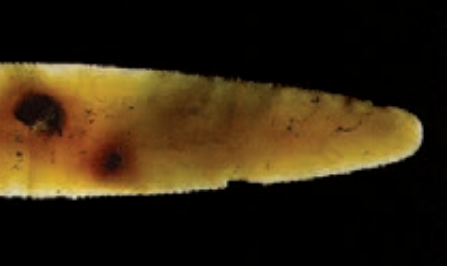
Shobhit Mahajan

THE STORY OF INVENTIONS

FROM ANTIQUITY TO THE PRESENT

h.f.ullmann



PREHISTORIC TIMES

DEVELOPING TOOLS (UP TO 4000 BC)

Ancient Egyptian flint tool

Pre-dynastic Egypt had a well-developed material culture. The burial sites included fine pottery with representational designs, stone vases and mace heads. Cosmetic palettes with elaborate designs were also in use. Flint was worked with extraordinary skills into making many implements. Ceremonial knives were made from flint, a custom which carried over to the dynastic times. This finely worked flint implement is an example of the highly developed skills in working with stone. (Egypt; Pre-dynastic; Ashmolean Museum, Oxford)

EVOLUTION OF HUMANS

It is believed that the earliest human beings, or Homo sapiens, evolved about 200,000 years ago somewhere in Africa. These belonged to the human tribe Hominini, which had developed from some ape-like species in the Pliocene Epoch, 5.3 to 1.8 million years ago. There is no general agreement on which ape-like species gave rise to the early hominins but the fact that humans are related to apes is well-established and accepted.

The evolution of ape-like species to hominins was accelerated by the enormous climatic changes during the preceding Miocene Epoch, 11 to 5.3 million years ago. The latter part of this epoch saw a period of glaciation which led to major disturbances in the ecology of the earth. These disturbances included changes in the habitats by advancing glaciers—shifting of ocean currents and drying of vast plains. The evergreen forests were replaced by open spaces with shrubs and grass, and this provided the impetus for many evolutionary adaptations in the flora and fauna of the time. The shift from the dense forests to the drier savanna was responsible for major evolutionary adaptations in hominins. The most significant of these was bipedalism, or an upright stance. Bipedalism essentially freed hands; free hands could be employed to grasp and make tools, among other things.

Tools

The earliest fossil evidence of tool-making is from around 2.6 million years ago. These were simple tools made from stone; so this period in history is called the Stone Age. This is not to say that tools were not made before this; they possibly were, but in the absence of evidence it is conjectured that they were made of wood, bone, leaves or even grass—materials that do not survive the vicissitudes of time. There is evidence in the form of chimpanzees and orangutans using stems, vines and even stones (to break open hard fruits or bones) as tools to get food.

The earliest tools—chipped flakes made of flint and other stones—date back to the Paleolithic period, a term used to describe the early Stone Age when humans made a living by hunting animals and gathering nuts and berries (about 2.5 to 0.2 million years ago). These early tools were possibly made by hammering a pebble of flint—or any suitable, easily available fine-grained rock—with another stone and detaching a series of flakes till a jagged cutting edge was achieved. Such sharp-

Periods in prehistory are defined by a geologic timescale. These periods are marked by changes in the environment, which in turn led to the diversification of the flora and fauna, and several evolutionary adaptations.

5.3 to 1.8 million years ago: Pliocene Epoch
This period was characterized by cool and dry climate, and large mammals. Australopithecines, the earliest hominins, developed in this period. Important inventions included rudimentary stone tools.

1.8 million to 11,500 years ago: Pleistocene Epoch
Referred to as the Great Ice Age, this period is recognized for glaciation or development of large ice-sheets. Many large mammals flourished and later became extinct in this epoch. The most significant development was the evolution of modern humans.

1.5 million years ago: Acheulean Stone Industry—hand axes made with stone in many areas of the world.

500,000 years ago: Use of fire.

200,000 years ago: Emergence of Homo sapiens.

50,000 years ago: Bone, antler tools. Microliths make their appearance in stone tools.

12,000 years ago: Pottery.

11,500 years ago: Beginning of Holocene Epoch
This epoch marks the beginning of an interglacial period. The withdrawal of the ice-sheets to their present positions and increase in precipitation led to the rise of human civilization.

9000 BC: Domestication of sheep.

9000 BC: Use of sun-dried bricks for making houses in Jericho.

8000 BC: First use of copper.

7000 BC: Beginnings of agriculture. Wheat, barley and pea domesticated in some places. By 7000 BC, there were farming communities in the Middle East, Greece, Anatolia, Crete as well as the western fringes of the Indus Valley. Agriculture also spread through south and central Europe.

Human ancestors using stone tools for hunting

7000 BC: Domestication of rice and millet in China.

6000 BC: Molded bricks used on the Anatolian plateau.

4500 BC: Beginning of the pre-dynastic period in Egypt.

4000 BC: First attempts at producing synthetic material—Egyptian faience.

4000 BC: Pottery kilns come into use, making it possible to produce fired pottery on a large scale.

4000 BC: First use of a seal—small circular discs of fired clay or stone with an impression.

Other Ancient Cultures

ANCIENT CHINA

The period from 4000 BC to 1000 AD was also the time when another great civilization was born and prospered far away from the Levant and Europe. The river valleys of Huang Ho and Yangtze rivers saw the birth and maturing of one of the most technologically advanced civilization—China. As early as second millennium BC, the Chinese had a highly developed writing system.

The first millennium BC saw the emergence of the Chinese practice of acupuncture for the treatment of various diseases, though some form of acupuncture was practised even in the early Bronze Age. Chinese medicine, which developed independently of the Greek and Indian traditions, was codified toward the end of the first millennium BC.

The Chinese, like other ancient cultures, were very interested in astronomy and astrology. They developed improved sundials to keep time, and sometime in the early first millennium BC, developed the abacus for counting. The first systematic observations of comets as well as detailed descriptions of planetary positions are recorded during this period.

mention of the use of saltpeter (potassium nitrate), charcoal and sulfur to manufacture the substance. Gunpowder, along with paper, printing and the magnetic compass, comprise the "four great inventions" of ancient China.

Although papyrus was used by the Egyptians much earlier, the Chinese were the first to make true paper from pulp around 100 AD. This was made by Cai Lun, a court official, with mulberry bark, old rags and other fibers. In a couple of hundred years, its use became widespread for writing. By the seventh to eighth century AD, paper bags were used for storing tea and as toilet paper. Paper-making reached central Asia by the eighth century and soon was prevalent all over the Caliphate.

Printing, the other great invention, seems to have been developed by the Japanese who used stone blocks to print prayer books in 760 AD. But it was the Chinese who by the ninth century had perfected the art of woodblock printing and, by the turn of the millennium, had even experimented with some kind of movable type made from ceramic. The type was unsuitable since the number of characters in the Chinese language were too many! The *Diamond Sutra* was the first printed book. Made from seven strips of paper joined together with an illustration on the first sheet, the 16-ft (5-m) long scroll was printed in 868 AD. Being the first to introduce paper and printing, the Chinese also invented paper money as early as the ninth century AD.

A woodblock printed version of the *Diamond Sutra*

The *Diamond Sutra*—the world's earliest surviving printed book—consists of individual sheets of printed text and a frontispiece illustrating the Buddha surrounded by acolytes and disciples. (China; Tang dynasty/868 AD; British Library, London)

In the field of military technology, the Chinese had developed and perfected several weapons many centuries before their appearance in the West. The crossbow was used by the Qin dynasty in the third century BC, and many were buried with the famous terracotta army in the tomb of the Qin emperor.

The military invention which changed the course of human history—gunpowder—was developed in the fourth century AD. There are indications of experimenting with various chemicals similar to those used for gunpowder in earlier texts, but it was in 300 AD that there was the first definitive

In the field of metallurgy, specifically iron-making, the Chinese took a totally different route than the other cultures. Elsewhere, iron ore was first reduced to a bloom which was then hammered into wrought iron. The hammering forced the impurities out of the bloom. In contrast, the Chinese went straight from the iron ore to cast iron, that is, molten metal which could be cast into molds. This was possible

EARLY MODERN

DISCOVERY AND EXPLORATION (1400–1700)

Map of Sao Jorge da Mina

In the quest to find a new sea route to the rich Cathay, the Genovan navigator and explorer Christopher Columbus led four trans-Atlantic voyages. Columbus' expeditions were financed by the Spanish queen and a consortium of Italian bankers. He landed in what is now the West Indies in 1492 on his first voyage. His subsequent trips were aimed at the conversion of pagans to Christianity and the colonization of the New World. Sao Jorge de Mina, on the Portuguese Gold Coast, was visited by him on his fourth and final voyage.

RENAISSANCE

The High Middle Ages in Europe in the 13th and 14th centuries had set the stage for a period of intense change in the 15th century. This change, called Renaissance or rebirth, was characterized by a reawakening of interest in the classical learning and scholarship.

The next 300 years saw many profound changes in the economy, polity and the intellectual landscape of Europe. The political and economic center of power that had moved east in the previous centuries moved back to Europe. The revival of Europe after centuries of stagnation was to continue beyond the Renaissance period.

This was the period of exploration of new geographies (the Americas were "discovered" and colonized by the Europeans), of the emergence of new techniques and instruments to study the heavens, of inventions or innovations in technology and also a decline in the feudal structure and growth of commerce. There were also many changes in the religious configuration of Europe that saw the rise of Protestantism and the reaction of the Catholic Church to these events.

One fundamental difference between the Renaissance period and the previous centuries was that the intellectual leadership was taken over by secular people. In the period from 12th to 14th centuries, it was the clerics who had dominated the scholarly activities and this, as seen, had led to the Scholastic philosophy. The 15th century saw the rise of Humanism, an intellectual movement (characterized by the rediscovery and study of the Greek and Roman cultures) which started in Italy. The movement and the revival it brought about spread all over Europe in the next century, in part because of the invention of printing and spread of texts.

The Humanists played an important role in helping Europe free itself from religious orthodoxy and to gain new confidence in human endeavor in the field of ideas and technology. Since the Humanists were not clerics but professionals like lawyers and notaries, they emphasized engagement with society rather than monastic life and stressed the unique capabilities of humans. They advocated a reading of the ancient texts and a systematic enquiry into the physical world in order to understand it and master it.

1403: The Capital of the Ming dynasty moved from Nanjing to Beijing.

1429: Joan of Arc ends the Siege of Orleans.

1453: Fall of Constantinople and the Byzantine Empire.

1455: The Gutenberg Bible printed.

1469: Marriage of Ferdinand and Isabella of Spain creates a united Spanish empire.

1492: Christopher Columbus lands in the New World in his search for the sea route to the East. He founds the first Spanish colony in Hispaniola.

1498: Vasco da Gama discovers the sea route to India via the Cape of Good Hope.

1500: The Incas complete the construction of Machu Pichu.

1513: The Portuguese land in Macau during the Ming Dynasty.

1515–1518: The Ottomans capture Anatolia, Egypt and Arabia.

1517: Luther posts his 95 theses in Germany, beginning the Reformation.

1520: The Spanish conquistador Herman Cortes lands in Mexico. Over the next 60 years, the Spaniards conquered all of Mesoamerica, destroying all the native cultures.

1519–22: A Spanish expedition, led by the Portuguese Ferdinand Magellan, circumnavigates the world, traveling west from Europe, around the southern tip of South America, across the Pacific.

Old sextant on display at the Arsenale in Venice

1526: Start of the Mughal rule in India with the victory of the Mughal emperor Babur over the Lodhis.

1531: The Church of England breaks away from the Roman Catholic Church. The first stock exchange at Antwerp is founded.

1532: Pizarro leads the conquest of the Inca kingdom. After fighting for over four decades, Francisco Toledo finally executed the last of the Incas, Tupac Amaru, in 1572.

1543: The Polish astronomer Nicolaus Copernicus publishes his heliocentric theory of the universe.

1556: Akbar, the Great Mughal Emperor, is crowned King of India.

1582: The first map made with the Mercator projection.

1582: Pope Gregory XIII reforms the Julian calendar by replacing it with the more accurate Gregorian calendar. It is adopted in several European countries.

1589: Galileo Galilei propounds his law of falling bodies which contradicts Aristotle's ideas about gravity.

1600: Potatoes introduced in Europe from the Andes.

1608: The first telescope is built. Galilei improves the telescope to observe the heavens.

1612: The English establish their first factory in India at Surat.

1613: Start of the Romanov dynasty in Russia.

1614: John Napier publishes the first logarithm tables as an aid to calculations.

1620: The *Mayflower* sets sail for North America and the Puritans establish a colony at Plymouth.

1628: William Harvey explains the circulation of blood in the body.

1637: René Descartes invents analytical geometry.

1643: Evangelista Torricelli uses the barometer to measure atmospheric pressure.

1652: Dutch colony established at the Cape of Good Hope in South Africa.

1656: Christiaan Huygens patents the pendulum clock.

1665: Robert Hooke uses a crude microscope to discover cells.

1687: Isaac Newton discovers calculus and the laws of gravitation.

1690: The British establish a trading post at Calcutta.

Communications

The field of communications saw revolutionary developments in the 19th century. The invention of the movable type and the printing press by Gutenberg had already spurred the growth of printing. Developments in printing technology and papermaking during the 18th and 19th centuries were crucial to further enhance the reach of the printed word. The high-speed rotary press was an important innovation which speeded printing enormously. In 1884, Ottmar Mergenthaler in the US patented the linotype—a typesetting machine which allowed casting of complete lines rather than individual letters, thus speeding up the composing process significantly.

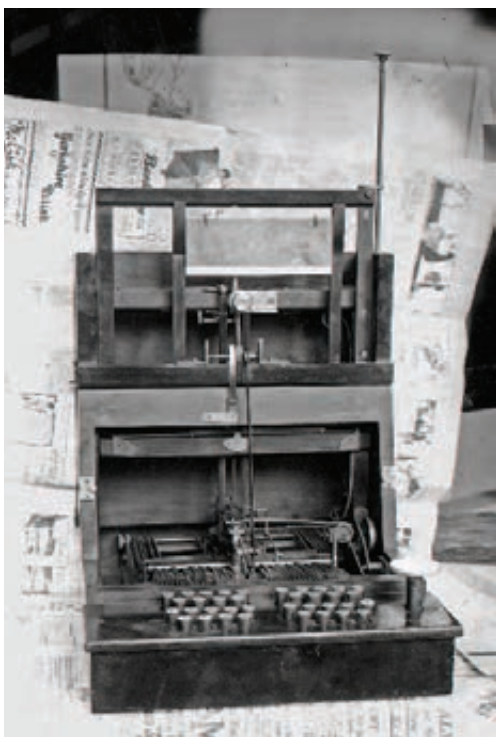
Typewriters were invented in 1867 by the American inventor Christopher Sholes who improved upon his initial design in 1868 and got a patent in the same year. In 1873, he started collaborating with E. Remington and Sons for the commercialization of typewriters, and soon they were being used all over the US.

In all this mechanization, writing technology also underwent some changes. The fountain pen was invented in 1884 to replace the instruments which had to be dipped in the inkwell. Invented by Lewis Waterman, the fountain pen used the capillary action for the ink to flow to the nib. This was followed by the development of the ballpoint pen in 1895, though its design was not very satisfactory. A successful design was introduced by László Biró, a Hungarian, in 1931.

But the biggest revolution was in imaging. The invention of photography was in some senses as important as the introduction of movable type a few centuries ago. In 1820s, Joseph Nicéphore Niépce took the first photograph using a pewter plate with bitumen. Over the next few years, his partner Louis Daguerre improved upon the photographic process by using light-sensitive silver chemicals, and by the 1850s, daguerreotypes were being used extensively.

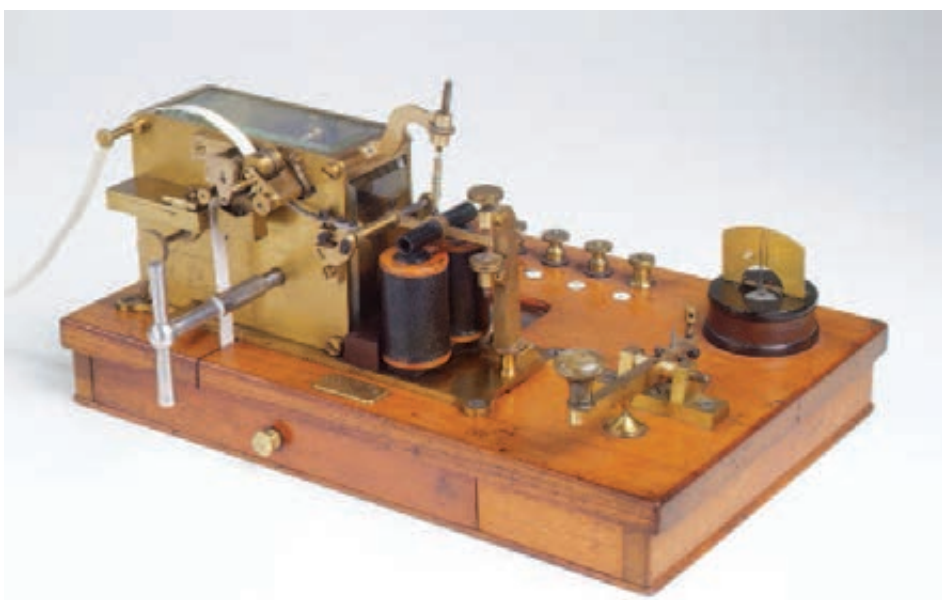
In 1880, the American inventor George Eastman patented a process of making dry plates for taking pictures. He also introduced easy to use Kodak cameras in 1888—these were handheld cameras with a roll of film. This was a major step in popularizing photography. The film was based on celluloid, a material invented in 1856 by the Englishman Alexander Parkes but not popularized till the 1870s.

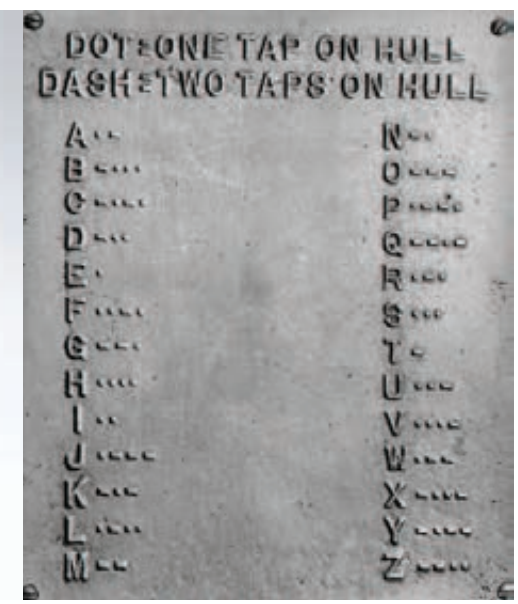
The telegraph was another invention which changed communications in a big way. Optical telegraphy, most notably the semaphore system invented in France in the 18th century, was already in use when electrical telegraphy was invented. The work done in the production of electricity and



Early typewriter

After many unsuccessful attempts in the 19th century to make a practical typewriter, the American inventor Christopher Sholes invented a writing machine whose speed exceeded that of a pen. It was a crude machine which went through several improvements in subsequent years before the first typewriters were sold in 1874. This 1866 model was a forerunner of the typewriter patented by Sholes in 1868.





Morse code

The American painter Samuel Morse developed the first electric telegraph and the Morse code. A system of dots and dashes was used extensively throughout the world for telegraphy. The words of the first message sent by Morse code—from Baltimore to Washington in 1844—were: "What hath God wrought!" Seen here, a telegraph receiver printing Morse code onto ticker tape and a slate displaying the code.

THE WAR PERIOD

DEVELOPMENT AND DEVASTATION (1914–1950)

Heralding the nuclear age

With the development and use of fission weapons in 1945, military warfare underwent a qualitative change. The post-World War II political scenario was defined by the cold war and competitive weapons development between the US and the Soviet Union. Bigger, more effective nuclear weapons and delivery systems were developed over the next few decades. Operation Ivy Mike in 1952, the first test of a fusion bomb by the US, generated a white mushroom cloud, shown here.

THE WORLD WARS

The Industrial Revolution in Europe accelerated the pace of innovations in the 19th century. The rapid technological advancement—new sources of power (steam and electricity), new means of transportation (railways, automobile, aircraft, steamships), faster means of communication (telegraph, telephone) and more effective medical interventions (vaccination, antiseptics) were invented—made Europe the colossal economic and military leader. Subsequently, rising economies like North America and Japan, and nationalist movements in Europe's colonies began to challenge Europe's dominance, leading to World War I.

World War I resulted in the Great Depression of the 1930s. As governments of the European countries struggled to find their way out of the economic dip, the US, the Soviet Union and Japan emerged as new economic and military powers, ending the dominance of Europe. With the power equation changing after World War I, one of the defining characteristics of this period was the rise of the US as the industrial powerhouse.

The 20th century, which has been sometimes hailed as the American Century, saw the emergence of the US as the leading industrial, economic and military power during the period between the two world wars. There were several reasons why this has happened. The US was possibly the only big power which had remained relatively unaffected by World War I. The economies of Europe were still recovering from the huge costs of the four-year long devastating war. Another factor which contributed to the success of the US was the exploitation of natural resources of this continent-sized country as well as a massive increase in productivity, in both agriculture and industry. American entrepreneurs were especially good at assimilating technological innovations and converting them into successful

1913: Thermal cracking used for refining crude petroleum.

1914: World War I starts with wars between the major European powers but eventually engulfs the whole world.

1916: Einstein publishes his General Theory of Relativity.

1917: The October Revolution in Russia overthrows the Romanov dynasty and the establishment of the Soviet state. America enters the world war.

1918: World War I ends with the defeat of Germany. Weimar Republic established in Germany.

1920: In the aftermath of World War I, the great powers agree to create a League of Nations to keep peace. Women get the right to vote in the US.

1921: Founding of the Communist Party of China. Coup in Iran establishes Reza Khan as the king. Insulin discovered.

1922: Technicolor is introduced in movies.

1922: Benito Mussolini comes to power in Italy. Joyce publishes *Ulysses*. Ireland gains independence.

1923: Kemal Ataturk founds the Republic of Turkey after the fall of the Ottoman Empire. De Broglie proposes the wave-particle duality.

1925: Hitler publishes *Mein Kampf*.

1926: Schrödinger presents a self-consistent theory of quantum mechanics. Goddard flies the first liquid-fueled rocket. First movie with a sound track released.

1927: Lindberg's nonstop solo trans-Atlantic flight. Heisenberg formulates his Uncertainty Principle in quantum mechanics.

1928: Discovery of penicillin.

1929: Edwin Hubble discovers the expansion of the universe. Stock Markets crash leading to the Great Depression.

1930: Discovery of Pluto.

1931: The world's tallest building, The Empire State Building, built in New York.

1932: Establishment of the Kingdom of Saudi Arabia. Aldous Huxley publishes *Brave New World*.

1933: Nazis come to power in Germany and start a systematic campaign to exterminate the Jews in Germany. Start of the New Deal in the US. Roosevelt becomes president of the US.

1934: The Long March, massive military retreat of the Communist Army in China, begins.

1935: Mussolini captures Ethiopia.

1936: Start of the Spanish Civil War. Beginning of the Stalinist purges.

1937: Japanese forces attack China. Japanese occupation of China begins.

1938: Leaders of Britain, Germany, France and Italy sign the Munich Pact. Hitler annexes Austria. Volkswagen introduces the Beetle.

Volkswagen Beetle, introduced in Germany in 1938, was a bestseller

1939: Germany invades Poland, starting World War II. Russia and Germany sign a non-aggression pact. Russia invades Finland.

1940: Battle of Britain. Nazis invade Denmark, Belgium and France.

1941: Japanese aircraft attack Pearl Harbor. US enters the war. Atlantic Charter signed between the US and Britain. Germany attacks Soviet Union. Siege of Leningrad.

1942: Japan occupies Indonesia and Manila. Quit India movement started to end the British Rule in India. Japanese forces attack Burma. German forces defeated at Stalingrad. The first self-sustaining controlled nuclear reaction initiated.

1943: Italy surrenders to the Allies. Teheran Conference between Roosevelt, Churchill and Stalin to plan the defeat of Hitler.

1944: Allied forces land in Normandy. London bombarded by Germany with V-2 rockets.

1945: Yalta conference to decide the fate of post-war Europe. Dresden bombings. Dropping of atomic bombs on Hiroshima and Nagasaki. World War II ends with the defeat of Japan and Germany. The development of nuclear weapons begins.

1946: First meeting of the United Nations. First computer is made.

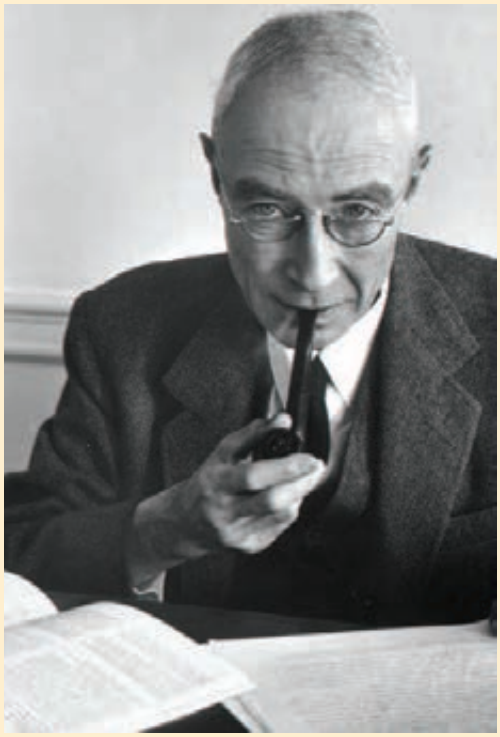
1947: India gains independence. British India is partitioned into India and Pakistan. Polaroid camera and transistor are invented.

1948: Beginning of the Marshal Plan, a massive reconstruction effort for Europe. Independent state of Israel comes into being.

1949: NATO formed. People's Republic of China is born. Sukarno takes over as president of Indonesia. First civilian jet airplane takes off.

1950: India becomes a Republic. Beginning of the Korean War.

R. Oppenheimer and How Inventions Shape History



J. Robert Oppenheimer

The brilliant physicist Robert Oppenheimer headed the Manhattan Project to develop the first atomic bomb. The Manhattan project was a huge organizational and scientific challenge which involved coordinating the work of hundreds of scientists and thousands of engineers, spread over many locations.

The 1930s was an eventful decade in the history of physics. In 1934, Irène and Frédéric Joliot-Curie had discovered that radioactivity, the spontaneous emission of particles by certain heavy elements, could also be induced artificially using alpha particles. Their work was followed up by the Italian scientist Enrico Fermi who for the first time showed that neutrons could be used for this purpose. In 1938, German scientists Otto Hahn and Fritz Strassmann showed that bombarding uranium with neutrons produced barium. Their work was interpreted by Otto Frisch as splitting of the uranium nucleus by the neutron into smaller constituents with the release of energy. Nuclear fission, as this process is known, was thus shown to be possible.

The importance of this development has been observed by the scientists. The rise of Nazism had forced many of the scientists from Europe to emigrate to the US and Britain to escape persecution. By 1938, it was clear to most scientists that the Nazis were actively carrying out research to realize the destructive potential of nuclear fission. Some of them, including Einstein, wrote to President Roosevelt about such a possibility and the devastating consequences of a Nazi fission bomb. The Manhattan Project, a massive enterprise to construct an atomic weapon before the Nazis—employing over 100,000 people at more than 30 locations—was a result of these developments.

The scientific director of the project was a brilliant theoretical physicist, J. Robert Oppenheimer. Oppenheimer coordinated the work of a virtual who's who of scientists over a period of almost five years to produce the first atomic or nuclear fission bomb. Although the basic principles of such a weapon were clear, the design and technology of a working atomic bomb posed a huge intellectual and administrative challenge.

After many false starts, in the summer of 1945, two types of bombs were finally completed—uranium and plutonium based weapons. The uranium bomb could not be tested since there was just about enough uranium available for one weapon. Thus, early morning on July 16, 1945, at a remote firing range in New Mexico, the plutonium bomb, named Trinity, was tested. The world would never be the same again after this one event.

The test was a stupendous success scientifically. The explosion was unlike anything ever witnessed by humans. The bomb was equivalent to 20 kilotons of TNT and it left a crater 10 ft (3 m) deep and more than a 1,000 ft (300 m) wide in the desert. The desert, for a few seconds, was illuminated in a light brighter than sunlight and the mushroom cloud loomed almost 7.5 miles (12 km) into the atmosphere. The enormity of the event led Oppenheimer, an erudite scholar, to recollect lines from the Hindu scripture Bhagvad Gita, "now I have become Time, the destroyer of worlds".

Within a month of the test, the whole world witnessed the destructive power of the new weapons when the US dropped atomic bombs on the Japanese cities of Hiroshima and Nagasaki. The devastation caused to life and property was unprecedented—the two cities were completely razed to the ground and hundreds of thousands of people died immediately. The deaths and illness caused by radiation continued for decades.

The invention of the nuclear weapon and its use could be regarded as one of the defining moments of the 20th century. Europe had been divided up into spheres of influence between the US and the Soviet Union. The American bomb led the Soviets to double their efforts to produce their own weapon which was tested in 1949. By then, the US was on its way to produce a much more powerful fusion weapon. In 1952, the first American fusion weapon was tested, followed a few months later by the Soviet one. The nuclear race was now under way between the two blocs; history and politics in the latter half of the 20th century would be molded by this arms race.

Scientific and technological inventions have always been a major determining factor in shaping history of mankind. In this light, perhaps the biggest invention in history was the domestication of plants during the Neolithic period leading to agriculture, which necessitated settled communities and finally civilization based on the surplus availability of food. On a much smaller scale, the use of metals, the invention of the wheel, the development

World Wide Web

The world wide web was developed at CERN in Geneva in 1988 to facilitate data exchange between multi-national collaborators on the particle physics accelerators. With the introduction of the first browser Mosaic in 1993, the Web became accessible to everyone. The World Wide Web, together with the Internet, revolutionized the way information is shared and accessed by a large fraction of humanity, especially in the developed countries. This globe of web pages represents globalization of information made possible by the Web.

Internet

By the end of the 1980s, personal computers had become quite popular in the West and were being used extensively in business and academia, too. They were getting more powerful with more and more features added every year. The peripheral devices like printers, CD-ROMs and audio output were also being added to the computers to make them versatile.

Much before personal computers had been developed, a US government agency, Defense Advanced Research Projects Agency, had been financing research in developing a communication system between computers. The idea was to have a distributed computer infrastructure which could survive in case of a nuclear attack. In 1969, the first such system, called the Arpanet, had been commissioned to connect government agencies and some universities. A precursor to the Internet, Arpanet allowed the sharing of data between computers but was very restrictive in its applications. Simple applications like electronic mail and file transfer protocol emerged for users to make use of the network.

In 1973, two researchers, Vinton Cerf and Robert Kahn, developed a protocol for efficiently transmitting information in an error-free way. The Transmission Control Protocol, or TCP, used packets for transmitting information and soon became the standard for all networks. By 1985, many new networks, commercial as well as governmental, had come into being and most networks had shifted to TCP/IP (Internet Protocol). The TCP split the large data files into smaller chunks or packets and these were then sent by different routes to be reassembled at the destination. The addressing system which allowed this and controlled the routing of the packets was the Internet Protocol. The Internet, a conglomeration of various interconnected networks, was gaining in popularity, but even now its use was restricted to large corporations, academia and the government.

This changed in 1991 when Tim Berners-Lee, a scientist working at the European Particle Physics laboratory CERN in Geneva, developed a way to share information among the large number of collaborators and scientists at CERN who were working across many continents. He developed a protocol based on hypertext and called it HTTP, which enabled the creation of the World Wide Web on the Internet.

In 1993, the National Center for Superconducting Applications (NCSA) released the first web browser: Mosaic. This technology was commercialized by a company called Netscape which released the first commercial browser, opening up new vistas to the broad public. The World Wide Web grew exponentially with more and more people using the Internet.

By the mid-1990s, both the Web and the Internet had become indispensable in everyday life. By the end of the century, about 6 per cent of the world's population had access to the Internet. The Internet, or more specifically the World Wide Web, became an important tool for information, commerce, education, communication and virtually all other activities.

Lasers

In 1916, Einstein described the theory of stimulated emission. He proposed that under certain conditions, atoms could be made to emit coherent light—a phenomenon which could either happen spontaneously or under simulation by light. These ideas were mere theoretical curiosities till 1951 when a young researcher, Charles Townes, at Columbia University applied the ideas to microwaves. There had been a lot of development in microwaves during the world

Microwave oven

Cooking with microwaves was discovered during World War II when some scientists were doing research on microwave radars. Although the technology was patented in 1945, it never really became popular. It was only in the late 1970s that the technology improved enough to make microwave ovens affordable and usable in ordinary homes. By the end of the century, microwave ovens were to be found in almost all homes in most developed countries.

Laboratories and Think Tanks

For the large part of human history, technological innovation has come from individuals tinkering or experimenting by themselves. These could be craftsmen, farmers, hunters, priests, courtiers or even gentlemen of leisure. With the growth of universities in the West after the 11th century AD, these new institutions gradually became the center for learning and new ideas. Nevertheless, it was only in the 20th century that technological innovation got institutionalized.

Bell Labs

Bell Telephone Labs or Bell Labs was one of the most successful examples of an industrial research laboratory. Although initially set up to carry out applied research into telephony related devices, in its later years it promoted basic as well as applied research in many fields. Many researchers working at the Bell Labs went on to win the Nobel Prize. A researcher is seen here working on a communicative oscilloscope at the Bell Labs.

Thomas Edison established the first industrial laboratory at Menlo Park toward the end of the 19th century. The idea was to have many engineers and technicians interacting and developing new ideas and techniques. The basic infrastructure and equipment which individuals might find hard to procure were made available at the laboratory. This was a stupendously successful model, and within a few years, the laboratory gave the world the phonograph, the incandescent bulb and several other inventions.

This idea was taken up by AT&T which established a research laboratory named the Bell Telephone Laboratories in 1925. Bell Labs became one of the most successful examples of a research laboratory. Spread over many locations in the US, Bell Labs was responsible for thousands of inventions, including several revolutionary ones like the transistor and the photovoltaic cell. Scientists at the lab also carried out work in fundamental science and discovered electron diffraction, radio astronomy, information theory and fractional Hall effect. In fact, so far six Nobel Prizes have been awarded to work done at the Bell Labs.

There are several other examples of very successful research laboratories sponsored by industry. These include the IBM research labs and the Xerox Palo Alto Research Center (PARC). Established in 2002, PARC pioneered technologies such as laser printing, Ethernet, the graphical user interface (GUI) and ubiquitous computing. The basic idea behind these institutions was to give scientists and engineers the freedom and opportunity to pursue their ideas without undue commercial pressures. Of course, the labs made huge amounts of money by licensing their inventions but this did not mean that only commercially viable ideas were encouraged.

Apart from the private sector, most countries also have research laboratories which are set up and funded by the government. In the US, there is a network of National Laboratories and Institutes which carry out basic and applied research in almost all fields. In most cases, these institutions are set up near research universities to gain from the presence of qualified human resources. Several of the laboratories carry out classified research with defense applications but there are many which do fundamental research.

Some universities have also founded research institutes to work as independent non-profit entities and carry out research on contract. A prime example of this is the SRI International, which was founded by Stanford University in 1946 and has developed several key inventions in the areas of communications, networks and computers.

Science and technology in the 21st century is an enormously huge and complex body of knowledge. The very vastness of any specific field or subject in science and technology leads to a growth in specialization. It is no longer possible for any individual to master the complexities of many subjects as it has been the case till the Industrial Revolution. Furthermore, the tools required for technological innovation and experimentation are such that they are beyond the reach of individuals. Hence state or corporate sponsored institutions are where almost all of technological development takes place. As the world of science and technology grows more and more complex, there would probably be a move toward more specialized laboratories rather than general research establishments.

NASA

NASA, established in 1958 by the US government, is an example of a huge scientific enterprise which has been responsible for developing many technologies in space science. Among its crowning achievements is the development of the reusable space vehicle or the space shuttle which, although it proved to be much more expensive than the projected costs, has been enormously useful for space research.

GLOSSARY

INVENTIONS AND INVENTORS

Adding Machine: In 1888, the American bank clerk William Burroughs (1857–1898) received a patent for an adding machine which reduced the drudgery of repeated calculations. Burroughs later formed a company that went on to produce electric calculators and later computers.

Air Conditioner: The first electrical air conditioner was invented by the American engineer Willis Carrier (1876–1950) in 1902. The machine controlled the temperature and the humidity and was initially used in factories where temperature and humidity control was crucial. Subsequently, the use of air conditioners became very widespread in domestic and commercial establishments.

Airplane: The Wright brothers, Orville (1871–9148) and Wilbur (1867–1912), demonstrated the first powered, heavier-than-air flying machine in 1903.

Arc Lamp: In the first decade of the 19th century, the famous English scientist Sir Humphry Davy (1778–1829) demonstrated the first arc lamp by using carbon pieces, separated by air and connected to a voltaic pile or battery. The arc lamp principle was used later with different gases to get different colored light.

Artificial Satellite: The first satellite Sputnik I was launched in 1957 by the Soviet Union, thereby opening up space for human beings.

Astrolabe: Hipparchus (190–120 BC) invented the astrolabe which was of great use for doing calculations in astronomy and also in navigation. The astrolabe continued to be in use for many centuries with modifications.

Atomic Clock: The first atomic clock, a device which uses the transitions of atoms to accurately determine intervals of time, was made at the US National Bureau of Standards in 1949. Atomic clocks are now used as time standards and are extremely accurate.

Bakelite: The American chemist Leo Baekeland (1863–1944) synthesized the first plastic from completely synthetic components in 1908. Bakelite, as the material was called, had insulating properties and was used in electrical components. It was also used for making toys, kitchenware and even jewelry.

Ballpoint Pen: In 1938, a Hungarian journalist, László Biró (1899–1985), patented the first ballpoint pen which used a roller mechanism on the tip to get ink from a cartridge. Ballpoint pen replaced fountain pens to a large extent over the next few decades since they were convenient and there were no ink spills.

Bessemer Process: Henry Bessemer (1813–1898), an English inventor, patented a process of making steel much faster and inexpensively than before. Bessemer process allowed a widespread use of steel for a variety of purposes like construction, weaponry, machine building and cutlery.

Braille: The French inventor Louis Braille (1809–1852) invented the Braille system in 1821. The system is widely used by the visually impaired for reading and writing.

Bronze: Around 3000 BC, in Mesopotamia, tinstone and copper were reduced together to produce bronze which was more useful than pure copper. It was much harder than copper and could be used for weapons and tools.

Buoyancy: Archimedes of Syracuse (287–212 BC) discovered the principle of floatation and the laws of buoyancy.

Canals: Around 4000 BC, Mesopotamians built the first canals to use the water of Tigris and Euphrates to irrigate the fields.

Cannons: In the 11th century, the Chinese used bamboo tubes—which were later replaced by cast iron tubes—to throw lead pellets. This principle was used in throwing heavy metal filled with gunpowder, or cannons.

Carburetor: Carburetor, a simple device which mixes air, with petrol was invented by the Hungarian engineer Donát Bánki (1859–1922) in 1893. The carburetor helped the development of the automobiles immensely since it provided an easy method of creating a fuel–air mixture which was needed for combustion.

Chariot: Around 2000 BC, when the Mesopotamians had contact with their northern neighbors from the central Asian steppes who had domesticated the horse, they developed the horse-drawn chariot.

Circumference of the Earth: Eratosthenes (276–194 BC), a Greek mathematician, discovered a method of finding the circumference of the earth by using the elevation of the sun at two different places. His measurement of the circumference was 84 per cent correct.

Cochlear Implant: The American physician William House (1923–2012) made the first cochlear implant in 1961. This electronic device is implanted inside the ear to improve the hearing of the hearing impaired.

Colt Revolver: In 1835, the American inventor Samuel Colt (1814–1862) patented a kind of revolver which used an ingenious mechanism to rotate the cylinders. Colt's revolver was immensely popular in the American West since it was the first practical repeating firearm.

Combine Harvester: A machine which combines the agricultural tasks of harvesting and threshing of corps was invented by the American inventor Hiram Moore (1798–1858) in 1834. The combine harvester was extremely useful, especially in the large farms of North America where labor was in short supply. The earliest combines used animal power which was later replaced by steam and finally by the internal combustion engine.

Compact Disc: Invented by James Russell (1931–) in 1965, the compact disc became popular when it was released in 1982 Phillips Consumer Electronics. The compact disc allowed for a much higher fidelity of reproduction and soon replaced magnetic tapes in the music industry.

Computer: The first general, all-purpose computer ENIAC was built for the US Army in 1946. The ENIAC used vacuum tubes and could be programmed.

Computerized Automated Tomography (CAT): CAT scanning, a technique which uses multiple X-ray images to produce an accurate image of the human body, was invented by Godfrey Hounsfield (1919–2004), an English engineer, in 1972. Since then, CAT scanning has become an important diagnostic tool in medicine.

Computer Mouse: The American engineer Douglas Engelbart (1925–) made the first computer roller ball mouse in 1963. The mouse became an essential device with computers after the advent of the Graphical User Interface (GUI) in the 1980s.

Copper: Around 3500 BC, somewhere in the Middle East, copper was reduced from its ores and melted in stone crucibles to be cast into molds.

Cotton Gin: A simple machine to separate out cotton fiber from the seedpods was invented in 1793 by the American inventor Eli Whitney (1765–1825). The cotton gin increased the production of cotton and was important for establishing cotton plantations in the American South.

Crankshaft: The Islamic polymath Ibn Ismail ibn al-Razzaz al-Jazari (1136–1206) invented the first crankshaft in the late 12th century AD. The crankshaft proved to be of great importance during the steam age.

Crossbow: Chinese sources from the fourth century BC talk about the use of a crossbow catapult. The crossbow was a remarkably effective weapon for its time.

Diesel Engine: The German automotive engineer Rudolf Diesel (1858–1913) in 1893 invented a kind of internal combustion engine which caused combustion by compression of the air. Diesel engines are more efficient and give greater power than gasoline engines.

Digital camera: Steven Sasson (1950–) created the first digital camera in 1975.

DNA Sequencing: In 1975, Frederick Sanger (1918–), an English biochemist, discovered a way to sequence the double-helix molecule of DNA. The sequencing or determining the order of the bases in the molecule proved to be important in understanding the functioning of the DNA.

DNA Structure: In 1953, two Cambridge scientists, James Watson (1928–) and Francis Crick (1916–2004) deciphered the structure of DNA, the genetic material in all living organisms. The understanding of the structure of DNA could be seen as the beginning of a revolution in genetics and biology.

Dynamite: In 1866, the Swedish chemist Alfred Nobel (1833–1896) discovered a way of making nitroglycerine, a highly explosive substance, safe. Dynamite, a mixture of nitroglycerine and other chemicals, is used extensively not only in warfare but also in mining and construction.

Electric Battery: The Italian scientist Alessandro Volta (1745–1827) invented the electric storage battery in 1800. The battery used chemical interaction to produce an electric voltage between its terminals. The unit for voltage is the Volt in Volta's honor.

Electric Motor: The first electric motor was made by the English scientist Michael Faraday (1791–1867) in 1821. The electric motor, a device which used magnetism to convert

electric energy into mechanical energy, was later improved upon and became the standard provider of power.

Electric Dynamo: In 1831, Michael Faraday (1791–1867) constructed the dynamo, a device for generating electric current by using electromagnetism. The dynamo made it possible to generate electricity by using mechanical power.

Electrical Telegraph: The first commercial electrical telegraph was patented by two English scientists, William Cooke (1806–1879) and Charles Wheatstone (1802–1875) in 1837. The telegraph revolutionized communication, especially for businesses, as it could be used to get information across hundreds of miles almost instantly.

Electrocardiograph (ECG/EKG): The Dutch physiologist Willem Einthoven (1860–1927) invented the first practical electrocardiograph in 1903. This machine, which records the electrical activity of the heart, has proved to be very useful in diagnosing the ailments of the heart.

Electroencephalograph (EEG): The German physiologist Hans Berger (1873–1941) invented the EEG, a machine which could record the electrical activity of the brain. The EEG is used not only for diagnosis but also as a research tool to understand the working of the brain.

Elevator, Safety Brake: In 1853, the American inventor Elisha Otis (1811–61) invented an elevator brake which prevented the elevator car from falling in case the cables broke. This made the elevators much safer, which were subsequently used extensively in high-rise skyscrapers.

Ethernet: In 1973, Robert Metcalfe (1946–) and David Boggs invented the Ethernet, a computer networking technology which became the dominant mode for networking of computers in the 1980s and later.

Fermented drinks: Mesopotamian seals show the first representation of fermenting date palm and barley to make fermented alcoholic drinks around 2500 bc.

Fountain Pen: The first capillary-fed fountain pen was made by the American insurance broker Lewis Waterman (1837–1901) in 1884. These pens were much easier to use and rarely leaked while writing.

Friction Match: In 1827, the English chemist John Walker (1781–1859) discovered that a mixture of antimony sulphide, potassium chlorate, starch and gum could be used to make a friction match which would ignite on being rubbed against a rough surface.

Fullerenes: In 1985, three scientists, R. Curl (1933–), R. Smalley (1943–2005) and H. Kroto (1939–), discovered a new form of carbon called fullerenes. Fullerenes opened up a whole new world of carbon nanotubes and carbon buckyballs with unique properties.

Fusion Bomb: In 1952, the Hungarian–American physicist Edward Teller (1908–2003) and the Polish mathematician Stanislaw Ulam (1909–1984) designed the first successful fusion bomb or hydrogen bomb.

Geiger Counter: In 1908, the German scientist Hans Geiger (1882–1945), together with the New Zealand physicist Ernest Rutherford (1871–1937), developed a counter to detect radioactivity. The Geiger counter is used extensively till today and has proved to be a very useful device in the nuclear industry.

Geometry: Around 300 bc, Euclid of Alexandria set down his postulates of geometry and wrote *Elements*, a collection of theorems. *Elements* is considered one of the most influential books in mathematics.

Global Positioning System (GPS): The US Department of Defense in 1995 launched of a global, satellite based navigation system, the Global Positioning System. The GPS allowed an accurate determination of position anywhere on the earth and is now finding use in the civilian domain.

Gregorian Calendar: On February 24, 1582, Pope Gregory XIII (1502–85) issued a papal bull to introduce a new reformed calendar to take care of the discrepancy between the seasons and the calendar dates. This was done by dropping some days and having rules for leap years.

Gunpowder: One of the "four great inventions" of ancient China, gunpowder was invented in the ninth century. Gunpowder made its way from China to Persia and then to Europe over the next few centuries.

Handguns: The first handguns were used in China in 1288 ad.

Helicopter: The helicopter, a vertical take-off and landing machine powered by rotors, was invented by the Russian–American aviation engineer Igor Sikorsky (1889–1972) in 1939. Although several designs had been tried out before, Sikorsky's design was the first successful and practical one. Helicopters were used extensively in warfare and also for civilian transport after World War II.

Holography: In 1947, the Hungarian physicist Dennis Gabor (1900–79) invented a process to produce a three-dimensional image of objects. Holograms could not be produced easily until the invention of laser in the 1960s.

Hovercraft: Christopher Cockerel (1910–99), an English engineer, first developed the principle of transporting on air cushion in 1952. This led to the invention of hovercraft.

Hot-air Balloon: The first machine to enable human beings to be airborne was the hot-air balloon invented by the French brothers Joseph (1740–1810) and Jacques (1745–99) Montgolfier in 1783.

Incandescent Bulb: In 1880, Thomas Alva Edison (1847–1931) demonstrated that using a carbon filament in a light bulb would give it a much longer life. Prior to this, the filaments of electric bulbs were prone to burn-outs and thus not very practical.

Insulin: In 1920, the Canadian doctor Frederick Banting (1891–1941) discovered insulin (derived from pig's pancreas) which plays a crucial role in the metabolism of sugar in the human body. Banting's discovery was responsible for the use of insulin in treating diabetes.

Integrated Circuit: In 1959, the American engineer Jack Kilby (1923–2005) was granted a patent for developing a complete electronic circuit on a germanium wafer. The integrated circuit, as this invention was called, was responsible for the growth of miniature electronics and is extensively used today.

Internal Combustion Engine: The German Karl Benz (1844–1929) built the first automobile powered by a four-stroke gasoline engine in 1885. Benz and other engineers like Daimler and Maybach later introduced many innovations in the technology of the internal combustion engine.

Internet: Robert Kahn (1938–) and Vinton Cerf (1943–) invented the TCP/IP protocol in 1983. This protocol, or set of rules, is used to transmit information over the Internet.

Iron: Sometime between 2000 bc and 1500 bc, the Hittites in Eastern Turkey discovered the use of iron. Over the next few centuries, this technology spread across Mesopotamia and Egypt.

Jet Engine: The British air force engineer Frank Whittle (1907–96) patented the first jet engine in 1932. The first jet engine was made by Whittle in 1937 but it was many years before it replaced the propeller as the power source in aircraft.

Kinetoscope and Kinetograph: In 1893, Thomas Alva Edison (1847–1931) demonstrated two pioneering inventions to shoot and view motion pictures. These inventions, which underwent many improvements in the next few decades, led to the birth of the movie industry.

LASER: The American physicist Theodore Maiman (1927–2007) produced the first working laser (Light Amplification by Stimulated Emission of Radiation) in 1960. Lasers find extensive use in a variety of fields like communication, surveying and consumer electronics.

Light Emitting Diode (LED): In 1962, the American scientist Nick Holonyak Jr. developed the first light emitting diode. LEDs are used in communication, display screens and also electronic circuits.

Lightning Conductor: The American statesman and scientist Benjamin Franklin (1706–1790) invented the lightning rod in 1752. Franklin had experimented with atmospheric electricity before and had shown that lightning was basically an electric spark.

Liquid Crystal Display (LCD): In 1970, the Swiss company Hoffman-LaRoche patented the use of the nematic effect in liquid crystals and started licensing the technology to produce liquid crystal displays (LCDs). LCDs became the standard display in many consumer electronics like wrist-watches and game consoles.

Liquid Fuel Rocket: The American space scientist Robert H. Goddard (1882–1945) in 1913 obtained a patent for a rocket which used liquid fuel—a mixture of gasoline and liquid nitrous oxide. The liquid fuel rocket was an important milestone in rocket science.

Lithography: A technique to print text or art onto paper, lithography was invented in 1796 by the German author Alois Senefelder (1771–1834). Lithography is essentially a chemical technique that has been refined for use in the manufacture of chips and other devices.

Locomotive, steam: In 1801, the English mining engineer Richard Trevithick (1771–1833) made the first working locomotive which ran on steam power. The engine used a crankshaft to convert linear motion of the piston into rotary motion. The design of the locomotive underwent many changes in the 19th century.

Logarithm: John Napier (1550–1617), an English mathematician, invented logarithms in the first decade of the 17th century. Logarithms were extremely useful in carrying out complicated calculations and continued to be used extensively till the advent of calculators and computers.

Loom: Egyptians and Mesopotamians used a simple form of a loom to weave a kind of coarse cotton cloth around 3000 bc.

Magnetic Compass: Shen Kuo (1031–1095 ad), a Chinese engineer in the 11th century, used a magnetized needle floating in water to make the first magnetic compass. The compass revolutionized navigation.

Magnetic Resonance Imaging (MRI): In 1971, the American scientist Raymond Damadian (1936–) developed the first magnetic resonance imaging device which could be used to give detailed images of the human body.

Editor: Ritu Malhotra
Design: Mallika Das
DTP: Neeraj Aggarwal

Cover: All images: © Getty Images
Cover design: Simone Sticker
Overall responsibility for production: h.f.ullmann publishing GmbH, Potsdam, Germany

Printed in China, 2013

ISBN 978-3-8480-0638-0

10 9 8 7 6 5 4 3 2 1
X IX VIII VII VI V IV III II I

www.ullmann-publishing.com
newsletter@ullmann-publishing.com