from the reign of Amenemhat III once had a polished granite pyramidion or capstone, now on display in the main hall of the Egyptian Museum in Cairo. Other uses in Ancient Egypt, include columns, door lintels, sills, jambs, and wall and floor veneer.

The ancient Egyptians had some of the first monumental stone building (such as in Sakkhara). How the Egyptians worked the solid granite is still a matter of debate. Dr. Patrick Hunt has postulated that the Egyptians used emery shown to have higher hardness on the Mohs scale. Regarding construction, of the various methods possibly used by builders, the lever moved and uplifted obelisks weighing more than 100 tons.

### **Obelisks and pillars**

Obelisks were a prominent part of the architecture of the ancient Egyptians, who placed them in pairs at the entrances of temples. In 1911, Encyclopædia Britannica wrote, "The earliest temple obelisk still in position is that of Senwosri I. of the XIIth Dynasty at Heliopolis (68 feet high)". The word "obelisk" is of Greek rather than Egyptian origin because Herodotus, the great traveler, was the first writer to describe the objects. Twenty-seven ancient Egyptian obelisks are known to have survived, plus the *unfinished obelisk* being built by Hatshepsut to celebrate her sixteenth year as pharaoh. It broke while being carved out of the quarry and was abandoned when another one was begun to replace it. The broken one was found at Aswan and provides the only insight into the methods of how they were hewn. The obelisk symbolized the sun deity Ra and during the brief religious reformation of Akhenaten, was said to be a petrified ray of the Aten, the sun disk. It is hypothesized by New York University Egyptologist Patricia Blackwell Gary and *Astronomy* senior editor Richard Talcott that the shapes of the ancient Egyptian pyramid and Obelisk were derived from natural phenomena associated with the sun (the sun-god Ra being the Egyptians' greatest deity). It was also thought that the deity existed within the structure. The Egyptians also used pillars extensively.

It is unknown whether the Ancient Egyptians had kites, but a team lead by Mory Gharib raised a 6,900-pound, 15-foot (4.6 m) obelisk into vertical position with a kite, a system of pulleys, and a support frame. Maureen Clemmons developed the idea that the ancient Egyptian used kites for work. Ramps have been reported as being widely used in Ancient Egypt. A ramp is inclined plane, or a plane surface set at an angle (other than a right angle) against a horizontal surface. The inclined plane permits one to overcome a large resistance by applying a relatively small force through a longer distance than the load is to be raised. In civil engineering the slope (ratio of rise/run) is often referred to as a grade or gradient. An inclined plane is one of the commonly-recognized simple machines.

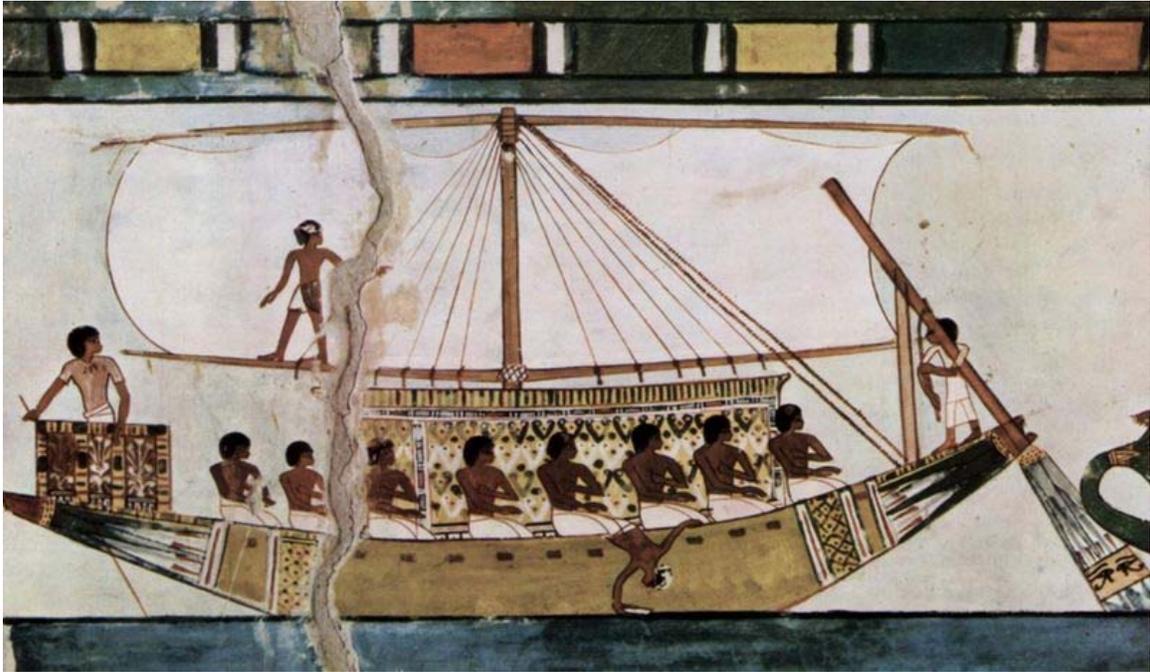


**Egyptian ship on the Red Sea, about 1250 B.C.** [From Torr's "Ancient Ships."] Mr. Langton Cole calls attention to the rope *truss* in this illustration, stiffening the beam of the ship. No other such use of the truss is known until the days of Modern engineering.

Egyptian ship, 1250 B.C. Egyptian ship on the Red Sea, showing a rope truss being used to stiffen the beam of this ship

## Navigation and ship building

The Ancient Egyptians had knowledge to some extent of sail construction. This is governed by the science of aerodynamics. The earliest Egyptian sails were simply placed to catch the wind and push a vessel. Later Egyptian sails dating to 2400 BCE were built with the recognition that ships could sail against the wind using the side wind. Queen Hatshepsut oversaw the preparations and funding of an expedition of five ships, each measuring seventy feet long, and *with several sails*. Various others exist, also.



Stern-mounted steering oar of an Egyptian riverboat depicted in the Tomb of Menna (c. 1422–1411 B.C.)

Ancient Egyptians had experience with building a variety of ships. Some of them survive to this day as Khufu Solar ship. The ships were found in many areas of Egypt as the Abydos boats and remnants of other ships were found near the pyramids.

Sneferu's ancient cedar wood ship Praise of the Two Lands is the first reference recorded to a ship being referred to by name.

Although quarter rudders were the norm in Nile navigation, the Egyptians were the first to use also stern-mounted rudders.

## **Irrigation and agriculture**

Irrigation as the artificial application of water to the soil was used to some extent in Ancient Egypt, a hydraulic civilization (which entail hydraulic engineering). In crop production it is mainly used to replace missing rainfall in periods of drought, as opposed to reliance on direct rainfall (referred to as dryland farming or as rainfed farming). There is evidence of the ancient Egyptian pharaoh Amenemhet III in the twelfth dynasty (about 1800 BCE) using the natural lake of the Fayûm as a reservoir to store surpluses of water for use during the dry seasons, as the lake swelled annually as caused by the annual flooding of the Nile.

## **Glassworking**

Egyptian knowledge of glassmaking was advanced. The earliest known glass beads from Egypt were made during the New Kingdom around 1500 BC and were produced in a variety of colors. They were made by winding molten glass around a metal bar and were highly prized as a trading commodity, especially blue beads, which were believed to have magical powers. The Egyptians made small jars and bottles using the core-formed method. Glass threads were wound around a bag of sand tied to a rod. The glass was continually reheated to fuse the threads together. The glass-covered sand bag was kept in motion until the required shape and thickness was achieved. The rod was allowed to cool, then finally the bag was punctured and the rod removed. The Egyptians also created the first colored glass rods which they used to create colorful beads and decorations. They also worked with cast glass, which was produced by pouring molten glass into a mold, much like iron and the more modern crucible steel.

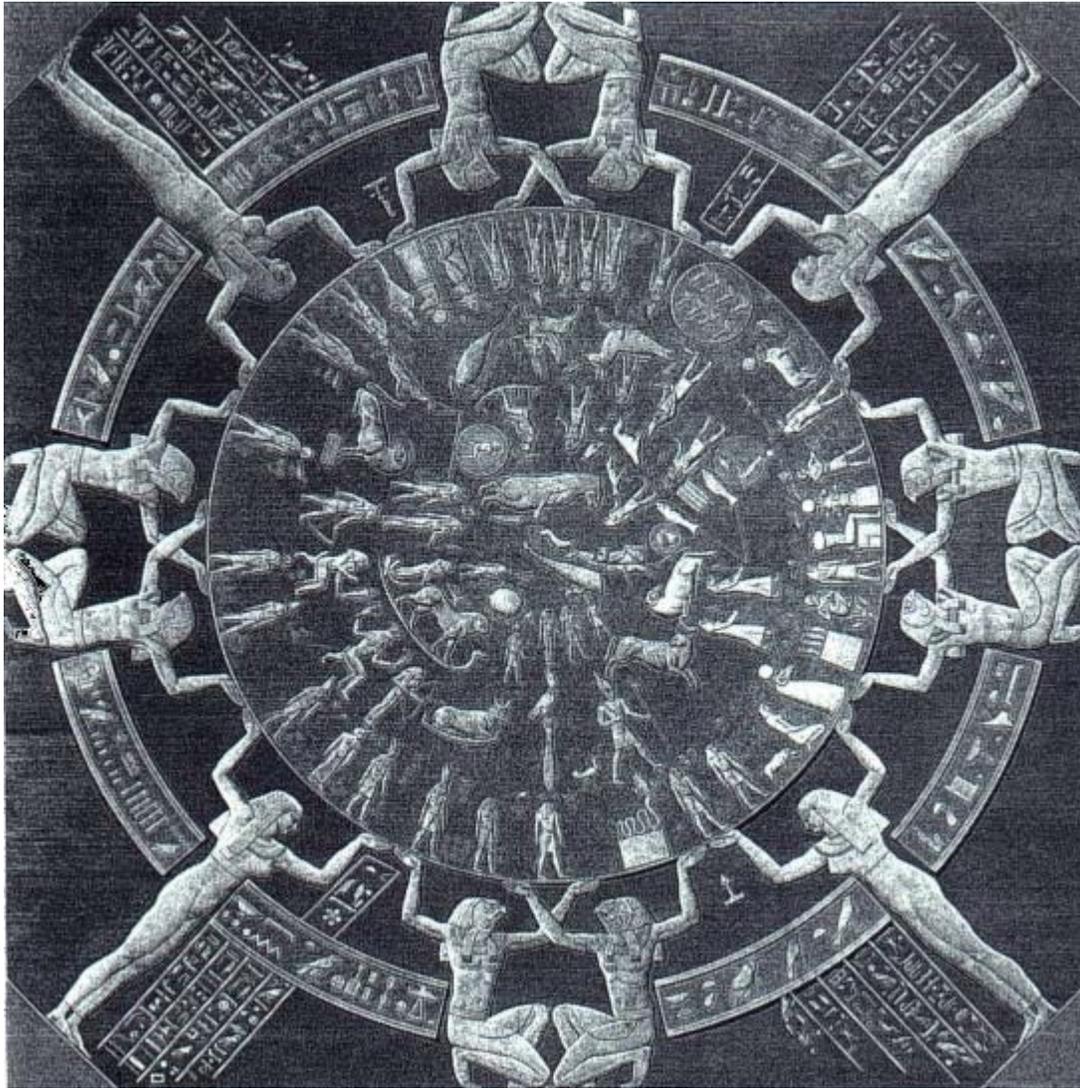
## **Astronomy**

The Egyptians were a practical people and this is reflected in their astronomy in contrast to Babylonia where the first astronomical texts were written in astrological terms. Even before Upper and Lower Egypt were unified in 3000 BCE, observations of the night sky had influenced the development of a religion in which many of its principal deities were heavenly bodies. In Lower Egypt, priests built circular mud-brick walls with which to make a false horizon where they could mark the position of the sun as it rose at dawn, and then with a plumb-bob note the northern or southern turning points (solstices). This allowed them to discover that the sun disc, personified as Ra, took 365 days to travel from his birthplace at the winter solstice and back to it. Meanwhile in Upper Egypt a lunar calendar was being developed based on the behaviour of the moon and the reappearance of Sirius in its heliacal rising after its annual absence of about 70 days.

After unification, problems with trying to work with two calendars (both depending upon constant observation) led to a merged, simplified civil calendar with twelve 30 day months, three seasons of four months each, plus an extra five days, giving a 365 year day but with no way of accounting for the extra quarter day each year. Day and night were split into 24 units, each personified by a deity. A sundial found on Seti I's cenotaph with instructions for its use shows us that the daylight hours were at one time split into 10 units, with 12 hours for the night and an hour for the morning and evening twilights. However, by Seti I's time day and night were normally divided into 12 hours each, the length of which would vary according to the time of year.

Key to much of this was the motion of the sun god Ra and his annual movement along the horizon at sunrise. Out of Egyptian myths such as those around Ra and the sky goddess Nut came the development of the Egyptian calendar, time keeping, and even concepts of royalty. An astronomical ceiling in the burial chamber of Ramesses VI shows the sun being born from Nut in the morning, traveling along her body during the day and being swallowed at night.

During the Fifth Dynasty six kings built sun temples in honour of Ra. The temple complexes built by Niuserre at Abu Gurab and Userkaf at Abusir have been excavated and have astronomical alignments, and the roofs of some of the buildings could have been used by observers to view the stars, calculate the hours at night and predict the sunrise for religious festivals.



The Dendera Zodiac was on the ceiling of the Greco-Roman temple of Hathor at Dendera

Claims have been made that precession of the equinoxes was known in Ancient Egypt prior to the time of Hipparchus. Some buildings in the Karnak temple complex, for instance, were oriented toward the point on the horizon where certain stars rose or set at key times of the year. Because of the precession, the stars in one "constellation" or section of the sky would be seen to be first in the nightly display each night until the precession moved along to the next section being first, with the previously-first constellation below the horizon until the arch was completed. A few centuries later, when precession made the orientations of the buildings obsolete, the temples were rebuilt.

Note however that the observation that a stellar alignment has grown wrong does not necessarily mean that the Egyptians understood or even cared what was going on. For instance, from the Middle Kingdom on they used a table with entries for each month to tell the time of night from the passing of constellations: these went in error after a few centuries because of their calendar and precession, but were copied (with scribal errors) for long after they lost their practical usefulness or possibly the understanding of them.

## **Medicine**

The Edwin Smith papyrus is one of the first medical documents still extant, and perhaps the earliest document which attempts to describe and analyze the brain: given this, it might be seen as the very beginnings of neuroscience. However, medical historians believe that ancient Egyptian pharmacology was largely ineffective. According to a paper published by Michael D. Parkins, 72% of 260 medical prescriptions in the Hearst Papyrus had no curative elements. According to Michael D. Parkins, sewage pharmacology first began in ancient Egypt and was continued through the Middle Ages, and while the use of animal dung can have curative properties, it is not without its risk. Practices such as applying cow dung to wounds, ear piercing, tattooing, and chronic ear infections were important factors in developing tetanus. Frank J. Snoek wrote that Egyptian medicine used fly specks, lizard blood, swine teeth, and other such remedies which he believes could have been harmful.

Mummification of the dead was not always practised in Egypt. Once the practice began, an individual was placed at a final resting place through a set of rituals and protocol. The Egyptian funeral was a complex ceremony including various monuments, prayers, and rituals undertaken in honor of the deceased. The poor, who could not afford expensive tombs, were buried in shallow graves in the sand, and because of the arid environment they were often naturally mummified.

## Other developments



Stained glass window depicting weaving and spinning in ancient Egypt

The Egyptians developed a variety of furniture. There in the lands of ancient Egypt is the first evidence for stools, beds, and tables (such as from the tombs similar to Tutenkhamen's). Recovered Ancient Egyptian furniture includes a third millennium B.C. bed discovered in the Tarkhan Tomb, a c.2550 B.C. gilded set from the tomb of Queen Hetepheres, and a c. 1550 B.C. stool from Thebes.

Recent scholarship suggests that the water wheel originates from Ptolemaic Egypt, where it appeared by the 3rd century BC. This is seen as an evolution of the paddle-driven water-lifting wheels that had been known in Egypt a century earlier. According to John Peter Oleson, both the compartmented wheel and the hydraulic Noria may have been

invented in Egypt by the 4th century BC, with the Sakia being invented there a century later. This is supported by archeological finds at Faiyum, Egypt, where the oldest archeological evidence of a water-wheel has been found, in the form of a Sakia dating back to the 3rd century BC. A papyrus dating to the 2nd century BC also found in Faiyum mentions a water wheel used for irrigation, a 2nd-century BC fresco found at Alexandria depicts a compartmented Sakia, and the writings of Callixenus of Rhodes mention the use of a Sakia in Ptolemaic Egypt during the reign of Ptolemy IV in the late 3rd century BC.

Some have suggested that the Egyptians had some form of understanding electric phenomena from observing lightning and interacting with electric fish (such as the *Malapterurus electricus*) or other animals (such as electric eels). The comment about lightning appears to come from a misunderstanding of a text referring to "high poles covered with copper plates" to argue this but Dr. Bolko Stern has written in detail explaining why the copper covered tops of poles (which were lower than the associated pylons) do not relate to electricity or lightning, pointing out that no evidence of anything used to manipulate electricity had been found in Egypt and that this was a magical and not a technical installation.



The single representation of the image, called the "Dendera light" by some alternative suggestions, exists on the left wall of the right wing in one of the crypts of the Hathor temple

Those exploring fringe theories of ancient technology have suggested that there were electric lights used in Ancient Egypt. Engineers have constructed a working model based on their interpretation of a relief found in the Hathor temple at the Dendera Temple complex. Authors (such as Peter Krassa and Reinhard Habeck) have produced a basic theory of the device's operation. The standard explanation, however, for the *Dendera light*, which comprises three stone reliefs (one single and a double representation) is that the depicted image represents a lotus leaf and flower from which a sacred snake is spawned in accordance with Egyptian mythological beliefs. This sacred snake sometimes is identified as the Milky Way (the snake) in the night sky (the leaf, lotus, or "bulb") that became identified with Hathor because of her similar association in creation.

## **Later technology in Egypt**

### **Greco-Roman Egypt**

Under Hellenistic rule, Egypt was one of the most prosperous regions of the Hellenistic civilization. The ancient Egyptian city of Rhakotis was renovated as Alexandria, which became the largest city around the Mediterranean Basin. Under Roman rule, Egypt was one of the most prosperous regions of the Roman Empire, with Alexandria being second only to ancient Rome in size.

Ancient Greek technology was often inspired by the need to improve weapons and tactics in war. Ancient Roman technology is a set of artifacts and customs which supported Roman civilization and made the expansion of Roman commerce and Roman military possible over nearly a thousand years.

### **Arabic-Islamic Egypt**

Under Arab rule, Egypt once again became one of the most prosperous regions around the Mediterranean. The Egyptian city of Cairo was founded by the Fatimid Caliphate and served as its capital city. At the time, Cairo was second only to Baghdad, capital of the rival Abbasid Caliphate. After the fall of Baghdad, however, Cairo overtook it as the largest city in the Mediterranean region until the early modern period.

Inventions in medieval Islam covers the inventions developed in the medieval Islamic world, a region that extended from Al-Andalus and Africa in the west to the Indian subcontinent and Central Asia in the east. The timeline of Islamic science and engineering covers the general development of science and technology in the Islamic world.

# History of Indian science and technology

The **history of science and technology in India** begins with prehistoric human activity at Mehrgarh, in present-day Pakistan, and continues through the Indus Valley Civilization to early states and empires. The British colonial rule introduced some elements of western education in India. Following independence science and technology in the Republic of India has included automobile engineering, information technology, communications as well as space, polar, and nuclear sciences.

## Prehistory



Hand-propelled wheel cart, Indus Valley Civilization (3000–1500 BCE). Housed at the National Museum, New Delhi.

4500 BC in sites such as Kuehgllaldkjg in the Indo-Gangetic Plains. By 5500 BCE a number of sites similar to Mehrgarh had appeared, forming the basis of later chalcolithic cultures. The inhabitants of these sites maintained trading relations with Near East and Central Asia.

Irrigation was developed in the Indus Valley Civilization by around 4500 BCE. The size and prosperity of the Indus civilization grew as a result of this innovation, which eventually led to more planned settlements making use of drainage and sewerage. Sophisticated irrigation and water storage systems were developed by the Indus Valley Civilization, including artificial reservoirs at Girnar dated to 3000 BCE, and an early canal irrigation system from circa 2600 BCE. Cotton was cultivated in the region by the 5th millennium BCE—4th millennium BCE. Sugarcane was originally from tropical South and Southeast Asia. Different species likely originated in different locations with *S. barberi* originating in India and *S. edule* and *S. officinarum* coming from New Guinea.

By 2800 BCE private bathrooms, located on the ground floor, were found in many houses of the Indus civilization. Pottery pipes in walls allowed drainage of water and there was, in some case, provision of a crib for sitting in toilets. 'Western-style' toilets were also made from bricks and used wooden toilet seats on top. The waste was then transmitted to drainage systems. Large scale sanitary sewer systems were in place by 2700 BCE. The drains were 7–10 feet wide and 2 feet below ground level. The sewage was then led into cesspools, built at the intersection of two drains, which had stairs leading to them for periodic cleaning. Plumbing using earthenware plumbing pipes with broad flanges for easy joining with asphalt to stop leaks was in place by 2700 BCE. The Harappans manufactured Copper, Bronze and some precious metals too.

The inhabitants of the Indus valley developed a system of standardization, using weights and measures, evident by the excavations made at the Indus valley sites. This technical standardization enabled gauging devices to be effectively used in angular measurement and measurement for construction. Calibration was also found in measuring devices along with multiple subdivisions in case of some devices. The world's first dock at Lothal (2400 BCE) was located away from the main current to avoid deposition of silt. Modern oceanographers have observed that the Harappans must have possessed knowledge relating to tides in order to build such a dock on the ever-shifting course of the Sabarmati, as well as exemplary hydrography and maritime engineering. This was the earliest known dock found in the world, equipped to berth and service ships.

Excavations at Balakot (c. 2500-1900 BC), present day Pakistan, have yielded evidence of an early furnace. The furnace was most likely used for the manufacturing of ceramic objects. Ovens, dating back to the civilization's mature phase (c. 2500-1900 BC), were also excavated at Balakot. The Kalibangan archeological site further yields evidence of potshaped hearths, which at one site have been found both on ground and underground. Kilns with fire and kiln chambers have also been found at the Kalibangan site.



View of the Asokan Pillar at Vaishali. One of the edicts of Ashoka (272—231 BCE) reads: "Everywhere King Piyadasi (Asoka) erected two kinds of hospitals, hospitals for people and hospitals for animals. Where there were no healing herbs for people and animals, he ordered that they be bought and planted."

Based on archaeological and textual evidence, Joseph E. Schwartzberg (2008)—a University of Minnesota professor emeritus of geography—traces the origins of Indian cartography to the Indus Valley Civilization (ca. 2500–1900 BCE). The use of large scale constructional plans, cosmological drawings, and cartographic material was known in India with some regularity since the Vedic period (1 millennium BCE). Climatic conditions were responsible for the destruction of most of the evidence, however, a number of excavated surveying instruments and measuring rods have yielded convincing evidence of early cartographic activity. Schwartzberg (2008)—on the subject of surviving maps—further holds that: "Though not numerous, a number of map-like graffiti appear among the thousands of Stone Age Indian cave paintings; and at least one complex Mesolithic diagram is believed to be a representation of the cosmos."

Archeological evidence of an animal-drawn plough dates back to 2500 BC in the Indus Valley Civilization. The earliest available swords of copper discovered from the Harappan sites date back to 2300 BCE. Swords have been recovered in archaeological

findings throughout the Ganges–Jamuna Doab region of India, consisting of bronze but more commonly copper.

## Early kingdoms



Ink drawing of Ganesha under an umbrella (early 19th century). Ink, called *masi*, an admixture of several chemical components, has been used in India since at least the 4th century BC. The practice of writing with ink and a sharp pointed needle was common in early South India. Several Jain sutras in India were compiled in ink.

Value	0	1	2	3	4	5	6	7	8	9
Western Arabic	•	١	٢	٣	٤	٥	٦	٧	٨	٩
Eastern Arabic	•	١	٢	٣	٤	٥	٦	٧	٨	٩
Devanagari	०	१	२	३	४	५	६	७	८	९
Gujarati	૦	૧	૨	૩	૪	૫	૬	૭	૮	૯
Gurmukhi	੦	੧	੨	੩	੪	੫	੬	੭	੮	੯
Limbu	␣	␣	␣	␣	␣	␣	␣	␣	␣	␣
Bengali	০	১	২	৩	৪	৫	৬	৭	৮	৯
Oriya	୦	୧	୨	୩	୪	୫	୬	୭	୮	୯
Telugu	౦	౧	౨	౩	౪	౫	౬	౭	౮	౯
Kannada	೦	೧	೨	೩	೪	೫	೬	೭	೮	೯
Malayalam	൦	൧	൨	൩	൪	൫	൬	൭	൮	൯
Tamil (Grantha)	௦	௧	௨	௩	௪	௫	௬	௭	௮	௯
Tibetan	༠	༡	༢	༣	༤	༥	༦	༧	༨	༩
Burmese	၀	၁	၂	၃	၄	၅	၆	၇	၈	၉
Thai	๐	๑	๒	๓	๔	๕	๖	๗	๘	๙
Khmer	០	១	២	៣	៤	៥	៦	៧	៨	៩
Lao	໐	໑	໒	໓	໔	໕	໖	໗	໘	໙

The *Hindu-Arabic numeral* system. The inscriptions on the edicts of Ashoka (1st millennium BCE) display this number system being used by the Imperial Mauryas.

The religious texts of the Vedic Period provide evidence for the use of large numbers. By the time of the last Veda, the *Yajurvedasaṃhitā* (1200-900 BCE), numbers as high as  $10^{12}$  were being included in the texts. For example, the *mantra* (sacrificial formula) at the end of the *annahoma* ("food-oblation rite") performed during the *asvamedha* ("horse sacrifice"), and uttered just before-, during-, and just after sunrise, invokes powers of ten from a hundred to a trillion. The Satapatha Brahmana (9th century BCE) contains rules for ritual geometric constructions that are similar to the Sulba Sutras.

Baudhayana (c. 8th century BCE) composed the *Baudhayana Sulba Sutra*, which contains examples of simple Pythagorean triples, such as: (3,4,5), (5,12,13), (8,15,17), (7,24,25), and (12,35,37) as well as a statement of the Pythagorean theorem for the sides of a square: "The rope which is stretched across the diagonal of a square produces an area double the size of the original square." It also contains the general statement of the

Pythagorean theorem (for the sides of a rectangle): "The rope stretched along the length of the diagonal of a rectangle makes an area which the vertical and horizontal sides make together." Baudhayana gives a formula for the square root of two.

The earliest Indian astronomical text—named *Vedānga Jyotiṣa*—dates back to around 1200 BC, and details several astronomical attributes generally applied for timing social and religious events. The *Vedānga Jyotiṣa* also details astronomical calculations, calendrical studies, and establishes rules for empirical observation. Since the texts written by 1200 BCE were largely religious compositions the *Vedānga Jyotiṣa* has connections with Indian astrology and details several important aspects of the time and seasons, including lunar months, solar months, and their adjustment by a lunar leap month of *Adhimāsa*. *Ritus* and *Yugas* are also described. Tripathi (2008) holds that 'Twenty-seven constellations, eclipses, seven planets, and twelve signs of the zodiac were also known at that time.'

The Egyptian *Papyrus of Kahun* (1900 BCE) and literature of the Vedic period in India offer early records of veterinary medicine. Kearns & Nash (2008) state that mention of leprosy is described in the medical treatise *Sushruta Samhita* (6th century BCE). However, *The Oxford Illustrated Companion to Medicine* holds that the mention of leprosy, as well as ritualistic cures for it, were described in the Hindu religious book *Atharva-veda*, written by 1500–1200 BCE. Cataract surgery was known to the physician Sushruta (6th century BCE). Traditional cataract surgery was performed with a special tool called the *Jabamukhi Salaka*, a curved needle used to loosen the lens and push the cataract out of the field of vision. The eye would later be soaked with warm butter and then bandaged. Though this method was successful, Susruta cautioned that it should only be used when necessary. Greek philosophers and scientists traveled to India where these surgeries were performed by physicians. The removal of cataract by surgery was also introduced into China from India. Brahmanic hospitals were established in what is now Sri Lanka as early as 431 BCE. Ashoka (reign: 273 BCE to 232 BCE) also established a chain of hospitals throughout the Mauryan empire (322–185 BCE) by 230 BCE.

During the 5th century BCE, the scholar Pāṇini had made several discoveries in the fields of phonetics, phonology, and morphology. Metal currency was minted in India before 5th century BCE, with coinage (400 BCE—100 CE) being made of silver and copper, bearing animal and plant symbols on them.

Zinc mines of Zawar, near Udaipur, Rajasthan, were active during 400 BC. Diverse specimens of swords have been discovered in Fatehgarh, where there are several varieties of hilt. These swords have been variously dated to periods between 1700-1400 BCE, but were probably used more extensively during the opening centuries of the 1st millennium BCE. Archaeological sites in such as Malhar, Dadupur, Raja Nala Ka Tila and Lahuradewa in present day Uttar Pradesh show iron implements from the period between 1800 BC - 1200 BC. Early iron objects found in India can be dated to 1400 BC by employing the method of radio carbon dating. Some scholars believe that by the early 13th century BC iron smelting was practiced on a bigger scale in India, suggesting that the date of the technology's inception may be placed earlier. In Southern India (present

day Mysore) iron appeared as early as 11th to 12th centuries BC. These developments were too early for any significant close contact with the northwest of the country.

## Post Maha Janapadas—High Middle Ages



The iron pillar of Delhi (375–413 CE). The first iron pillar was the Iron pillar of Delhi, erected at the times of Chandragupta II Vikramaditya.

The *Arthashastra* of Kautilya mentions the construction of dams and bridges. The use of suspension bridges using plaited bamboo and iron chain was visible by about the 4th century. The *stupa*, the precursor of the pagoda and torii, was constructed by the 3rd century BCE. Rock-cut step wells in the region date from 200-400 CE. Subsequently, the

construction of wells at Dhank (550-625 CE) and stepped ponds at Bhinmal (850-950 CE) took place.

During the 1st millennium BCE, the Vaisheshika school of atomism was founded. The most important proponent of this school was Kanada, an Indian philosopher who lived around 200 BCE. The school proposed that atoms are indivisible and eternal, can neither be created nor destroyed, and that each one possesses its own distinct *viśeṣa* (individuality). It was further elaborated on by the Buddhist school of atomism, of which the philosophers Dharmakīrti and Dignāga in the 7th century CE were the most important proponents. They considered atoms to be point-sized, durationless, and made of energy.

By the beginning of the Common Era glass was being used for ornaments and casing in the region. Contact with the Greco-Roman world added newer techniques, and local artisans learnt methods of glass molding, decorating and coloring by the early centuries of the Common Era. The Satavahana period further reveals short cylinders of composite glass, including those displaying a lemon yellow matrix covered with green glass. Wootz originated in the region before the beginning of the common era. Wootz was exported and traded throughout Europe, China, the Arab world, and became particularly famous in the Middle East, where it became known as Damascus steel. Archaeological evidence suggests that manufacturing process for Wootz was also in existence in South India before the Christian era.

Evidence for using bow-instruments for carding comes from India (2nd century CE). Early diamonds used as gemstones originated in India. Golconda served as an important early center for diamond mining and processing. Diamonds were then exported to other parts of the world. Early references to diamonds comes from Sanskrit texts. The *Arthashastra* also mentions diamond trade in the region. The Iron pillar of Delhi was erected at the times of Chandragupta II Vikramaditya (375–413). The *Rasaratna Samuccaya* (800 AD) explains the existence of two types of ores for zinc metal, one of which is ideal for metal extraction while the other is used for medicinal purpose.



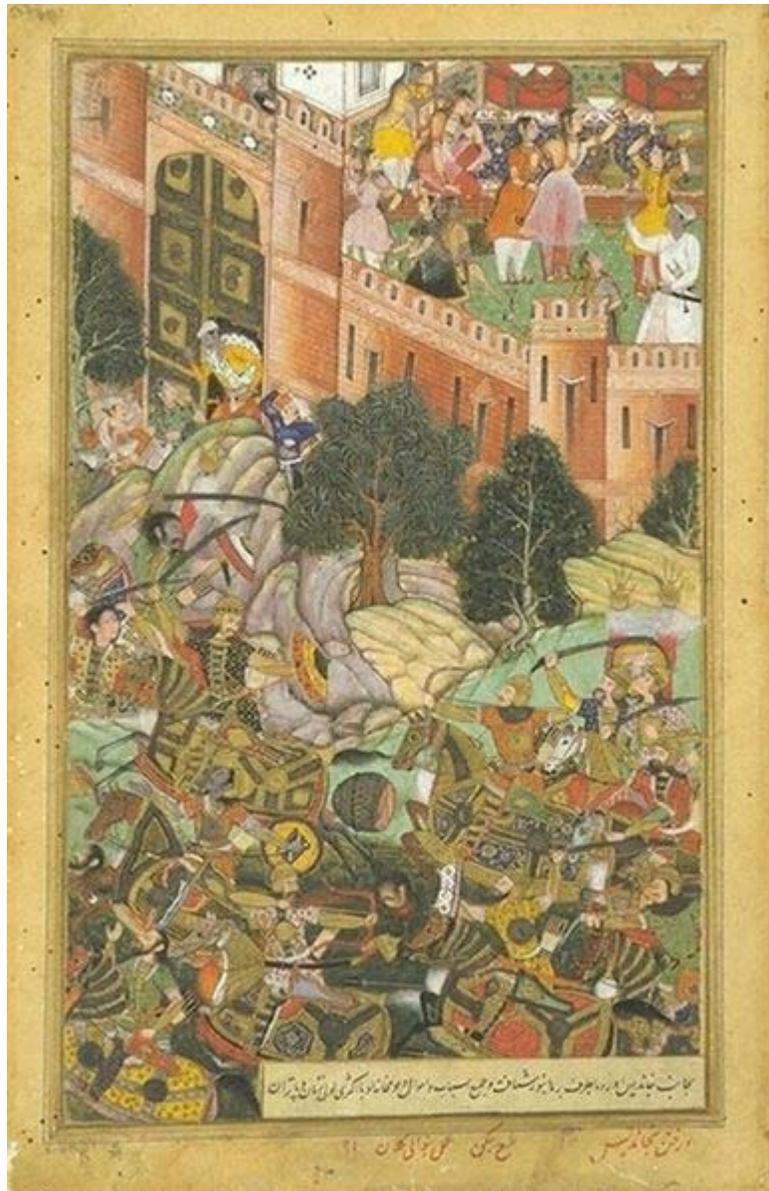
Model of a Chola (200–848 CE) ship's hull, built by the ASI, based on a wreck 19 miles off the coast of Poombuhar, displayed in a Museum in Tirunelveli.

The origins of the spinning wheel are unclear but India is one of the probable places of its origin. The device certainly reached Europe from India by the 14th century CE. The cotton gin was invented in India as a mechanical device known as *charkhi*, the "wooden-worm-worked roller". This mechanical device was, in some parts of the region, driven by water power. The Ajanta caves yield evidence of a single roller cotton gin in use by the 5th century CE. This cotton gin was used until further innovations were made in form of foot powered gins. Chinese documents confirm at least two missions to India, initiated in 647, for obtaining technology for sugar-refining. Each mission returned with different results on refining sugar.

Pingala (fl. 300-200 BCE) was a musical theorist who authored a Sanskrit treatise on prosody. There is evidence that in his work on the enumeration of syllabic combinations, Pingala stumbled upon both the Pascal triangle and Binomial coefficients, although he did not have knowledge of the Binomial theorem itself. A description of binary numbers is also found in the works of Pingala. The use of negative numbers was known in early India, and their role in situations like mathematical problems of debt was understood. Consistent rules for working with these numbers were formulated. The diffusion of this concept led the Arab intermediaries to pass it to Europe.

The decimal number system originated in India. Other cultures discovered a few features of this number system but the system, in its entirety, was compiled in India, where it attained coherence and completion. By the 9th century CE, this complete number system had existed in India but several of its ideas were transmitted to China and the Islamic world before that time. The concept of 0 as a number, and not merely a symbol for separation is attributed to India. In India, practical calculations were carried out using zero, which was treated like any other number by the 9th century CE, even in case of division. Brahmagupta (598–668) was able to find (integral) solutions of Pell's equation. Conceptual design for a perpetual motion machine by Bhaskara II dates to 1150. He described a wheel that he claimed would run forever.

The trigonometric functions of Sine and 'Versine, from which it was trivial to derive the Cosine, were used by the mathematician, Aryabhata, in the late 5th century. The calculus theorem now known as "Rolle's theorem" was stated by mathematician, Bhāskara II, in the 12th century. In the 12th century, Bhāskara II developed the concept of a derivative and a differential representing infinitesimal change.



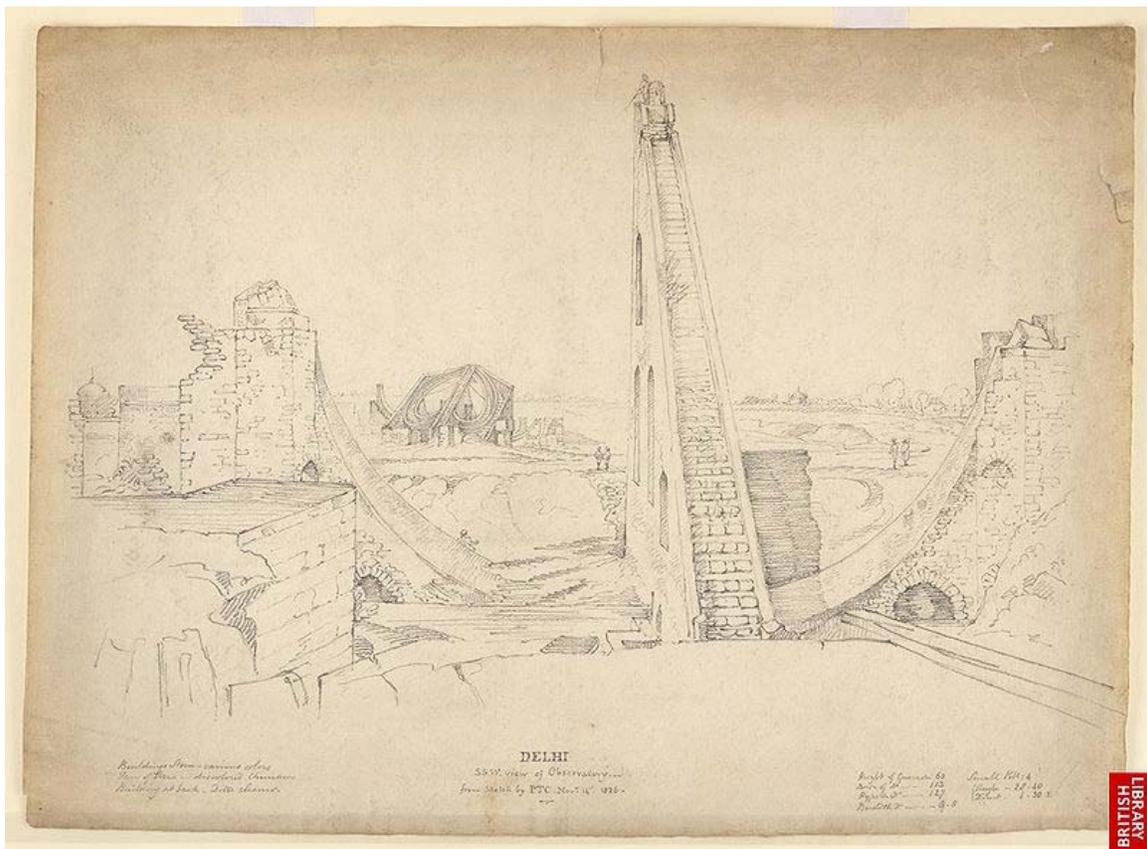
Akbarnama—written by August 12, 1602—depicts the defeat of Baz Bahadur of Malwa by the Mughal troops, 1561. The Mughals extensively improved metal weapons and armor used by the armies of India.

Indigo was used as a dye in India, which was also a major center for its production and processing. The *Indigofera tinctoria* variety of Indigo was domesticated in India. Indigo, used as a dye, made its way to the Greeks and the Romans via various trade routes, and was valued as a luxury product. The cashmere wool fiber, also known as *pashm* or *pashmina*, was used in the handmade shawls of Kashmir. The woolen shawls from Kashmir region find written mention between 3rd century BC and the 11th century CE. Crystallized sugar was discovered by the time of the Gupta dynasty, and the earliest reference to candied sugar comes from India. Jute was also cultivated in India. Muslin was named after the city where Europeans first encountered it, Mosul, in what is now

Iraq, but the fabric actually originated from Dhaka in what is now Bangladesh. In the 9th century, an Arab merchant named Sulaiman makes note of the material's origin in Bengal (known as *Ruhml* in Arabic).

Evidence of inoculation and variolation for smallpox is found in the 8th century, when Madhav wrote the *Nidāna*, a 79-chapter book which lists diseases along with their causes, symptoms, and complications. He included a special chapter on smallpox (*masūrikā*) and described the method of inoculation to protect against smallpox. European scholar Francesco I reproduced a number of Indian maps in his magnum opus *La Cartografia Antica dell India*. Out of these maps, two have been reproduced using a manuscript of *Lokaprakasa*, originally compiled by the polymath Ksemendra (Kashmir, 11th century CE), as a source. The other manuscript, used as a source by Francesco I, is titled *Samgrahani*.

## Late Middle Ages



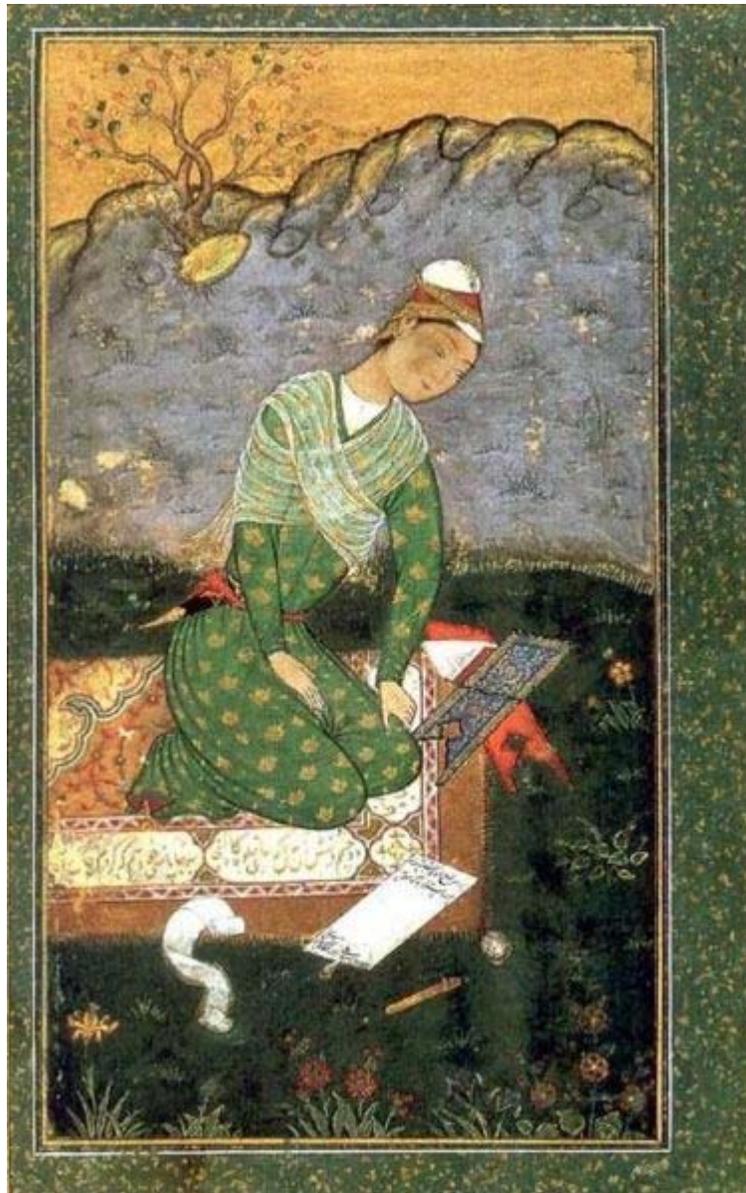
Jantar Mantar, Delhi—consisting of 13 architectural astronomy instruments, built by Jai Singh II of Jaipur, from 1724 onwards.

The infinite series for  $\pi$  was stated by Madhava of Sangamagrama (c. 1340-1425) and his Kerala school of astronomy and mathematics. He made use of the series expansion of arctanx to obtain an infinite series expression, now known as the *Madhava-Gregory*

*series*, for  $\pi$ . Their rational approximation of the *error* for the finite sum of their series are of particular interest. They manipulated the error term to derive a faster converging series for  $\pi$ . They used the improved series to derive a rational expression,  $104348 / 33215$  for  $\pi$  correct up to nine decimal places, *i.e.* 3.141592653. The development of the series expansions for trigonometric functions (sine, cosine, and arc tangent) was carried out by mathematicians of the Kerala School in the 15th century CE. Their work, completed two centuries before the invention of calculus in Europe, provided what is now considered the first example of a power series (apart from geometric series).

Shēr Shāh of northern India issued silver currency bearing Islamic motifs, later imitated by the Mughal empire. The Chinese merchant Ma Huan (1413–51) noted that gold coins, known as *fanam*, were issued in Cochin and weighed a total of one *fen* and one *li* according to the Chinese standards. They were of fine quality and could be exchanged in China for 15 silver coins of four-*li* weight each.

The Seamless celestial globe was invented in Kashmir by Ali Kashmiri ibn Luqman in 998 AH (1589-90 CE), and twenty other such globes were later produced in Lahore and Kashmir during the Mughal Empire. Before they were rediscovered in the 1980s, it was believed by modern metallurgists to be technically impossible to produce metal globes without any seams, even with modern technology. These Mughal metallurgists pioneered the method of lost-wax casting in order to produce these globes.



Portrait of a young Indian scholar, Mughal miniature by Mir Sayyid Ali, ca. 1550.

It was written in the *Tarikh-i Firishta* (1606–1607) that the envoy of the Mongol ruler Hulegu Khan was presented with a pyrotechnics display upon his arrival in Delhi in 1258 CE. As a part of an embassy to India by Timurid leader Shah Rukh (1405–1447), 'Abd al-Razzaq mentioned naphtha-throwers mounted on elephants and a variety of pyrotechnics put on display. Firearms known as *top-o-tufak* also existed in the Vijayanagara Empire by as early as 1366 CE. From then on the employment of gunpowder warfare in the region was prevalent, with events such as the siege of Belgaum in 1473 CE by the Sultan Muhammad Shah Bahmani.

In *A History of Greek Fire and Gunpowder*, James Riddick Partington describes Indian rockets, mines and other means of gunpowder warfare:

The Indian war rockets were formidable weapons before such rockets were used in Europe. They had bam-boo rods, a rocket-body lashed to the rod, and iron points. They were directed at the target and fired by lighting the fuse, but the trajectory was rather erratic. The use of mines and counter-mines with explosive charges of gunpowder is mentioned for the times of Akbar and Jahāngir.

By the 16th century, Indians were manufacturing a diverse variety of firearms; large guns in particular, became visible in Tanjore, Dacca, Bijapur and Murshidabad. Guns made of bronze were recovered from Calicut (1504) and Diu (1533). Gujarāt supplied Europe saltpeter for use in gunpowder warfare during the 17th century. Bengal and Mālwa participated in saltpeter production. The Dutch, French, Portuguese, and English used Chāpra as a center of saltpeter refining.

The construction of water works and aspects of water technology in India is described in Arabic and Persian works. During medieval times, the diffusion of Indian and Persian irrigation technologies gave rise to an advanced irrigation system which brought about economic growth and also helped in the growth of material culture. The founder of the cashmere wool industry is traditionally held to be the 15th century ruler of Kashmir, Zayn-ul-Abidin, who introduced weavers from Central Asia.

The scholar Sadiq Isfahani of Jaunpur compiled an atlas of the parts of the world which he held to be 'suitable for human life'. The 32 sheet atlas—with maps oriented towards the south as was the case with Islamic works of the era—is part of a larger scholarly work compiled by Isfahani during 1647 CE. According to Joseph E. Schwartzberg (2008): 'The largest known Indian map, depicting the former Rajput capital at Amber in remarkable house-by-house detail, measures 661 × 645 cm. (260 × 254 in., or approximately 22 × 21 ft).'

## **Ancient Greek technology**

**Ancient Greek technology** developed at an unprecedented speed during the 5th century BC, continuing up to and including the Roman period, and beyond. Inventions that are credited to the ancient Greeks such as the gear, screw, rotary mills, screw press, bronze casting techniques, water clock, water organ, torsion catapult and the use of steam to operate some experimental machines and toys and a chart to find prime numbers. Many of these inventions occurred late in the Greek period, often inspired by the need to improve weapons and tactics in war. However, peaceful uses are shown by their early development of the watermill, a device which pointed to further exploitation on a large scale under the Romans. They developed surveying and mathematics to an advanced state, and many of their technical advances were published by philosophers like Archimedes and Hero.

## Water technology

One of the foundations for many modern technological achievements would include water resources. Some fields that were encompassed in the area of water resources (mainly for urban use), would include such areas as groundwater exploitation, construction of aqueducts for water supply, stormwater and wastewater sewerage systems, flood protection and drainage, construction and use of fountains, baths and other sanitary and purgatory **facilities**, and even recreational uses of water.

## Mining

The Greeks developed extensive silver mines at Laurium, the profits from which helped to support the growth of Athens as a city-state. It involved mining the ore in underground galleries, washing the ores and smelting it to produce the metal. Elaborate washing tables still exist at the site using rain water held in cisterns and collected during the winter months.

## Technology

The failure of the Greeks to develop their technology has sometimes been status of people providing labor. Manual labor was despised, and anyone attempting to apply science to it was likely to lose status in society, removing much of the incentive to seek technological innovation. A sophisticated tunnel built for an aqueduct in the 6th century BCE by the engineer Eupalinos at Samos has led to some reevaluation of the skills of the Greeks.

## Ancient Greek technology

Technology	Date	Comment	
Streets	ca. 400 BC	Example: The Porta Rosa (4th-3rd century BC) was the main street of Elea (Italy). It connects the northern quarter with the southern quarter. The street is 5 meters wide and has an incline of 18% in the steepest part. It is paved with limestone blocks, griders cut in square blocks, and on one side a small gutter for the drainage of rain water. The building is dated during the time of the reorganization of the city during Hellenistic age (4th to 3th centuries BC)	

**Cartography** ca. 600 BC First widespread amalgamation of geographical maps developed by Anaximander.

**Rutway** ca. 600 BC The 6 to 8.5 km long Diolkos represented a rudimentary form of railway.



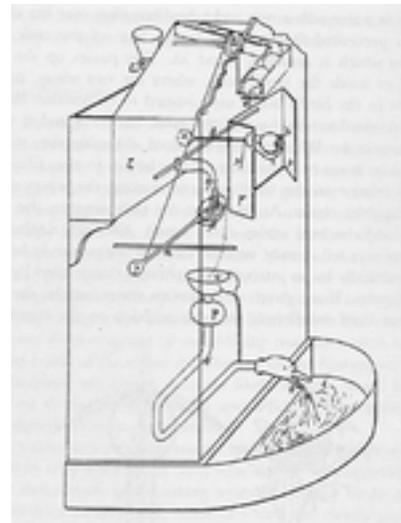
**Caliper** 6th c. BC Earliest example found in the Giglio wreck near the Italian coast. The wooden piece already featured one fixed and a movable jaw.

**Truss roof** 550 BC

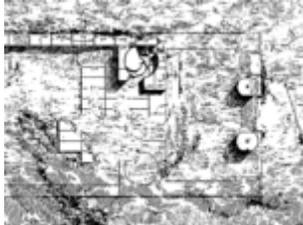
**Crane** ca. 515 BC Labor-saving device which allowed the employment of small and efficient work teams on construction sites. Later winches were added for heavy weights.



**Escapement** 3rd century BC Described by the Greek engineer Philo of Byzantium (3rd century BC) in his technical treatise *Pneumatics* (chapter 31) as part of a washstand automaton for guests washing their hands. Philon's comment that "its construction is similar to that of clocks" indicates that such escapements mechanism were already integrated in ancient water clocks.



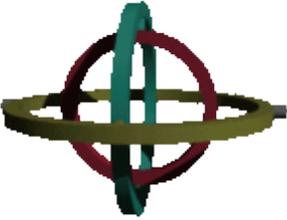
**Tumbler lock** ca. 5th c. BC The tumbler lock, as well as other varieties, was introduced to Greece in the 5th century BC.

<b>Gears</b>	ca. 5th c. BC	Developed further than in prehistoric times for a variety of practical purposes.	
<b>Plumbing</b>	ca. 5th c. BC	Excavations at Olympus as well as Athens have revealed extensive plumbing systems for baths and fountains as well as for personal use.	
<b>Spiral staircase</b>	480-470 BC	The earliest spiral staircases appear in Temple A in Selinunte, Sicily, to both sides of the cella. The temple was constructed around 480-470 BC.	
<b>Urban planning</b>	ca. 5th c. BC	Miletus is one of the first known towns in the world to have a grid like plan for residential and public areas. It accomplished this feat through a variety of related innovations in areas such as surveying.	
<b>Crossbow</b>	ca. 5th c. BC	The Greeks made use of a handheld crossbow called the gastraphetes.	
<b>Winch</b>	5th c. BC	The earliest literary reference to a winch can be found in the account of Herodotus of Halicarnassus on the Persian Wars ( <i>Histories</i> 7.36), where he describes how wooden winches were used to tighten the cables for a pontoon bridge across the Hellespont in 480 B.C. Winches may have been employed even earlier in Assyria, though. By	

		<p>the 4th century BC, winch and pulley hoists were regarded by Aristotle as common for architectural use (<i>Mech.</i> 18; 853b10-13).</p> <p>Two building material inventories for 408/407 and 407/406 B.C. from the temple of Eleusis list, among other machines and tools, a one-wheeler (hyperteria monokyklou).</p>
<b>Wheelbarrow</b>	5th c. BC	
<b>Showers</b>	4th c. BC	<p>A shower room for female athletes with plumbed-in water is depicted on an Athenian vase. A whole complex of shower-baths was also found in a 2nd century BC gymnasium at Pergamum.</p>
<b>Central heating</b>	ca. 350 BC	<p>Great Temple of Ephesus was warmed by heated air that was circulated through flues laid in the floor.</p>
<b>Lead sheathing</b>	ca. 350 BC	<p>To protect a ships hull from boring creatures.</p>
<b>Astrolabe</b>	ca. 300 BC	<p>First used around 200 B.C. by astronomers in Greece. Used to determine the altitude of objects in the sky.</p>
<b>Lighthouse</b>	ca. 3rd c. BC	<p>The Lighthouse of Alexandria was designed and constructed by Sostratus of Cnidus.</p>
<b>Alarm clock</b>	3rd c. BC	<p>The Hellenistic engineer and inventor Ctesibius (fl. 285–222 BC) fitted his clepsydras with dial and pointer for indicating the time, and added elaborate "alarm systems, which could be made to drop pebbles on a gong,</p>



		<p>or blow trumpets (by forcing bell-jars down into water and taking the compressed air through a beating reed) at pre-set times" (Vitruv 11.11).</p> <p>Odometer, a device used in the late Hellenistic time and by Romans for indicating distance traveled by a vehicle was invented sometime in the 3rd century BC. Some historians attribute it to Archimedes, others to Hero of Alexandria. It helped revolutionize the building of roads and travelling by them by accurately measuring distance and being able to illustrate this with a milestone.</p>
<b>Odometer</b>	ca. 3rd c. BC	
<b>Chain drive</b>	3rd c. BC	<p>First described by Philo of Byzantium. The device powered a repeating crossbow, the first known of its kind.</p>
<b>Cannon</b>	ca. 3rd c. BC	<p>Ctesibius of Alexandria invented a primitive form of the cannon, operated by compressed air.</p>
<b>Double-action principle</b>	3rd c. BC	<p>Universal mechanical principle which was discovered and applied first by the engineer Ctesibius in his double action piston pump which later was developed further by Heron to a fire hose (see below).</p>
<b>Levers</b>	ca. 260 BC	<p>First described about 260 BC by the ancient Greek mathematician Archimedes. Although used in prehistoric times, they were first put to practical use for more developed technologies in Ancient Greece.</p>
<b>Water mill</b>	ca. 250 BC	<p>The use of water power was pioneered by the Greeks: The</p>

<b>Gimbal</b>	3rd c. BC	<p>earliest mention of a water mill in history occurs in Philo's <i>Pneumatics</i>, previously been regarded as a later Arabic interpolation, but according to recent research to be of authentic Greek origin.</p> <p>The inventor Philo of Byzantium (280-220 BC) described an eight-sided ink pot with an opening on each side, which can be turned so that any face is on top, dip in a pen and ink it-yet the ink never runs out through the holes of the side. This was done by the suspension of the inkwell at the center, which was mounted on a series of concentric metal rings which remained stationary no matter which way the pot turns itself.</p>	
<b>Dry dock</b>	ca. 200 BC	<p>Invented in Ptolemaic Egypt some time after the death of Ptolemy IV Philopator (reigned 221-204 BC) as recorded by Athenaeus of Naucratis.</p>	
<b>Air and water pumps</b>	ca. 2nd c. BC	<p>Ctesibius and various other Greeks of Alexandria of the period developed and put to practical use various air and water pumps which served a variety of purposes, such as a water organ.</p>	
<b>Surveying tools</b>	ca. 2nd c. BC	<p>Various records relating to mentions of surveying tools have been discovered, mostly in Alexandrian sources, these greatly helped the development of the precision of Roman Aqueducts.</p>	

**Analog computers**

ca. 150 BC



**Fire hose**

1st c. BC

Invented by Hero in the basis of Ctesibius' double action piston pump. Allowed for more efficient fire fighting.

**Vending machine**

1st c. BC

The first vending machine was described by Hero of Alexandria. His machine accepted a coin and then dispensed a fixed amount of holy water. When the coin was deposited, it fell upon a pan attached to a lever. The lever opened up a valve which let some water flow out. The pan continued to tilt with the weight of the coin until it fell off, at which point a counter-weight would snap the lever back up and turn off the valve.

**Wind vane**

50 BC

The Tower of the Winds on the Roman *agora* in Athens featured atop a wind vane in the form of a bronze Triton holding a rod in his outstretched hand rotating to the wind blowing. Below, its frieze was adorned with the eight wind deities. The 8 m high structure also featured sundials and a water clock inside dates from around 50 BC.

**Clock tower** 50 BC

Apart from a wind vane the Tower of the Winds also featured eight sundials arranged around the top of the polygonal structure. Recent research has shown that the height of 8 m was motivated by the intention to place the sundials and the wind-vane at a visible height on the Agora, making it effectively an early example of a clocktower.



**Automatic doors** ca. 1st c. AD

Hero of Alexandria, a 1st century BC inventor from Alexandria, Egypt, created automatic doors for a temple with the aid of steam power.

## Chapter-4

# Roman Technology



The Pont du Gard in France is a Roman aqueduct built in ca. 19 BC.



Mercury gilded statue - Marcus Aurelius

**Roman technology** is the engineering practice which supported Roman civilization and made the expansion of Roman commerce and Roman military possible over nearly a thousand years.

The Roman Empire had the most advanced set of technologies of its time, some of which was lost during the turbulent eras of Late Antiquity and the early Middle Ages. Gradually, some of the technological feats of the Romans were rediscovered and/or improved upon, while others went ahead of what the Romans had done during the Middle Ages and the beginning of the Modern Era. Several Roman technological feats in different areas like civil engineering, construction materials, transport technology, and

some inventions such as the mechanical reaper, were surprising achievements until the 19th century, and some, such as the arch, have remained untouched to this day.

## **Innovation and progress**

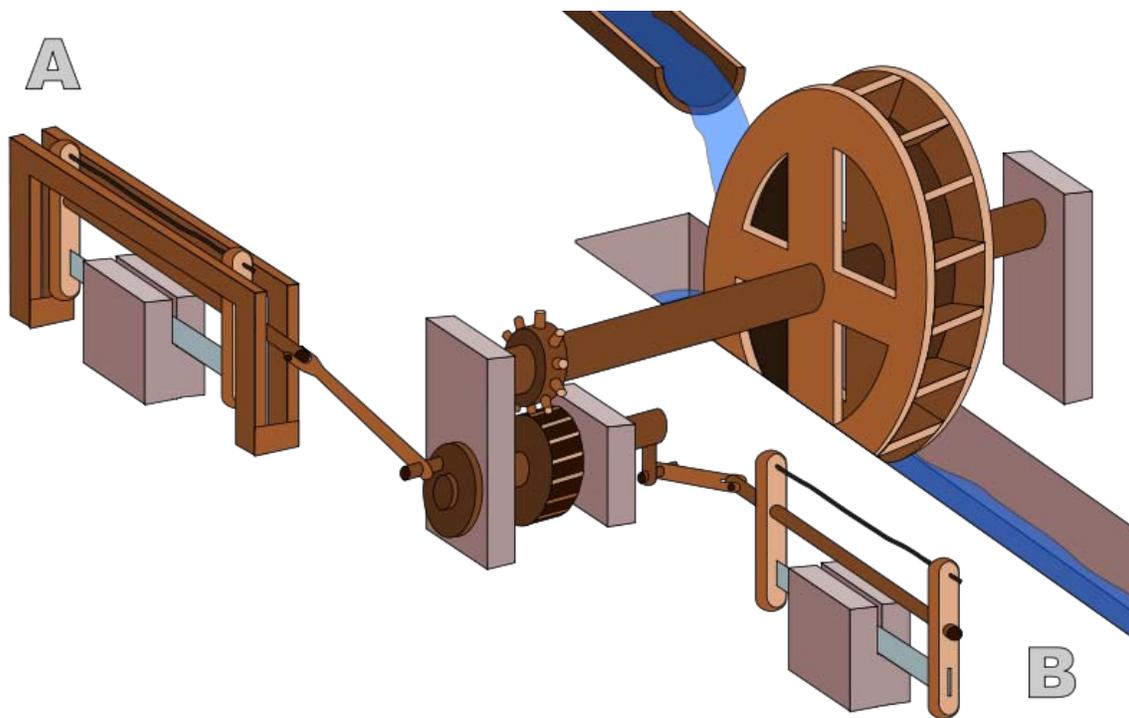
Small scale innovation was common as devices were gradually made more efficient, such as the improvement of the overshot water wheel and the improvements in wagon construction. Technology could and did evolve. The scale of the Empire encouraged the geographical spread of innovations. The ideal Roman citizen was an articulate veteran soldier who could wisely govern a large family household, which was supported by slave labor. Innovators did have some prestige; Pliny, for example, often records their names, or has some story to account for the innovation. Romans also knew enough history to be aware that technological change had occurred in the past and brought benefits. Military innovation was always valued. One text, *De Rebus Bellicis*, devoted to a number of innovations in military machinery, has survived.

The apparent period in which technological progress was fastest and greatest was during the 2nd century and 1st century BC, which was the period in which Roman power greatly increased. Innovation continued until the fall of the Empire, and it would take hundreds of years for all of its technological advancements to be rediscovered by other civilizations. Our understanding of Roman technology is provided by Pliny's *Naturalis Historia*, the *De Architectura* of Vitruvius and the *De aquaeductu* of Frontinus, all reliable works which give good information, and many inventions they mention have been confirmed by modern archaeology. By the beginning of the 1st century, most of what is considered today as typical Roman technology was already invented and refined, such as concrete, plumbing facilities, cranes, wagon technology, mechanized harvesting machines, domes, the arch in building practice, wine and oil presses, and glass blowing. They were also influenced by the Greeks.

## The energy constraint



The sixteen overshot wheels at Barbegal are considered the biggest ancient mill complex. Their capacity was sufficient to feed the whole nearby city of Arles.



Scheme of the Roman Hierapolis sawmill, the earliest known machine to incorporate a crank and connecting rod mechanism.

All technology uses energy to transform the material into a desirable object. The cheaper energy is, the wider the class of technologies that are considered economic. This is why technological history can be seen as a succession of ages defined by energy type i.e. human, animal, water, peat, coal, and oil. The Romans had water power, and exploited wood and coal for heating. There were huge reserves of wood, peat and coal in the Roman Empire, but they were all in the wrong place. Wood could be floated down rivers to the major urban centres but otherwise it was a very poor fuel, being heavy for its calorific value. If this was improved by being processed into charcoal, it was bulky. Nor was wood ever available in any concentration. Diocletian's Price Edict can give us a glimpse of the economics of transporting wood. The maximum price of a wagon load of 1,200 lbs of wood was 150 d.(denari). The maximum freight charge per mile for the same wagon load was 20 d. per mile. Room heating was normally better done by charcoal braziers than hypocausts. But hypocausts did allow them to exploit any poor-quality smoky fuels like straw, vine prunings and small wood locally available. Hypocausts also allowed them to generate a humid heat for their baths.

The Romans worked almost all the coalfields of England that outcropped on the surface, by the end of the 2nd century (Smith 1997; 323). But there is no evidence that this exploitation was on any scale. After c.200 AD the commercial heart of the Empire was in Africa and the East where the climate severely limited timber growth. There was no large coalfield on the edge of the Mediterranean.

Nevertheless, the Romans were the first technological culture to assemble all essential components of the much later steam engine:

With the crank and connecting rod system, all elements for constructing a steam engine (invented in 1712) — Hero's aeolipile (generating steam power), the cylinder and piston (in metal force pumps), non-return valves (in water pumps), gearing (in water mills and clocks) — were known in Roman times.

## **Craft basis**



Roman Cage Cup from the 4th century AD. Hypothesised as a floating wick oil lamp to give magical downwards lighting effects.

Roman technology was largely based on a system of crafts, although the term engineering is used today to describe the technical feats of the Romans. The Greek words used were mechanic or machine-maker or even mathematician which had a much wider meaning than now. There were a large number of engineers employed by the army. The most famous engineer of this period was Apollodorus of Damascus. Normally each trade, each group of artisans—stone masons, glass blowers, surveyors, etc.—within a project had its own practice of masters and apprentices, and many tried to keep their trade secrets, passing them on solely by word of mouth, a system still in use today by those who do not want to patent their inventions. Writers such as Vitruvius, Pliny the Elder and Frontinus published widely on many different technologies, and there was a corpus of manuals on basic mathematics and science such as the many books by Archimedes, Ctesibius, Heron (a.k.a. Hero of Alexandria), Euclid and so on. Not all of the manuals which were available to the Romans have survived, as lost works illustrates.

Much of what is known of Roman technology comes indirectly from archaeology and from the third-hand accounts of Latin texts copied from Arabic texts, which were in turn copied from the Greek texts of scholars such as Hero of Alexandria or contemporary travelers who had observed Roman technologies in action. Writers like Pliny the Elder and Strabo had enough intellectual curiosity to make note of the inventions they saw during their travels, although their typically brief descriptions often arouse discussion as to their precise meaning. On the other hand, Pliny is perfectly clear when describing gold mining, his text in book xxxiii having been confirmed by archaeology and field-work at such sites as Las Medulas and Dolaucothi.

## Engineering and construction



The Colosseum in Rome, Italy

The Romans made great use of aqueducts, dams, bridges, and amphitheaters. They were also responsible for many innovations to roads, sanitation, and construction in general. Roman architecture in general was greatly influenced by the Etruscans. Most of the columns and arches seen in famous Roman architecture were adopted from the Etruscan civilization.

In the Roman Empire, cements made from pozzolanic ash/pozzolana and an aggregate made from pumice were used to make a concrete very similar to modern Portland cement concrete. In 20s BC the architect Vitruvius described a low-water-content method for mixing concrete. The Romans found out that insulated glazing (or "double glazing") improved greatly on keeping buildings warm, and this technique was used in the construction of public baths.

Another truly original process which was born in the empire was the practice of glassblowing, which started in Syria and spread in about one generation in the empire.

## **Machines**



Reconstruction of a 10.4-metre-high Roman construction crane at Bonn, Germany

There were many types of presses to press olives. In the 1st century, Pliny the Elder reported the invention and subsequent general use of the new and more compact screw presses. However, the screw press was almost certainly not a Roman invention. It was first described by Hero of Alexandria, but may have already been in use when he mentioned it in his *Mechanica* III.

Cranes were used for construction work and possibly to load and unload ships at their ports, although for the latter use there is according to the “present state of knowledge” still no evidence. Most cranes were capable of lifting about 6-7 tons of cargo, and according to a relief shown on Trajan's column were worked by treadwheel.

## Roads



Via Appia, a road connecting the city of Rome to the Southern parts of Italy remains usable even today.

The Romans primarily built roads for their military. Their economic importance was probably also significant, although wagon traffic was often banned from the roads to preserve their military value. At its largest extent the total length of the Roman road network was 85,000 kilometres (53,000 mi).

Way stations providing refreshments were maintained by the government at regular intervals along the roads. A separate system of changing stations for official and private couriers was also maintained. This allowed a dispatch to travel a maximum of 800 kilometres (500 mi) in 24 hours by using a relay of horses.

The roads were constructed by digging a pit along the length of the intended course, often to bedrock. The pit was first filled with rocks, gravel or sand and then a layer of concrete. Finally they were paved with polygonal rock slabs. Roman roads are considered the most advanced roads built until the early 19th century. Bridges were constructed over waterways. The roads were resistant to floods and other environmental hazards. After the fall of the Roman empire the roads were still usable and used for more than 1000 years.

## **Aqueducts**



Aqueduct of Segovia

The Romans constructed numerous aqueducts to supply water. The city of Rome itself was supplied by eleven aqueducts that provided the city with over 1 million cubic metres of water each day, sufficient for 3.5 million people even in modern day times, and with a combined length of 350 kilometres (220 mi). Most aqueducts were constructed below the surface with only small portions above ground supported by arches. The longest Roman aqueduct, 178 kilometres (111 mi) in length, was traditionally assumed to be that which

supplied the city of Carthage. The complex system built to supply Constantinople had its most distant supply drawn from over 120 km away along a sinuous route of more than 336 km.

Roman aqueducts were built to remarkably fine tolerances, and to a technological standard that was not to be equaled until modern times. Powered entirely by gravity, they transported very large amounts of water very efficiently. Sometimes, where depressions deeper than 50 metres had to be crossed, inverted siphons were used to force water uphill. An aqueduct also supplied water for the overshot wheels at Barbegal in Roman Gaul, a complex of water mills hailed as "the greatest known concentration of mechanical power in the ancient world".

## Bridges



1st century Roman bridge in Vaison la Romaine, France

Roman bridges were among the first large and lasting bridges built. They were built with stone and had the arch as its basic structure. Most utilized concrete as well. Built in 142 BC, the Pons Aemilius, later named *Ponte Rotto* (broken bridge) is the oldest Roman stone bridge in Rome, Italy. The biggest Roman bridge was Trajan's bridge over the lower Danube, constructed by Apollodorus of Damascus, which remained for over a

millennium the longest bridge to have been built both in terms of overall and span length. They were most of the time at least 60 feet above the body of water.

An example of temporary military bridge construction are the two Caesar's Rhine bridges.

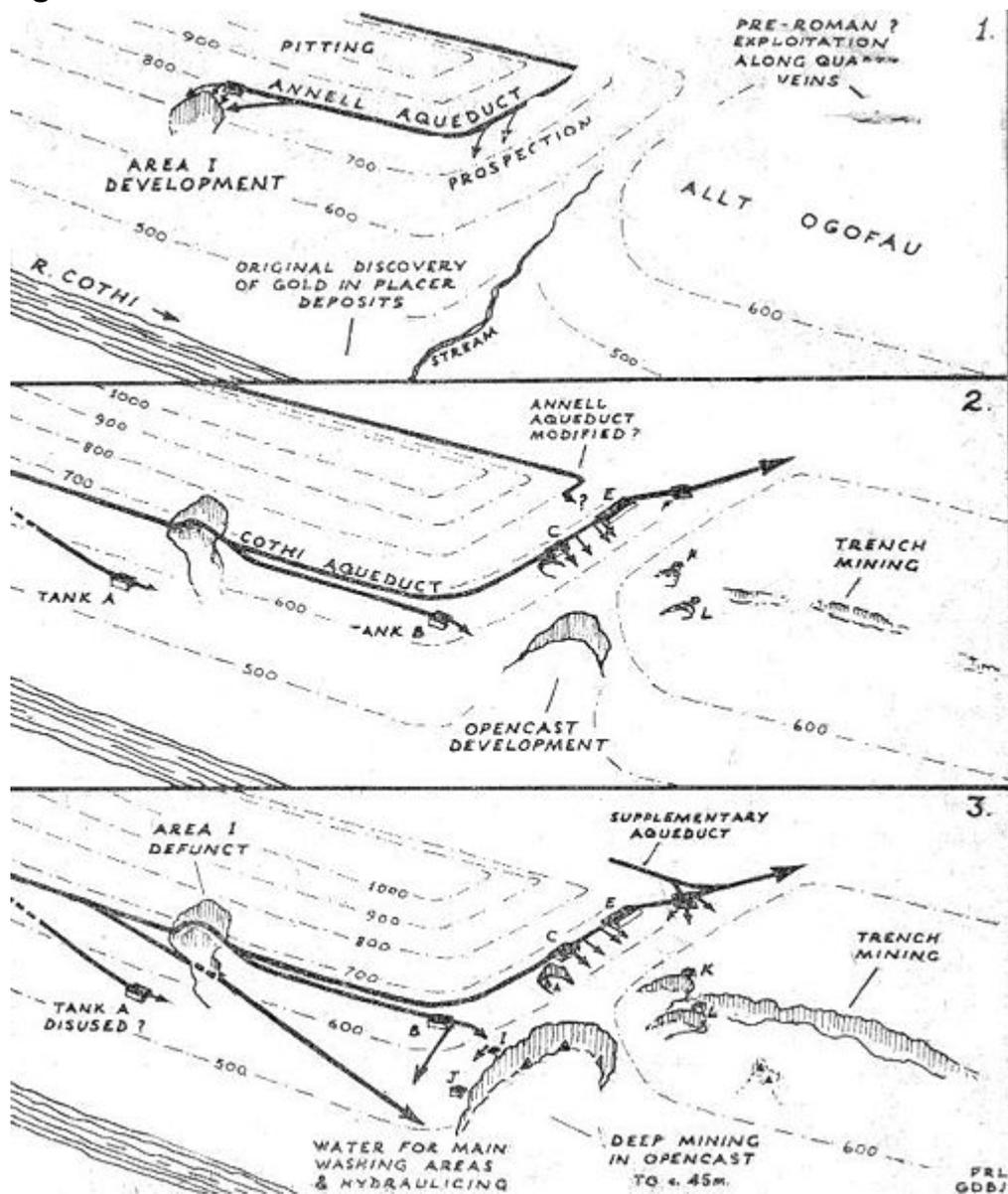
## Dams



The sizable Roman Harbaqa Dam in Syria is 21 m high and 365 m long.

They also built many dams for water collection, such as the Subiaco Dams, two of which fed Anio Novus, one of the largest aqueducts of Rome. They built 72 dams in just one country, Spain and many more are known across the Empire, some of which are still in use. At one site, Montefurado in Galicia, they appear to have built a dam across the river Sil to expose alluvial gold deposits in the bed of the river. The site is near the spectacular Roman gold mine of Las Medulas. Several earthen dams are known from Britain, including a well-preserved example from Roman Lanchester, Longovicium, where it may have been used in industrial-scale smithing or smelting, judging by the piles of slag found at this site in northern England. Tanks for holding water are also common along aqueduct systems, and numerous examples are known from just one site, the gold mines at Dolaucothi in west Wales. Masonry dams were common in North Africa for providing a reliable water supply from the wadis behind many settlements.

## Mining



Development of Dolaucothi mine

The Romans also made great use of aqueducts in their extensive mining operations across the empire, some sites such as Las Medulas in north-west Spain having at least 7 major channels entering the minehead. Other sites such as Dolaucothi in south Wales was fed by at least 5 leats, all leading to reservoirs and tanks or cisterns high above the present opencast. The water was used for hydraulic mining, where streams or waves of water are released onto the hillside, first to reveal any gold-bearing ore, and then to work the ore itself. Rock debris could be sluiced away by hushing, and the water also used to douse fires created to break down the hard rock and veins, a method known as fire-setting.

Alluvial gold deposits could be worked and the gold extracted without needing to crush the ore. Washing tables were fitted below the tanks to collect the gold-dust and any nuggets present. Vein gold needed crushing, and they probably used crushing or stamp mills worked by water-wheels to comminute the hard ore before washing. Large quantities of water were also needed in deep mining to remove waste debris and power primitive machines, as well as for washing the crushed ore. Pliny the Elder provides a detailed description of gold mining in book xxxiii of his *Naturalis Historia*, most of which has been confirmed by archaeology. That they used water mills on a large scale elsewhere is attested by the flour mills at Barbegal in southern France, and on the Janiculum in Rome.

## Sanitation

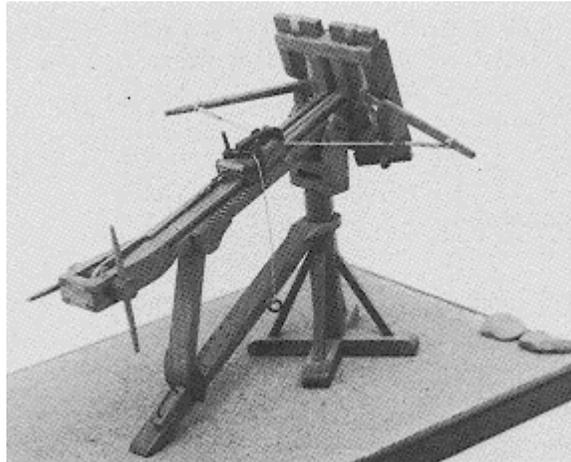


Roman public baths in Bath, England. The loss of the original roof has encouraged green algae growth.

The Romans were one of the first known civilizations to invent indoor plumbing. The Roman public baths, or *thermae* served hygienic, social and cultural functions. The baths contained three main facilities for bathing. After undressing in the apodyterium or changing room, Romans would proceed to the tepidarium or warm room. In the moderate dry heat of the tepidarium, some performed warm-up exercises and stretched while others oiled themselves or had slaves oil them. The tepidarium's main purpose was to promote sweating to prepare for the next room, the caldarium or hot room. The caldarium, unlike the tepidarium, was extremely humid and hot. Temperatures in the caldarium could reach

40 degrees Celsius (104 degrees Fahrenheit). Many contained steam baths and a cold-water fountain known as the labrum. The last room was the frigidarium or cold room, which offered a cold bath for cooling off after the caldarium. The Romans also had flush toilets.

## **Roman military technology**



A Roman Ballista

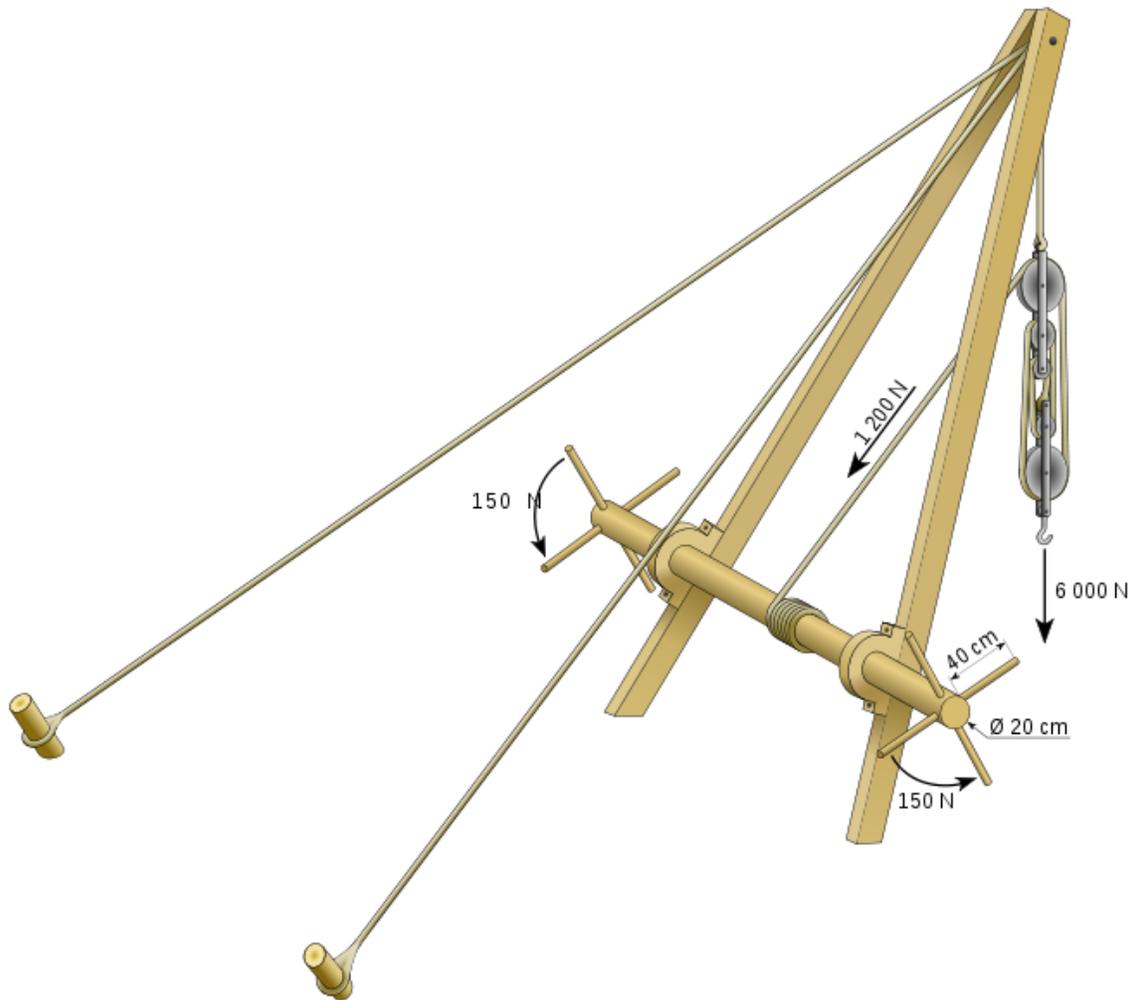
The Roman military technology ranged from personal equipment and armament to deadly siege engines. They inherited almost all ancient weapons.

While heavy, intricate armour was not uncommon (cataphracts), the Romans perfected a relatively light, full torso armour made of segmented plates (lorica segmentata). This segmented armour provided flexibility and protection of most vital areas, and was not associated with the laborious craftwork that other armours (such as chainmail) were. Furthermore, the rest of the Roman soldier's equipment used similarly innovative and effective technology.

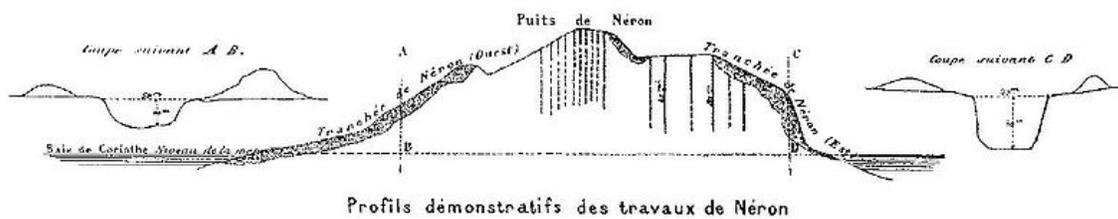
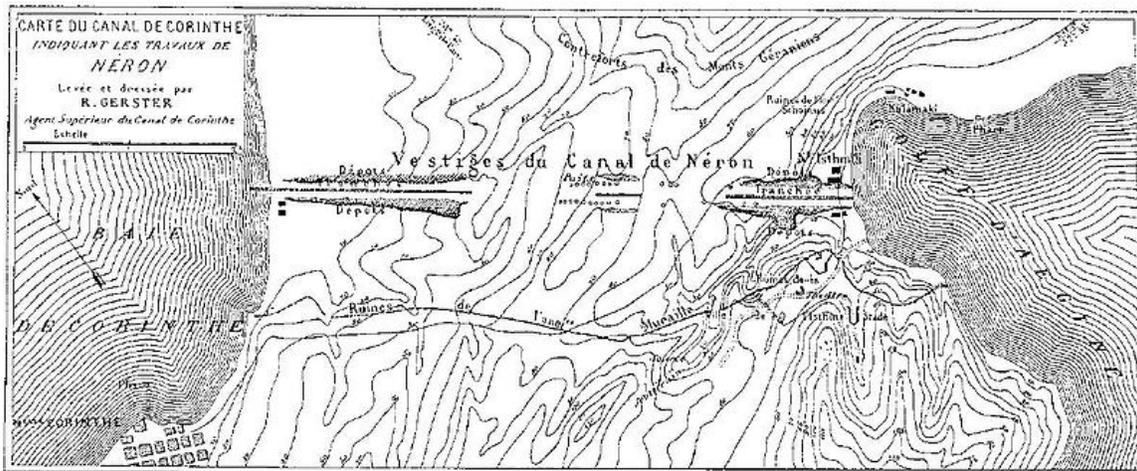
The Roman cavalry saddle had four horns and was believed to have been copied from Celtic peoples.

Roman siege engines such as ballistas, scorpions and onagers were not unique. But the Romans were probably the first people to put ballistas on carts for better mobility on campaigns. On the battlefield, it is thought that they were used as support for the footsoldiers.

## Technologies invented or developed by the Romans



Roman *Pentaspastos* ("Five-pulley-crane"), a medium-sized variant (ca. 450 kg load)



The unfinished Roman Corinth Canal, 1st century AD



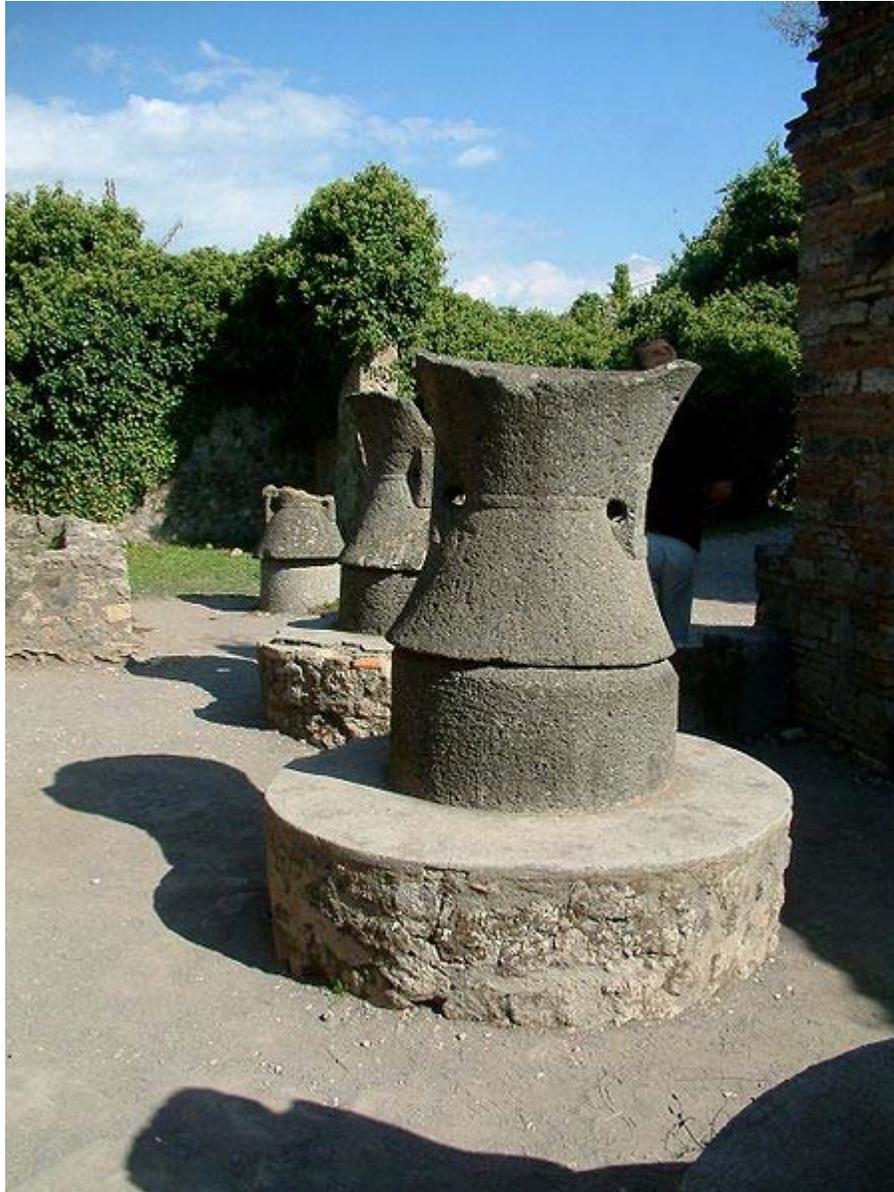
Ship with spritsail, the earliest fore-and-aft rig, 3rd century AD



Pointable fire engine nozzle



Late Roman paddle-wheel boat, 4th century AD (medieval copy)



Donkey mills at Pompeii



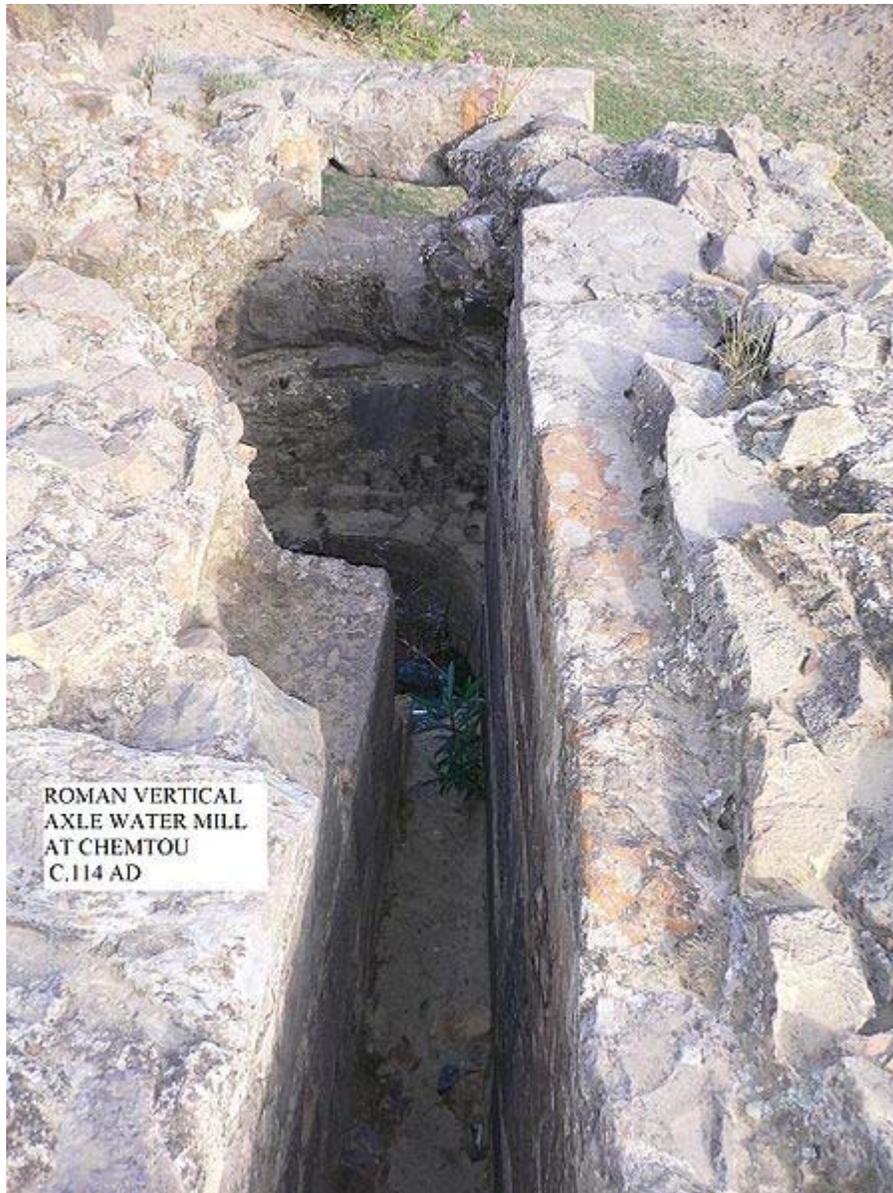
Oil press, Roman type



Modern oil screw press following Roman conceptual innovation



stern mounted rudder



Roman turbine mill at Chemtou, Tunisia



Roman harvesting machine: overview



Roman harvesting machine: detail



Roman surgery tools



Glassware from Pompeii



Roman crank handle from Augusta Raurica, dating to no later than ca. 250 AD

Technology	Comment
Abacus, Roman	Portable.
Alum	The production of alum ( $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ ) from alunite ( $\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$ ) is archaeologically attested on the island Lesbos. This site was abandoned in the 7th century but dates back at least to the 2nd century AD.
Amphitheatre	
Aqueduct, true arch	Pont du Gard, Segovia etc
Arch, monumental	
Bath, monumental public (Thermae)	
Book (Codex)	First mentioned by Martial in the 1st C. AD. Held many advantages over the scroll.
Brass	The Romans had enough understanding of zinc to produce a brass denomination coinage.
Bridge, true arch	
Bridge, segmental arch	More than a dozen Roman bridges are known to feature segmental (=flat) arches. A prominent example was Trajan's bridge over the Danube, a lesser known the extant Limyra Bridge in Lycia
Bridge, pointed arch	Possibly the earliest known bridge featuring a pointed arch is the 5-6th century AD Karamagara Bridge
Cameos	Probably a Hellenistic innovation e.g. Cup of the Ptolemies but taken up by the Emperors e.g. Gemma Augustea, Gemma Claudia etc.
Cast Iron	Recently archaeologically detected in the Val Gabbia in northern

	Lombardy from the 5th and 6th centuries AD. This technically interesting innovation appears to have had little economic impact. But archaeologists may have failed to recognize the distinctive slag, so the date and location of this innovation may be revised.
Cement	
Concrete	Pozzolana variety
Crank handle	A Roman iron crank handle was excavated in Augusta Raurica, Switzerland. The 82.5 cm long piece with a 15 cm long handle is of yet unknown purpose and dates to no later than ca. 250 AD.
Crank and connecting rod	Found in several water-powered saw mills dating from the late 3rd (Hierapolis sawmill) to 6th century AD (at Ephesus respectively Gerasa).
Crane, treadwheel	
Dam, Arch	Currently best attested for the dam at Glanum, France dated ca. 20 BC. The structure has entirely disappeared. Its existence attested from the cuts into the rock on either side to key in the dam wall, which was 14.7 metres high, 3.9m thick at base narrowing to 2.96m at the top. Earliest description of arch action in such types of dam by Procopius around 560 AD, the Dara Dam
Dam, Arch-gravity	Examples include curved dams at Orükaya, Çavdarhisar, both Turkey (and 2nd c.)Kasserine Dam in Tunisia, and Puy Foradado Dam in Spain (2nd–3rd c.)
Dam, Bridge	The Band-i-Kaisar, constructed by Roman prisoners of war in Shustar, Persia, in the 3rd c. AD, featured a weir combined with an arch bridge, a multifunctional hydraulic structure which subsequently spread throughout Iran.
Dam, Buttress	Attested in a number of Roman dams in Spain, like the 600 m long Consuegra Dam
Dam, Multiple Arch Buttress	Esparragalejo Dam, Spain (1st c. AD) earliest known
Dome, monumental	
Foot-powered loom	Before 298 AD, with a hint the invention arose at Tarsus
Flamethrower	(Is this Roman? trad date 670 AD Greek Fire)
<i>Flos Salis</i>	A product of salt evaporation ponds <i>Dunaliella salina</i> used in the perfume industry (Pliny <i>Nat. Hist.</i> 31,90)
Force pump used in fire engine	
Glass blowing	This led to a number of innovations in the use of glass. Window glass is attested at Pompeii in AD 79. In the 2nd century AD hanging glass oil lamps were introduced. These used floating wicks and by reducing

	<p>self shading gave more lumens in a downwards direction. Cage cups are hypothesised as oil lamps.</p> <p>Dichroic glass as in the Lycurgus Cup. Note, this material attests otherwise unknown chemistry (or other way?) to generate nano-scale gold-silver particles.</p> <p>Glass mirrors (Pliny the Elder <i>Naturalis Historia</i> 33,130)</p>
Greenhouse cold frames	(Pliny the Elder <i>Naturalis Historia</i> 19.64; Columella on Ag. 11.3.52)
Hydraulis	A water organ. Later also the pneumatic organ.
Hushing	Described by Pliny the Elder and confirmed at Dolaucothi and Las Médulas
Hydraulic mining	Described by Pliny the Elder and confirmed at Dolaucothi and Las Médulas
Hydrometer	Mentioned in a letter of Synesius
Hypocaust	A floor and also wall heating system. Described by Vitruvius
Knife, multifunctional	
Lighthouses	<p>The best surviving examples are those at Dover castle and the Tower of Hercules at La Coruna</p> <p>The preservation of skins with vegetable tannins was a pre-Roman invention but not of the antiquity once supposed. (Tawing was far more ancient.) The Romans were responsible for spreading this technology into areas where it was previously unknown such as Britain and Qasr Ibrim on the Nile. In both places this technology was lost when the Romans withdrew.</p>
Leather, Tanned	
Mills	<p>M.J.T.Lewis presents good evidence that water powered vertical pounding machines came in by the middle of the 1st c. AD for fulling, grain hulling (Pliny <i>Nat. Hist.</i> 18,97) and ore crushing (archaeological evidence at Dolaucothi Gold Mines and Spain).</p> <p>Grainmill, rotary. According to Moritz (p57) rotary grainmills were not known to the ancient Greeks but date from before 160 BC. Unlike reciprocating mills, rotary mills could be easily adapted to animal or water power. Lewis (1997) argues that the rotary grainmill dates to the 5th century BC in the western Mediterranean. Animal and water powered rotary mills came in the 3rd century BC.</p> <p>Sawmill, water powered. Recorded by 370 AD. Attested in Ausonius's poem <i>Mosella</i>. Translated "<i>the Ruwer sends mill-stones swiftly round to grind the corn, And drives shrill saw-blades through smooth marble blocks</i>". Recent archaeological evidence from Phrygia, Anatolia, now pushes back the date to the 3rd century AD and confirms the use of a crank in the sawmill.</p> <p>Shipmill, (Though small, the conventional term is "shipmill" not boat mill, probably because there was always a deck, and usually an</p>

Steam engine, essentials of	<p>enclosed superstructure, to keep the flour away from the damp.) where water wheels were attached to boats, was first recorded at Rome in 547 AD in Procopius of Caesarea's <i>Gothic Wars</i> (1.19.8-29) when Belisarius was besieged there.</p> <p>By the late 3rd century AD, all essential elements for constructing a steam engine were known by Roman engineers: steam power (in Hero's aeolipile), the crank and connecting rod mechanism (in the Hierapolis sawmill), the cylinder and piston (in metal force pumps), non-return valves (in water pumps) and gearing (in water mills and clocks)</p> <p>Watermill. Improvements upon earlier models. For the largest mill complex known see Barbegal</p>
Mercury Gilding	as in the Horses of San Marco
Newspaper, rudimentary	
Odometer	
Paddle wheel boats	In de Rebus Bellicis (possibly only a paper invention).
Pewter	<p>Mentioned by Pliny the Elder (<i>Naturalis Historia</i> 34,160-1). Surviving examples are mainly Romano-British of the 3rd and 4th centuries e.g. and. Roman pewter had a wide range of proportions of tin but proportions of 50%, 75% and 95% predominate (Beagrie 1989).</p>
Pleasure lake	<p>An artificial reservoir, highly unusual in that it was meant for recreational rather than utilitarian purposes was created at Subiaco, Italy, for emperor Nero (54–68 AD). The dam remained the highest in the Roman Empire (50 m), and in the world until its destruction in 1305.</p>
Pottery, glossed	iron-bladed (A much older innovation (e.g. Bible; I Samuel 13,20-1) that became much more common in the Roman period)
Reaper	<p>wheeled (Pliny the Elder <i>Naturalis Historia</i> 18.171-3) (More important for the Middle Ages, than this era.)</p> <p>i.e. Samian ware</p>
Sails, fore-and-aft rig	<p>An early harvesting machine: <i>vallus</i> (Pliny the Elder <i>Naturalis Historia</i> 18,296, Palladius 7.2.2-4)</p> <p>Introduction of fore-and-aft rigs 1) the Lateen sail 2) the Sprintsail, this last already attested in 2nd century BC in the northern Aegean Sea</p> <p>Note: there is no evidence of any combination of fore and aft rigs with square sails on the same Roman ship.</p>
Sails, Lateen	<p>Representations show lateen sails in the Mediterranean as early as the 2nd century AD. Both the quadrilateral and the triangular type were employed.</p>
Rudder, stern-mounted	

Sausage, fermented dry (probably)	
Screw press	An innovation of about the mid 1st century AD
Sewers	
Soap, hard (sodium)	First mentioned by Galen (earlier, potassium, soap being Celtic).
Spiral staircase	Though first attested as early as the 5th century BC in Greek Selinunte, spiral staircases only become more widespread after their adoption in Trajan's column and the Column of Marcus Aurelius.
Street map, early	See Forma Urbis Romae (Severan Marble Plan), a carved marble ground plan of every architectural feature in ancient Rome.
Sundial, portable	
Surgical instruments, various	
Towpath	e.g. beside the Danube, see the "road" in Trajan's bridge
Tunnels	Excavated from both ends simultaneously. The longest known is the 5.6-kilometre (3.5 mi) drain of the Fucine lake
Vehicles, one wheeled	Solely attested by a Latin word in 4th C. AD Scriptores Historiae Augustae Heliogabalus 29. As this is fiction, the evidence dates to its time of writing.

## Chapter-5

# Medieval Technology



Pumhart von Steyr, a 15th century supergun



Medieval port crane for mounting masts and lifting heavy cargo in the former Hanse town of Danzig

**Medieval technology** refers to the technology used in medieval Europe under Christian rule. After the Renaissance of the 12th century, medieval Europe saw a radical change in the rate of new inventions, innovations in the ways of managing traditional means of production, and economic growth. The period saw major technological advances, including the adoption of gunpowder, the invention of vertical windmills, spectacles, mechanical clocks, and greatly improved water mills, building techniques (Gothic style, medieval castle), agriculture in general (three-field crop rotation).

The development of water mills from its ancient origins was impressive, and extended from agriculture to sawmills both for timber and stone. By the time of the Domesday Book, most large villages had turnable mills, around 6,500 in England alone. Water-power was also widely used in mining for raising ore from shafts, crushing ore, and even powering bellows.

European technical advancements in the 12th to 14th centuries were either built on long-established techniques in medieval Europe, originating from Roman and Byzantine antecedents, or adapted from cross-cultural exchanges through trading networks with the Islamic world, China, and India. Often, the revolutionary aspect lay not in the act of

invention itself, but in its technological refinement and application to political and economic power. Though gunpowder had long been known to the Chinese, it was the Europeans who developed and perfected its military potential, precipitating European expansion and eventual imperialism in the Modern Era.

Also significant in this respect were advances in maritime technology. Advances in shipbuilding included the multi-masted ships with lateen sails, the sternpost-mounted rudder and the skeleton-first hull construction. Along with new navigational techniques such as the dry compass, the Jacob's staff and the astrolabe, these allowed economic and military control of all seas adjacent to Europe and enabled the global navigational achievements of the dawning Age of Exploration.

At the turn to the Renaissance, Gutenberg's invention of mechanical printing made possible a dissemination of knowledge to a wider population, that would not only lead to a gradually more egalitarian society, but one more able to dominate other cultures, drawing from a vast reserve of knowledge and experience. The technical drawings of late medieval artist-engineers Guido da Vigevano and Villard de Honnecourt can be viewed as forerunners of later Renaissance works such as Taccola or da Vinci.

## **Civil technologies**

In the following, a list of some important medieval technology. The approximate date or first mention of a technology in Medieval Europe is given. Technologies were often a matter of cultural exchange and date and place of first inventions are not listed here.

### **Agriculture**

#### **Heavy plough (5th->8th)**

The heavy wheeled plough with a mouldboard first appears in the 5th century in Slavic lands, is then introduced into Northern Italy (the Po Valley) and by the 8th century it was used in the Rhineland. Essential in the efficient use of the rich, heavy, often wet soils of Northern Europe, its use allowed the area's forests and swamps to be brought under cultivation.

#### **Hops (11th)**

Added to beer, importance lay primarily in its ability to preserve beer and improve transportability for trade.

#### **Horse collar (6th->9th)**

Multiple evolutions from Classical Harness (Antiquity), to Breast Strap Harness (6th) to Horse collar (9th). Allowed more horse pulling power, such as with heavy ploughs.

**Horseshoes (9th)**

Allowed horse to adapt to non-grassland terrains in Europe (rocky terrain, mountains) and carry heavier loads. Possibly known to the Romans and Celts as early as 50 BC.

**Wine press (12th)**

First practical means of applying pressure on a plane surface. The principle later used for printing press.

**Architecture and construction**

**Artesian well (1126)** A thin rod with a hard iron cutting edge is placed in the bore hole and repeatedly struck with a hammer, underground water pressure forces the water up the hole without pumping. Artesian wells are named after the town of Artois in France, where the first one was drilled by Carthusian monks in 1126.

**Rib vault (12th)**

Essential element for the rise of Gothic architecture. Allowed vaults to be built for the first time over rectangles of unequal lengths. Also greatly facilitated scaffolding. Largely replaced older groin vault.

**Segmental arch bridge (1345)**

The Ponte Vecchio in Florence is considered medieval Europe's first stone segmental arch bridge.



Treadwheel crane

**Treadwheel crane (1220s)**

Earliest reference to a treadwheel in archival literature in France about 1225, followed by an illuminated depiction in a manuscript of probably also French origin dating to 1240. Apart from tread-drums, windlasses and occasionally cranks were employed for powering cranes. However, such devices were probably used by the Romans.

**Stationary harbor crane (1244)**

Stationary harbor cranes are considered a new development of the Middle Ages, its earliest use being documented for Utrecht in 1244. The typical harbor crane was a

pivoting structure equipped with double treadwheels. There were two types: wooden gantry cranes pivoting on a central vertical axle and stone tower cranes which housed the windlass and treadwheels with only jib arm and roof rotating. These cranes were placed docksides for the loading and unloading of cargo where they replaced or complemented older lifting methods like see-saws, winches and yards. **Slewing cranes** which allowed a rotation of the load and were thus particularly suited for dockside work appeared as early as 1340.

### **Floating crane**

Beside the stationary cranes, floating cranes which could be flexibly deployed in the whole port basin came into use by the 14th century.

### **Mast crane**

Some harbour cranes were specialised at mounting masts to newly built sailing ships, such as in Danzig, Cologne and Bremen.

### **Wheelbarrow (1170s)**

Proved useful in building construction, mining operations, and agriculture. Literary evidence for the use of wheelbarrows appeared between 1170 and 1250 in North-western Europe. First depiction in a drawing by Matthew Paris in the middle of the 13th century.

## Art



*Portrait of a Man in a Turban*, oil painting by Jan van Eyck (1433)

### **Oil paint** (ca. 1410)

As early as the 13th century, oil was used to add details to tempera paintings. Major breakthrough by Flemish painter Jan van Eyck around 1410 who is credited with introducing a stable oil mixture.

## **Clocks**

### **Hourglass (1338)**

Reasonably dependable, affordable and accurate measure of time. Unlike water in a clepsydra, the rate of flow of sand is independent of the depth in the upper reservoir, and the instrument is not liable to freeze. Hourglasses are a medieval innovation (first documented in Siena, Italy).

### **Mechanical clocks (13th->14th)**

A European innovation, these weight-driven clocks were used primarily in clock towers.

## **Mechanics**

### **Compound crank**

The Italian physician Guido da Vigevano combines in his 1335 *Texaurus*, a collection of war machines intended for the recapture of the Holy Land, two simple cranks to form a compound crank for manually powering war carriages and paddle wheel boats. The devices were fitted directly to the vehicle's axle respectively to the shafts turning the paddle wheels.

## **Metallurgy**

### **Blast furnace (1150-1350)**

European cast iron first appears in Middle Europe (for instance Lapphyttan in Sweden, Dürstel in Switzerland and the Märkische Sauerland in Germany) around 1150, in some places according to recent research even before 1100. Technique considered to be an independent European development.

## **Milling**

### **Paper mill (13th)**

The first certain of a water-powered paper mill, evidence for which is elusive in both Chinese and Muslim papermaking, dates to 1282.

### **Rolling mill (15th)**

Used on producing metal sheet of even thickness. First used on soft, malleable metals, such as lead, gold and tin. Leonardo da Vinci described rolling mill for wrought iron.

### **Tidal Mills (6th)**

The earliest tide mills were excavated on the Irish coast where watermillers knew and employed the two main waterwheel types: a 6th century tide mill at Killoteran near Waterford was powered by a vertical waterwheel, while the tide changes at Little Island were exploited by a twin-flume horizontal-wheeled mill (c. 630) and a vertical undershot waterwheel alongside it. Another early example is the Nendrum Monastery mill from 787 which is estimated to have developed 7–8 HP at its peak.

### **Vertical windmills (1180s)**

Invented in Europe as the pivotable post mill, first surviving mention of one comes from Yorkshire in England in 1185. Efficient at grinding grain or draining water. Later also as the stationary tower mill.

### **Water hammer (12th latest)**

Used in metallurgy on forging the metal blooms from bloomeries and Catalan forges. Replaced manual hammerwork. Eventually superseded by steam hammers in the 19th century.

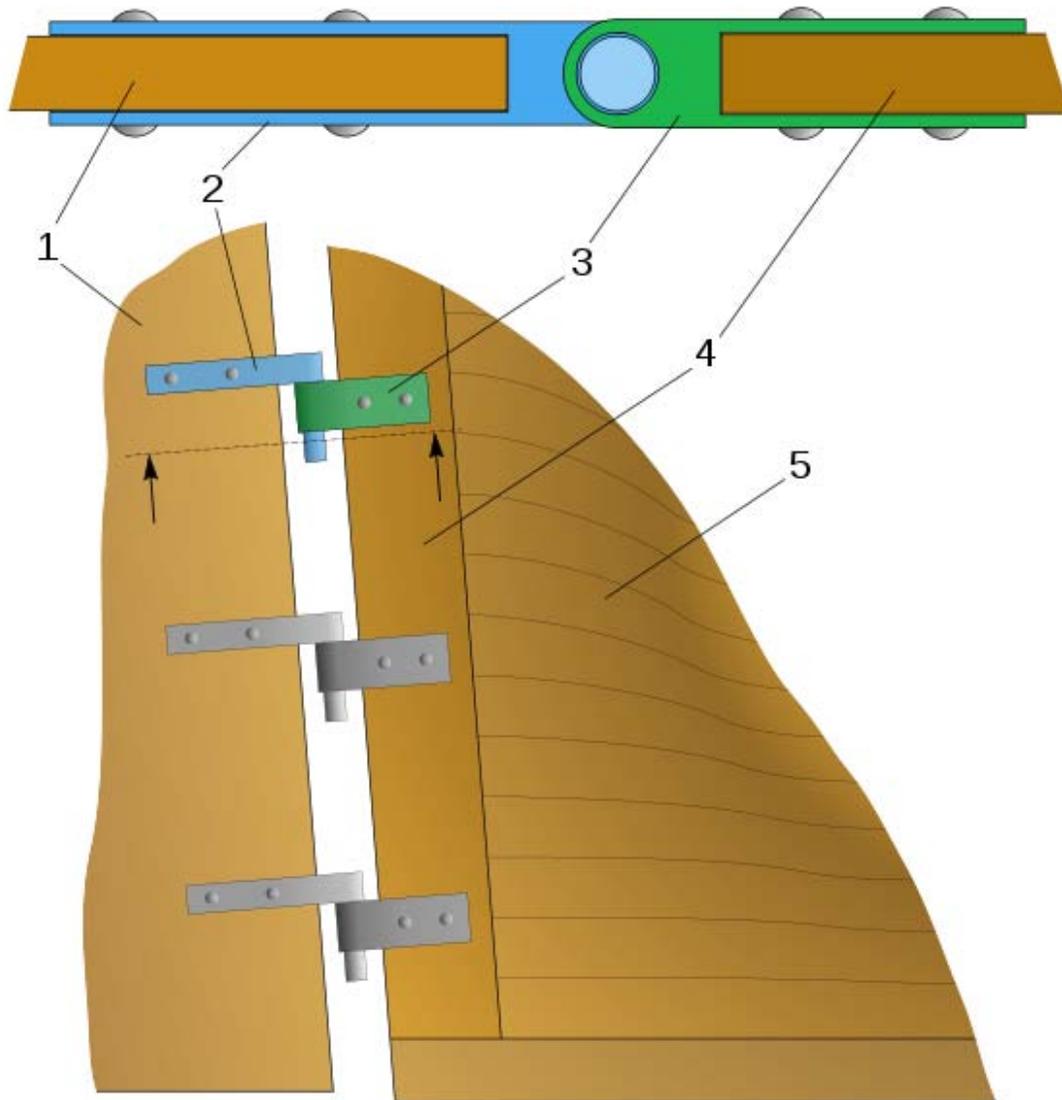
## **Navigation**

### **Dry Compass (12th)**

The first mention of the directional compass is in Alexander Neckam's *On the Natures of Things*, written in Paris around 1190. Either transmitted from China or the Arabs or an independent European innovation. Dry compass invented in the Mediterranean around 1300.

### **Astronomical compass (1269)**

The French scholar Pierre de Maricourt describes in his experimental study *Epistola de magnete* (1269) three different compass designs he has devised for the purpose of astronomical observation.



Scheme of a sternpost-mounted medieval rudder

### **Stern-mounted rudders (1180s)**

First depiction of a pintle-and gudgeon rudder on church carvings dating to around 1180. First appeared with cogs in the North and Baltic Sea, quickly spread to Mediterranean. The iron hinge system was the first stern rudder permanently attached to the ship hull and made a vital contribution to the navigation achievements of the age of discovery and thereafter.

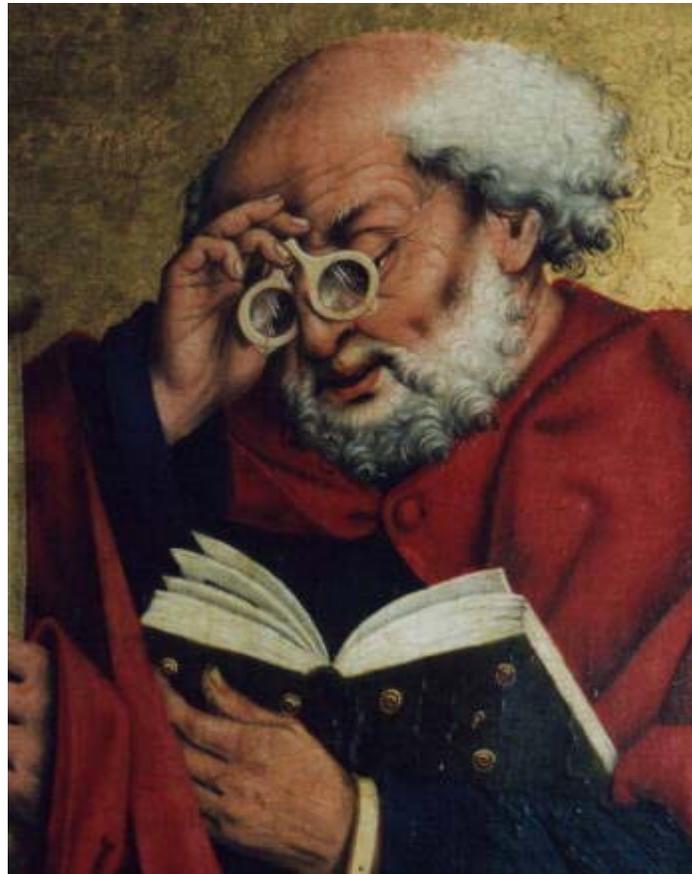
## Printing, paper and reading

### Movable type printing press (1440s)

Invented by Johannes Gutenberg. His great innovation was not the printing itself, but instead of using readily-carved plates as before, he used separate letters (*types*) from which the printing plates for pages were made up. This meant the types were recyclable and a page cast could be made up far faster than with readily-carved plates.

### Paper (13th)

Invented in China, transmitted through Islamic Spain to Europe in the 13th century where the papermaking processes were mechanized by water-powered mills and paper presses.



Reading Saint Peter with eyeglasses (1466)

### Spectacles (1280s)

European innovation. Florence, Italy. Convex lenses, of help only to the far-sighted. Concave lenses were not developed prior to the 15th century.

### **Watermark (1282)**

Medieval innovation to mark paper products and to discourage counterfeiting. First introduced in Bologna, Italy.

### **Science and learning**

#### **Arabic Numerals (13th c.)**

First recorded mention in Europe 976, first widely published in 1202 by Fibonacci with his *Liber Abaci*.

#### **University**

The first medieval universities were founded between the 11th and 13th century leading to a rise in literacy and learning. By 1500, the institution had spread throughout most of Europe and played a key role in the Scientific Revolution. Today, the educational concept and institution has been globally adopted.

### **Textile industry and garments**

#### **Functional button (13th)**

Buttons with buttonholes used to fasten or close garment, being the most convenient method before the introduction of the zipper, appear in the 13th century Germany as indigenous innovation. Became soon widespread with the rise of snug-fitting clothing.

#### **Horizontal loom (11th)**

Horizontal and operated by foot-treadles, faster and more efficient.

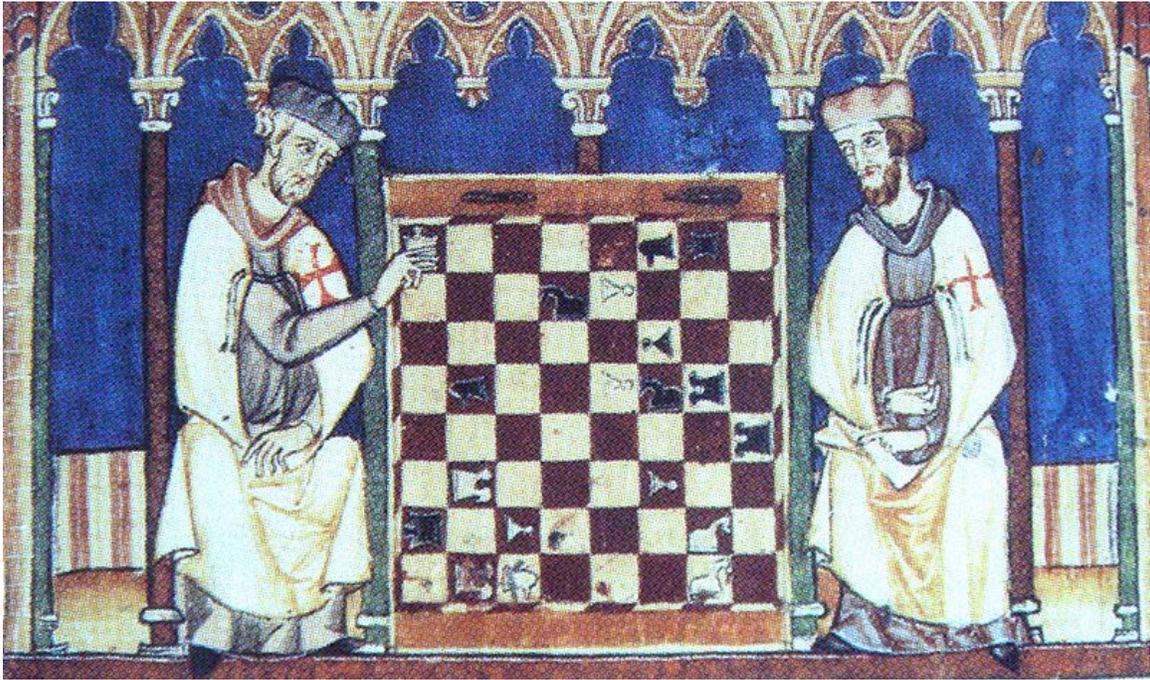
#### **Silk (6th)**

Manufacture of silk began in Eastern Europe in the 6th, in Western Europe in the 11th or 12th centuries. Imported over the Silk Road since antiquity. Technology of "silk throwing" mastered in Tuscany in the 13th century. The silk works used waterpower and some regard these as the first mechanized textile mills.

#### **Spinning wheel (13th)**

Brought to Europe probably from India.

## Miscellaneous



Knights Templar playing chess, *Libro de los juegos* (1283)

### **Chess** (1450)

The earliest predecessors of the game originated in 6th century AD India and spread via Persia and the Muslim world to Europe. Here the game evolved into its current form in the 15th century.

### **Forest glass** (ca. 1000)

Type of glass which uses wood ash and sand as the main raw materials and is characterised by a variety of greenish-yellow colours.

### **Grindstones** (834)

Rough stone, usually sandstone, used to sharpen iron. The first rotary grindstone (turned with a leveraged handle) occurs in the *Utrecht Psalter*, illustrated between 816 and 834. According to Hägermann, the pen drawing is a copy of a late antique manuscript. A second crank which was mounted on the other end of the axle is depicted in the *Luttrell Psalter* from around 1340.

**Liquor (12th)**

Alcohol distillation by way of Islamic alchemists, initially used as medicinal elixir. Popular remedy for the Black Death during the 14th century; "national" drinks like vodka, gin, brandy come into form.

**Magnets (12th)**

First reference in the *Roman d'Enéas*, composed between 1155 and 1160.

**Mirrors (1180)**

First mention of "glass" mirror in 1180 by Alexander Neckham who said "Take away the lead which is behind the glass and there will be no image of the one looking in."

**Illustrated surgical atlas (1345)**

Guido da Vigevano (ca. 1280–1349) was the first author to add illustrations to his anatomical descriptions. His *Anathomia* provides pictures of neuroanatomical structures and techniques such as the dissection of the head by means of trephination, and depictions of the meninges, cerebrum, and spinal cord.

**Quarantine (1377)**

Initially a 40-day-period, the Quarantine was introduced by the Republic of Ragusa as measure of disease prevention related to the Black Death. Later adopted by Venice from where the practice spread all around in Europe.

**Rat traps (1170s)**

First mention of a rat trap in the medieval romance *Yvain, the Knight of the Lion* by Chrétien de Troyes.

**Soap (9th)**

Soap came into widespread European use in the 9th century in semi-liquid form, with hard soap perfected by the Arabs in the 12th century.

# Military technologies

## Armor



Jousting armor commissioned by Maximilian I in 1494

### Plate armour (14th, late)

Apex of pre-industrial personal armour in terms of body protection and metallurgical skills involved. Large and complete full plates of armour appear by the end of the 14th century.

## **Cavalry**

### **Arched saddle (1050s)**

Enabled mounted knights to wield lance underarm and prevent the charge turning into an unintentional pole-vault. This innovation gave birth to true shock cavalry, enabling the knights to charge on full gallop, thus exceeding the shock value of the cataphracts.

### **Spurs (11th)**

Invented by the Normans, appearing at the same time as cantled saddle. Enabled the knight to control his horse with his feet instead of hands, replacing the whip and leaving his arms free. Rowel spurs familiar from cowboy films were already known in the 13th century. Gilded spurs were the ultimate symbol of the knighthood - even today someone is said to "earn his spurs" by proving his or her worthiness.

### **Stirrup (6th)**

Invented by the steppe nomads in what is today Mongolia and northern China in the 4th century and transmitted west. Appeared in Byzantium in the 6th, in the Carolingian Empire in the 8th century. Allowed mounted knight to wield sword and strike from a distance leading to a great advantage for mounted cavalry.

## **Gunpowder weapons**

### **Cannon (1324)**

Cannons are first recorded in Europe at the siege of Metz in 1324. In 1350 Petrarch wrote "these instruments which discharge balls of metal with most tremendous noise and flashes of fire...were a few years ago very rare and were viewed with greatest astonishment and admiration, but now they are become as common and familiar as any other kinds of arms."

### **Volley gun**

### **Corned gunpowder (14th, late)**

First practiced in Western Europe, corning the black powder allowed for more powerful and faster ignition of cannon. Also facilitated storage and transportation to operational area, thus constituting a crucial step in the evolution of gunpowder warfare.



Scottish bombard Mons Meg

### **Supergun** (14th, late)

Extant examples include the wrought-iron Pumhart von Steyr, Dulle Griet and Mons Meg as well as the cast-bronze Faule Mette and Faule Grete (all 15th century).

### **Mechanical artillery**

#### **Counterweight trebuchet** (12th)

Powered solely by the force of gravity, these catapults revolutionized medieval siege warfare and construction of fortifications by hurling huge stones unprecedented distances. Originating somewhere in the eastern Mediterranean basin, counterweight trebuchets were introduced in the Crusader states by the 1120s, Byzantium by the 1130s and in the Latin West by the second half of the century.

## **Missile weapons**

### **Longbow with massed, disciplined archery (13th)**

Having a high rate of fire and penetration power, the longbow contributed to the eventual demise of the medieval knight class. Used particularly by the English to great effect against the French cavalry during the Hundred Years' War (1337-1453).

### **Steel crossbow (14th, late)**

European innovation. Came with several different cocking aids to enhance draw power, making the weapons also the first hand-held mechanical crossbows.

## **Miscellaneous**

### **Combined arms tactics (1333)**

The battle of Halidon Hill 1333 was the first battle where intentional and disciplined combined arms infantry tactics were employed. The English men-at-arms dismounted beside the archers, combining thus the staying power of super-heavy infantry and striking power of their two-handed weapons with the missiles and mobility of the archers. Combining dismounted knights and men-at-arms with archers was the archetypal Western Medieval battle tactics until the battle of Flodden 1513 and final emergence of firearms.

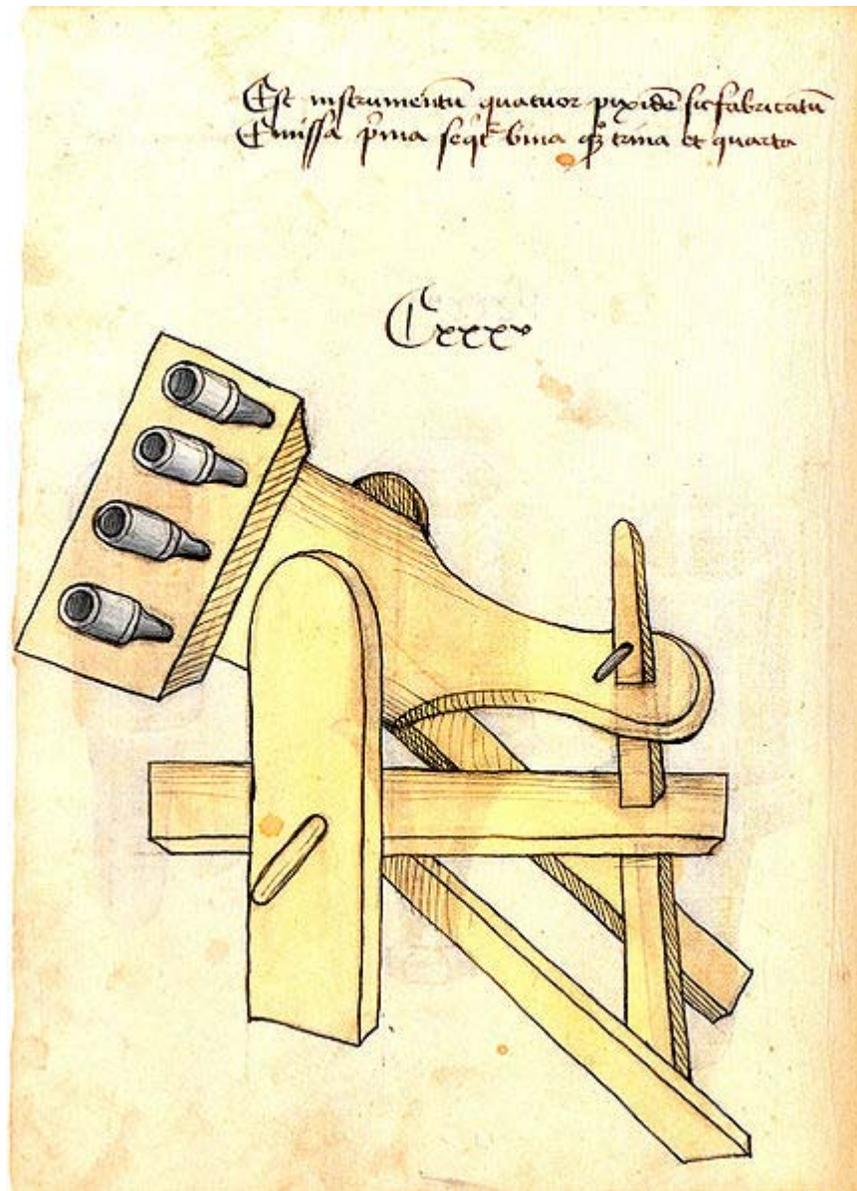
## Gallery



Longbowmen (ca. 1493)



Cranked rack-and-pinion device for cocking a crossbow (ca. 1493)



Organ gun in the *Bellifortis* (ca. 1405)

## Renaissance Technology

**Renaissance technology** is the set of European artifacts and customs which span the Renaissance period, roughly the 14th through the 16th century. The era is marked by profound technical advancements such as the printing press, linear perspective in drawing, patent law, double shell domes and Bastion fortresses. Sketchbooks from artisans of the period (Taccola and Leonardo da Vinci for example) give a deep insight into the mechanical technology then known and applied.

Renaissance science spawned the Scientific Revolution; science and technology began a cycle of mutual advancement.

## **Basic technology**

Some important Renaissance technologies, including both innovations and improvements on existing techniques:

- mining and metallurgy
- blast furnace enabled iron to be produced in significant quantities
- finery forge enabled pig iron (from the blast furnace) into bar iron (wrought iron)
- slitting mill mechanized the production of iron rods for nailmaking
- smelting increased the output of lead over previous methods (bole hill)

## 15th century

### Crank and connecting rod



Quelle: Deutsche Fotothek

Water-raising pump powered by crank and connecting rod mechanism (Georg Andreas Böckler, 1661)

The crank and connecting rod mechanism which converts circular into reciprocal motion is of utmost importance for the mechanization of work processes; it is first attested for Roman water-powered sawmills. During the Renaissance, its use is greatly diversified and mechanically refined; now connecting-rods are also applied to double compound cranks, while the flywheel is employed to get these cranks over the 'dead-spot'. Early evidence of such machines appears, inter alia, in the works of the 15th century engineers

Anonymous of the Hussite Wars and Taccola. From then on, cranks and connecting rods become an integral part of machine design and are applied in ever more elaborate ways: Agostino Ramelli's *The Diverse and Artifactitious Machines* of 1588 depicts eighteen different applications, a number which rises in the 17th century *Theatrum Machinarum Novum* by Georg Andreas Böckler to 45.

### Printing press



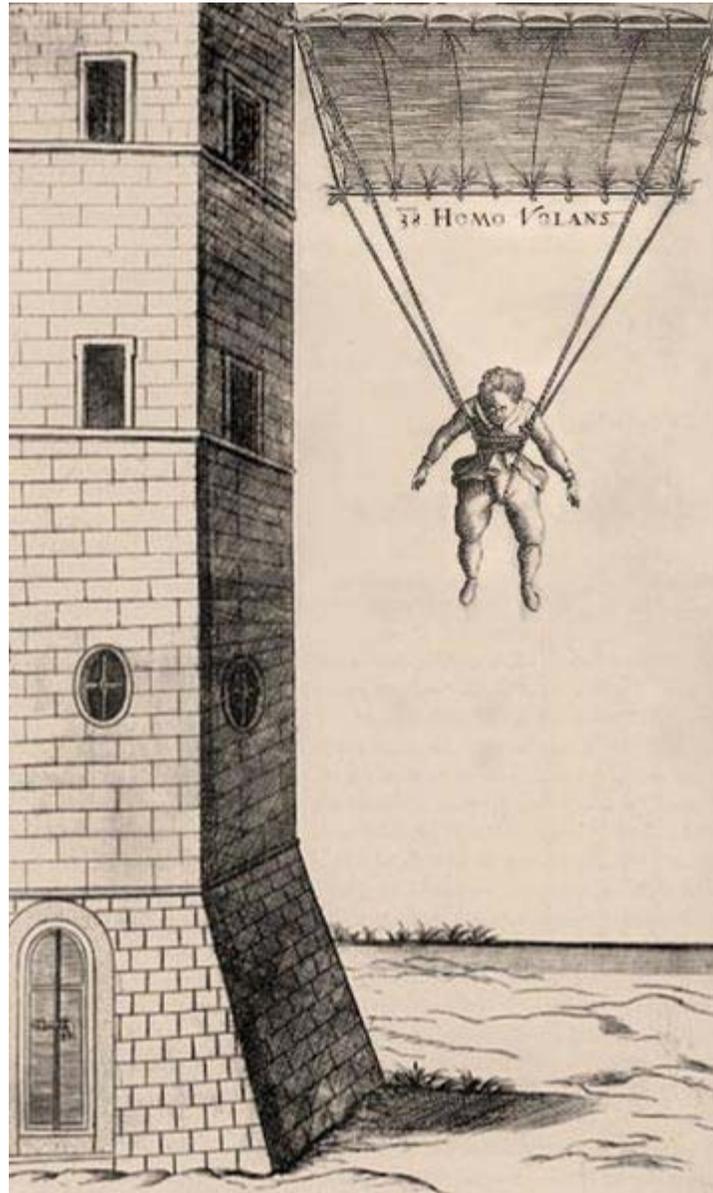
Two printers operating a Gutenberg-style printing press (1568). Such presses could make around 3.600 impressions per workday.

The invention of the printing press by the German goldsmith Johannes Gutenberg (1398–1468) is widely regarded as the single most important event of the second millennium,

and is one of the defining moments of the Renaissance. The Printing Revolution which it sparks throughout Europe works as a modern "agent of change" (Eisenstein) in the transformation of medieval society. The mechanical device consists of a screw press modified for printing purposes which can produce 3.600 pages per workday, allowing the mass production of printed books on a proto-industrial scale. By the start of the sixteenth century, printing presses are operating in over 200 cities in a dozen European countries, producing more than twenty million volumes. By 1600 their output had risen tenfold to an estimated 150 to 200 million copies, while Gutenberg book printing spread from Europe further afield.

The relatively free flow of information transcends borders and induced a sharp rise in Renaissance literacy, learning and education; the circulation of (revolutionary) ideas among the rising middle classes, but also the peasants, threatens the traditional power monopoly of the ruling nobility and is a key factor in the rapid spread of the Protestant Reformation. The dawn of the Gutenberg Galaxy, the era of mass communication, is instrumental in fostering the gradual democratization of knowledge which sees for the first time modern media phenomena such as the press or bestsellers emerging. The prized incunables, which are testimony to the aesthetic taste and high technical competence of Renaissance book printers, are one lasting legacy of the fifteenth century.

## Parachute



Veranzio's 1595 parachute design titled "Flying Man"

The earliest known parachute design appears in an anonymous manuscript from 1470s Renaissance Italy; it depicts a free-hanging man clutching a crossbar frame attached to a conical canopy. As a safety measure, four straps run from the ends of the rods to a waist belt. Around 1485, a more advanced parachute was sketched by the polymath Leonardo da Vinci in his *Codex Atlanticus* (fol. 381v), which he scales in a more favorable proportion to the weight of the jumper. Leonardo's canopy was held open by a square wooden frame, altering the shape of the parachute from conical to pyramidal. The Venetian inventor Fausto Veranzio (1551–1617) modifies da Vinci's parachute sketch by keeping the square frame, but replacing the canopy with a bulging sail-like piece of cloth.

This he realizes decelerates the fall more effectively. In 1617, Veranzio successfully tests his parachute design by jumping from a tower in Venice.

### **Mariner's astrolabe**

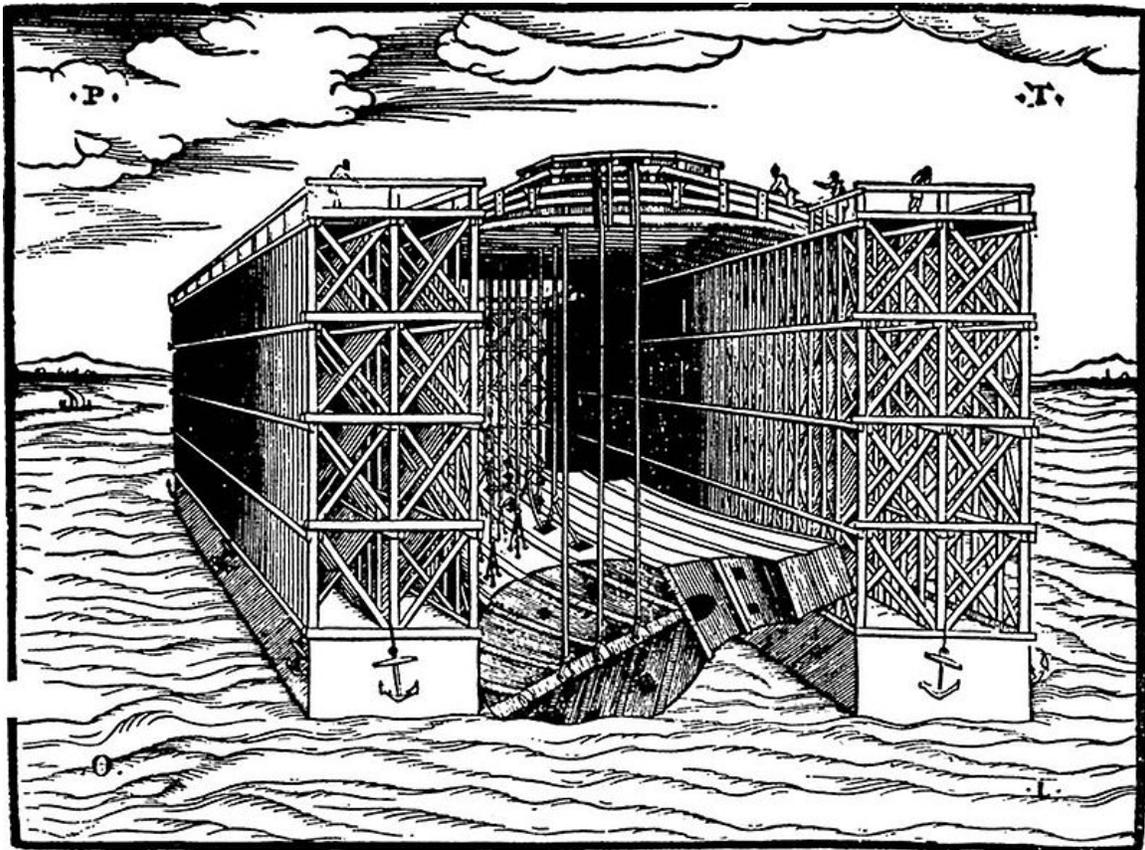
The earliest recorded uses of the astrolabe for navigational purposes are by the Portuguese explorers Diogo de Azambuja (1481), Bartholomew Diaz (1487/88) and Vasco da Gama (1497/98) during their sea voyages around Africa.

### **Dry dock**

While dry docks were already known in Hellenistic shipbuilding, these facilities were reintroduced in 1495/96, when Henry VII of England ordered one to be built at the Portsmouth navy base.

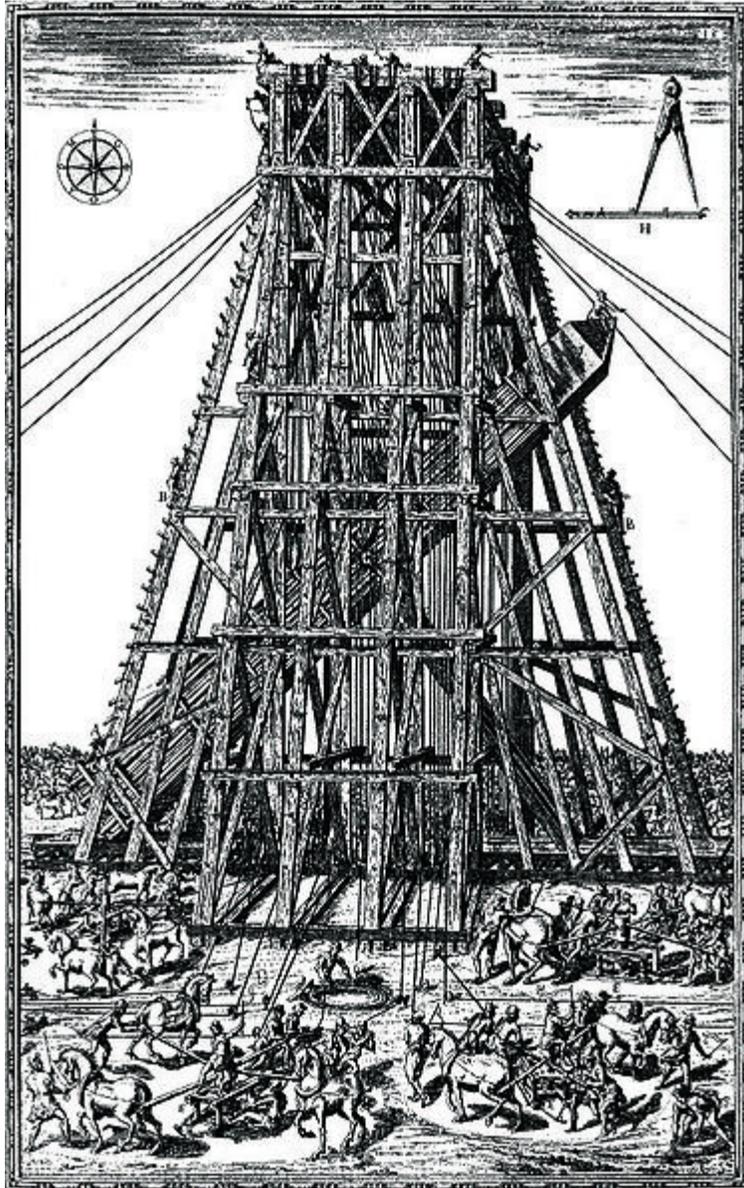
## **16th century**

### **Floating dock**



Floating dock at Venice (1560)

The earliest known description of a floating dock comes from a small Italian book printed in Venice in 1560, titled *Descrittione dell'artifitiosa machina*. In the booklet, an unknown author asks for the privilege of using a new method for the salvaging of a grounded ship and then proceeds to describe and illustrate his approach. The included woodcut shows a ship flanked by two large floating trestles, forming a roof above the vessel. The ship is pulled in an upright position by a number of ropes attached to the superstructure.



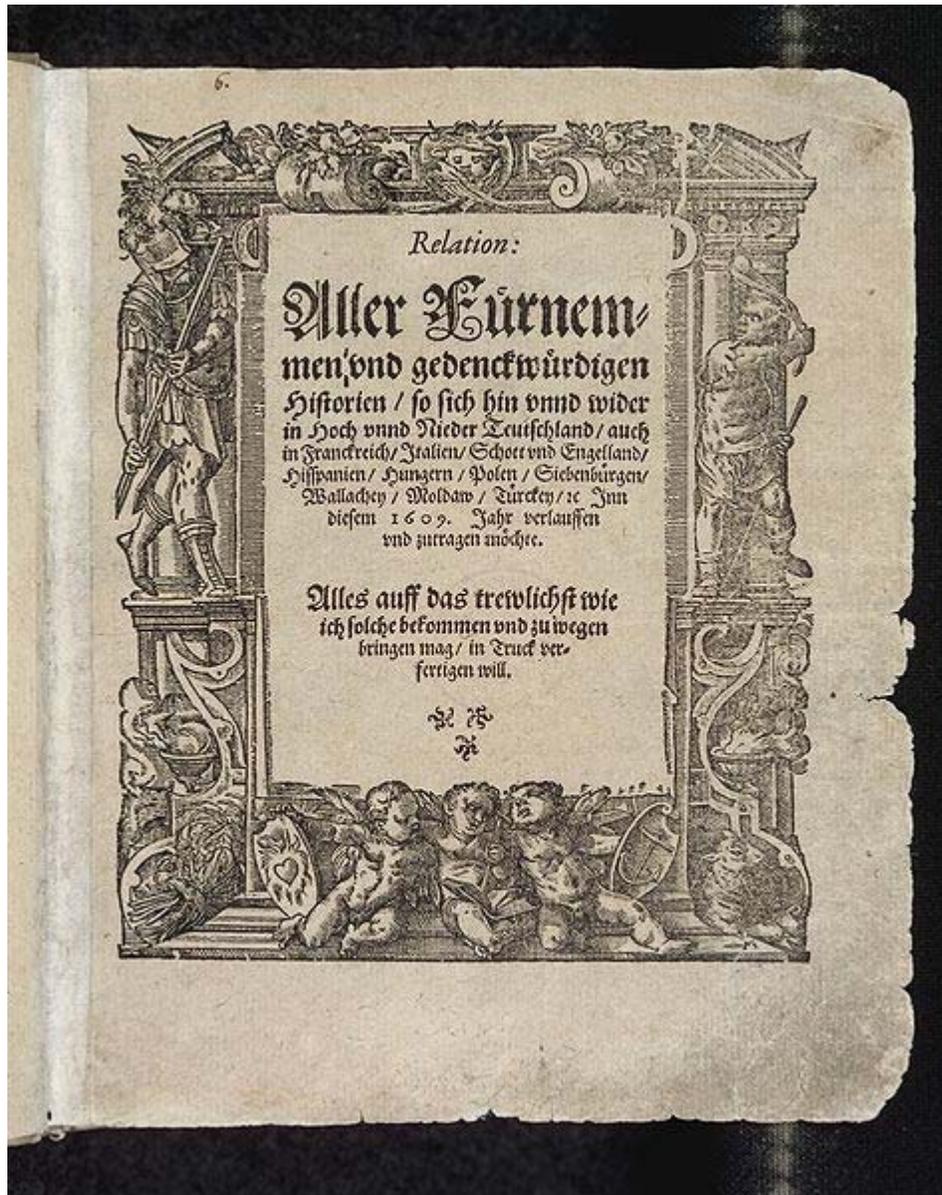
Relocation of the Vatican Obelisk, Rome, by Domenico Fontana (1586)

## Lifting tower

A lifting tower was used to great effect by Domenico Fontana to relocate the monolithic Vatican obelisk in Rome. Its weight of 361 t was far greater than any of the blocks the Romans are known to have lifted by cranes.

## Early 17th century

### Newspaper



Title page of the *Relation* (1609), the earliest newspaper

The newspaper is an offspring of the printing press from which the press derives its name. The 16th century sees a rising demand for up-to-date information which can not be covered effectively by the circulating hand-written newsheets. For "gaining time" from the slow copying process, Johann Carolus of Strassburg is the first to publish his German-language *Relation* by using a printing press (1605). In rapid succession, further German newspapers are established in Wolfenbüttel (*Avisa Relation oder Zeitung*), Basel, Frankfurt and Berlin. From 1618 onwards, enterprising Dutch printers take up the practice and begin to provide the English and French market with translated news. By the mid-17th century it is estimated that political newspapers which enjoyed the widest popularity reach up to 250,000 readers in the Holy Roman Empire, around one fourth of the literate population.

## **Tools, devices, work processes**

### **15th century**

#### **Cranked Archimedes screw**

The German engineer Konrad Kyeser equips in his *Bellifortis* (1405) the Archimedes screw with a crank mechanism which soon replaces the ancient practice of working the pipe by treading.

#### **Cranked reel**

In the textile industry, cranked reels for winding skeins of yarn were introduced in the early 15th century.

#### **Brace**

The earliest carpenter's braces equipped with a U-shaped grip, that is with a compound crank, appears between 1420 and 1430 in Flandres.

#### **Cranked well-hoist**

The earliest evidence for the fitting of a well-hoist with cranks is found in a miniature of c. 1425 in the German *Hausbuch of the Mendel Foundation*.

#### **Paddle wheel boat powered by crank and connecting rod mechanism**

While paddle wheel boats powered by manually turned crankshafts were already conceived of by earlier writers such as Guido da Vigevano and the Anonymous Author of the Hussite Wars, the Italian Roberto Valturio much improves on the design in 1463 by devising a boat with five sets of parallel cranks which are all joined to a single power source by one connecting rod; the idea is also taken up by his compatriot Francesco di Giorgio.

### Rotary grindstone with treadle

Evidence for rotary grindstones operated by a crank handle goes back to the Carolingian *Utrecht Psalter*. Around 1480, the crank mechanism is further mechanized by adding a treadle.

### Geared hand-mill

The geared hand-mill, operated either with one or two cranks, appears in the 15th century.

### 16th century



German grenade muskets from the 16th century (the two upper ones)

### Grenade musket

Two 16th century German grenade muskets working with a wheellock mechanism are on display in the Bayerisches Nationalmuseum, Munich.

## Technical drawings of artist-engineers

The revived scientific spirit of the age can perhaps be best exemplified by the voluminous corpus of technical drawings which the artist-engineers left behind, reflecting the wide variety of interests the Renaissance Homo universalis pursued. The establishment of the laws of linear perspective by Brunelleschi gave his successors, such as Taccola, Francesco di Giorgio Martini and Leonardo da Vinci, a powerful instrument to depict mechanical devices for the first time in a realistic manner. The extant sketch books give modern historians of science invaluable insights into the standards of technology of the time. Renaissance engineers showed a strong proclivity to experimental study, drawing a variety of technical devices, many of which appeared for the first time in history on paper.

However, these designs were not always intended to be put into practice, and often practical limitations impeded the application of the revolutionary designs. For example, da Vinci's ideas on the conical parachute or the winged flying machine were only applied much later. While earlier scholars showed a tendency to attribute inventions based on their first pictorial appearance to individual Renaissance engineers, modern scholarship is more prone to view the devices as products of a technical evolution which often went back to the Middle Ages.

Technology	Date	Author	Treatise	Comment
Pile driver	1475	Francesco di Giorgio Martini	<i>Trattato di Architettura</i>	Drawing of such a device whose principle must be according to the Brazilian historian of technology Ladislao Reti "considered original with Francesco".
Centrifugal pump	1475	Francesco di Giorgio Martini	<i>Trattato di Architettura</i>	Water or mud-lifting machine "that must be characterized as the prototype of the centrifugal pump".