LIVES IN ENGINEERING

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Contents

INTRODUCTION[1]

Human history as cultural history

We need to reform our teaching of history so that the emphasis will be placed on the gradual growth of human culture and knowledge, a growth to which all nations and ethnic groups have contributed.

This book is part of a series on cultural history. Here is a list of the other books in the series that have, until now, been completed:

- Lives in Astronomy
- Lives in Chemistry
- Lives in Medicine
- Lives in Ecology
- Lives in Physics
- Lives in Economics
- Lives in the Peace Movement

The pdf files of these books may be freely downloaded and circulated from the following web address:

http://eacpe.org/about-john-scales-avery/

Human mastery over nature

Science and engineering have combined to give humans mastery over nature. This book traces that historical development, looking mainly at the contributions of engineering. It is a success story, but human society has now reached a critical point where our mastery of nature may destroy not only nature but also ourselves.

Chapter 11 of this book discusses Ecological Engineering, in other words, the engineering that we need to produce urgently needed renewable energy infrastructure. Without very rapid action, uncontrollable feedback loops may take over. At the same time we can be encouraged by the fact that renewables are now cheaper than fossil fuels.

[1]This book makes some use of my previously published book chapters, but much of the material is new.

Pride in human achievements can be seen in a famous poem by Sophocles, who wrote:

Numberless are the world's wonders, but none
More wonderful than man; the storm gray sea
Yields to his prows, the huge crests bear him high;
Earth, holy and inexhaustible, is graven
With shining furrows where his plows have gone
Year after year, the timeless labor of stallions.

The light-boned birds and beasts that cling to cover,
The lithe fish lighting their reaches of dim water,
All are taken, tamed in the net of his mind;
The lion on the hill, the wild horse windy-maned,
Resign to him; and his blunt yoke has broken
The sultry shoulders of the mountain bull.

We can take pride in human mastery over nature, but at the same time we must remember that excessive pride was called "hubris" by the ancient Greeks, and in their dramas, it as always punished by the gods. We are not outside nature. We are part of the natural world, and our survival depends on whether we respect nature, and care for it.

Chapter 1

ENGINEERING IN THE ANCIENT WORLD

1.1 Megalithic structures in prehistoric Europe

Timeline[1]

- c. 9500 BCE: Construction in Asia Minor (GÃ¶bekli Tepe); from proto-Hattian or else a yet-to-be-discovered culture (the oldest religious structure in the world).
- Submerged by around 7400 BCE: a 12m long monolith probably weighing around 15000 kg found 40m under water in the Strait of Sicily south-west of Sicily whose function is unknown
- c. 7000 BCE: Construction in proto-Canaanite Israel (Atlit Yam). Possibly first standing stones in Portugal.
- c. 6000 BCE: Constructions in Portugal (Almendres Cromlech, Évora)
- c. 5000 BCE: Emergence of the Atlantic Neolithic period, the age of agriculture along the western shores of Europe during the sixth millennium BC pottery culture of La Almagra, Spain near by, perhaps precedent from Africa.
- c. 4800 BCE: Constructions in Brittany, France (Barnenez) and Poitou (Bougon).
- c. 4500 BCE: Constructions in south Egypt (Nabta Playa).
- c. 4300 BCE: Constructions in south Spain (Dolmen de Alberite, CÃ¡diz).
- c. 4000 BCE: Constructions in Brittany (Carnac), Portugal (Great Dolmen of Zambujeiro, Évora), France (central and southern), Corsica, Spain (Galicia), England and Wales, Constructions in Andalusia, Spain (Villa MartÃn, CÃ¡diz), Construction in proto-Canaanite Israel c. 4000-3000 BC: Constructions in the rest of the proto-Canaanite Levant, e.g. Rujm el-Hiri and dolmens.
- c. 3700 BCE: Constructions in Ireland (Knockiveagh and elsewhere).
- c. 3600 BCE: Constructions in Malta (Skorba temples).
- c. 3600 BCE: Constructions in England (Maumbury Rings and Godmanchester), and Malta (Ä gantija and Mnajdra temples).

[1]from the Wikipedia article *Megalith*

- c. 3500 BCE: Constructions in Spain (MÃ¡laga and Guadiana), Ireland (south-west), France (Arles and the north), Malta (and elsewhere in the Mediterranean), Belgium (north-east), and Germany (central and south-west).
- c. 3400 BCE: Constructions in Sardinia (circular graves), Ireland (Newgrange), Netherlands (north-east), Germany (northern and central) Sweden and Denmark.
- c. 3300 BCE: Constructions in France (Carnac stones)
- c. 3200 BCE: Constructions in Malta (Hagar Qim and Tarxien).
- c. 3100 BCE: Constructions in Russia (Dolmens of North Caucasus)
- c. 3000 BCE: Constructions in Sardinia (earliest construction phase of the prehistoric altar of Monte d'Accoddi), France (Saumur, Dordogne, Languedoc, Biscay, and the Mediterranean coast), Spain (Los Millares), Sicily, Belgium (Ardennes), and Orkney, as well as the first henges (circular earthworks) in Britain.
- c. 2500 BCE: Constructions in Brittany (Le Menec, Kermario and elsewhere), Italy (Otranto), Sardinia, and Scotland (northeast), plus the climax of the megalithic Bell-beaker culture in Iberia, Germany, and the British Isles (stone circle at Stonehenge). With the bell-beakers, the Neolithic period gave way to the Chalcolithic, the age of copper.
- c2500 BCE: Tombs at Algarve, Portugal. Additionally, a problematic dating (by optically stimulated luminescence) of Quinta da Queimada Menhir in western Algarve indicates "a very early period of megalithic activity in the Algarve, older than in the rest of Europe and in parallel, to some extent, with the famous Anatolian site of Göbekli Tepe"
- c. 2400 BCE: The Bell-beaker culture was dominant in Britain, and hundreds of smaller stone circles were built in the British Isles at this time.
- c. 2000 BCE: Constructions in Brittany (Er Grah), Italy : (Bari); Sicily (Cava dei Servi, Cava Lazzaro);, and Scotland (Callanish). The Chalcolithic period gave way to the Bronze Age in western and northern Europe.
- c. 1800 BCE: Constructions in Italy (Giovinazzo, in Sardinia started the nuragic civilization).
- c. 1500 BCE: Constructions in Portugal (Alter Pedroso and Mourela).
- c. 1400 BCE: Burial of the Egtved Girl in Denmark, whose body is today one of the best-preserved examples of its kind.
- c. 1200 BCE: Last vestiges of the megalithic tradition in the Mediterranean and elsewhere come to an end during the general population upheaval known to ancient history as the Invasions of the Sea Peoples.

Figure 1.1: **The formations at Göbekli Tepe, in southeast Turkey, are the oldest (c9000 BCE) known megalithic constructions anywhere in the world.**

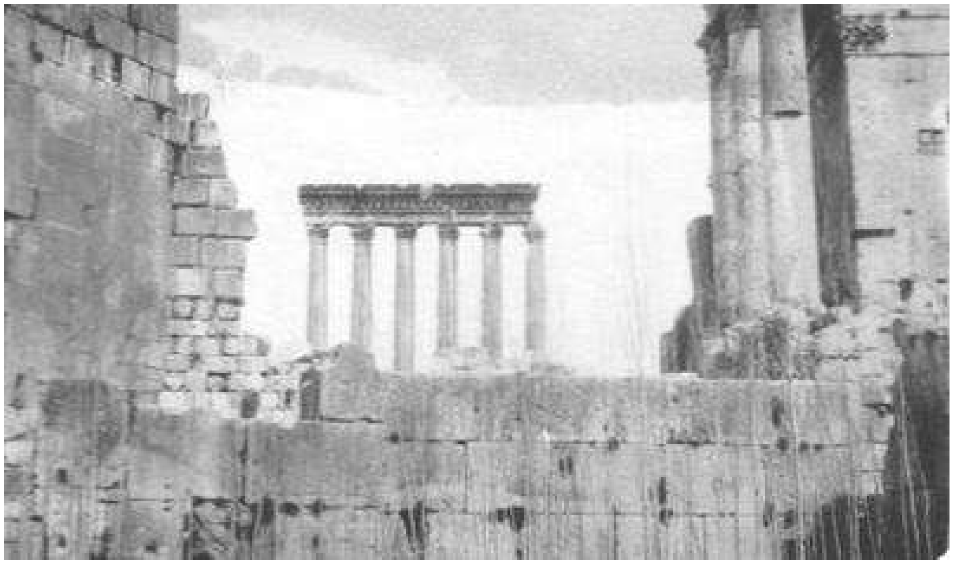

Figure 1.2: **Baalbek, on the road to Damascus. Here we see a Roman temple, built on top of an ancient temple to Baal.**

Figure 1.3: **An extremely large stone near to Baalbek. It is hard to understand how the ancient people of the region moved it.**

Figure 1.4: **Stonehenge, Wiltshire, United Kingdom, is one of the world's best known megalithic structures (constructed between 3100-2200 BCE).**

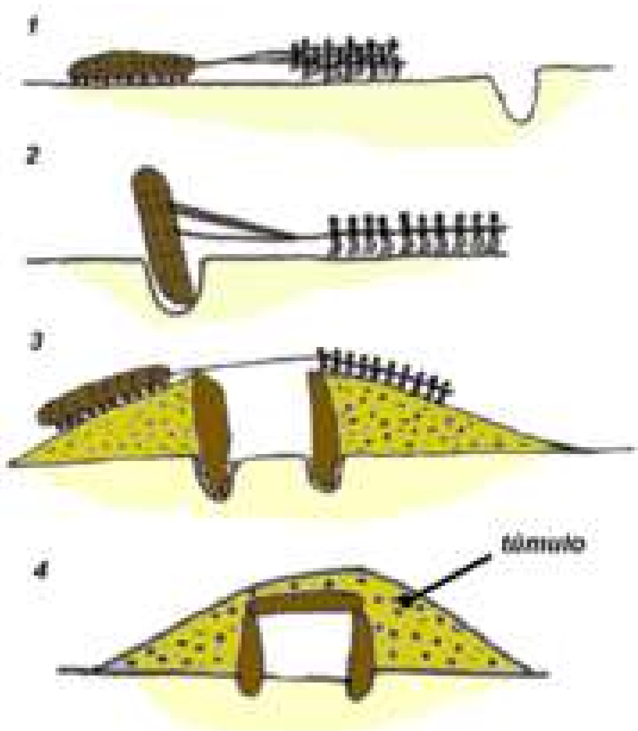

Figure 1.5: **Construction of a megalith grave.**

Figure 1.6: **Menhir of Goni in Sardinia. Ancient megalithic monuments are not confined to Europe. There are also many in Asia. Korea is estimated to have between 30,000 and 100,000 such monuments. One must also remember the megaliths on Easter Island. There are even megalithic cultures practicing toay, for example in Indonesia.**

1.2 Imhotep and the pyramid builders

The Egyptian civilization

The prosperity of ancient Egypt was based partly on its rich agriculture, nourished by the Nile, and partly on gold. Egypt possessed by far the richest gold deposits of the Middle East. They extended the whole length of the eastern desert, where more than a hundred ancient mines have been found; and in the south, Nubia was particularly rich in gold. The astonishing treasure found in the tomb of Tutankhamen, who was certainly not the most powerful of the pharaohs, gives us a pale idea of what the tombs of greater rulers must have been like before they were plundered.

In the religion of ancient Egypt, the distinction between the gods and the pharaohs was never very clear. Living pharaohs were considered to be gods, and they traced their ancestry back to the sun-god, Ra. Since all of the pharaohs were thought to be gods, and since, before the unification of Egypt, there were very many local gods, the Egyptian religion was excessively complicated. A list of gods found in the tomb of Thuthmosis III enumerates no fewer than seven hundred and forty! The extreme conservatism of Egyptian art (which maintained a consistent style for several thousand years) derives from the religious function played by painting and sculpture.

The famous gods, Osiris, Isis, Horus and Set probably began their existence as real people, and their story, which we know both from hieroglyphic texts and from Pliny, depicts an actual historical event - the first unification of Egypt: Osiris, the good ruler of the lower Nile, was murdered and cut to pieces by his jealous brother Set; but the pieces of Osiris' body were collected by his faithful wife Isis, who performed the first mummification and thus made Osiris immortal. Then Horus, the son of Osiris and Isis, like an Egyptian Hamlet, avenged the murder of his father by tracking down his wicked uncle Set, who attempted to escape by turning into various animals. However, in the end Horus killed Set, and thus Horus became the ruler of all of Egypt, both the lower Nile and the upper Nile.

This first prehistoric unification of Egypt left such a strong impression on the national consciousness that when a later pharaoh named Menes reunified Egypt in 3,200 B.C., he did so in the name of Horus. Like the Mesopotamian story of the flood, and like the epics of Homer, the story of the unification of Egypt by Horus probably contains a core of historical fact, blended with imaginative poetry. At certain points in the story, the characters seem to be real historical people - for example, when Osiris is described as being “handsome, dark-skinned and taller than other men”. At other times, imagination seems to predominate. For example, the goddess Nut, who was the mother of Osiris, was thought to be the sky, while her husband Geb was the earth. The long curved body of Nut was imagined to be arched over the world so that only the tips of her toes and fingers touched the earth, while the stars and moon moved across her belly. Meanwhile her husband Geb lay prostrate, with all the vegetation of the earth growing out of his back.

The idea of the resurrection and immortality of Osiris had a strong hold on the ancient Egyptian imagination. At first only the pharaohs were allowed to imitate Osiris and become

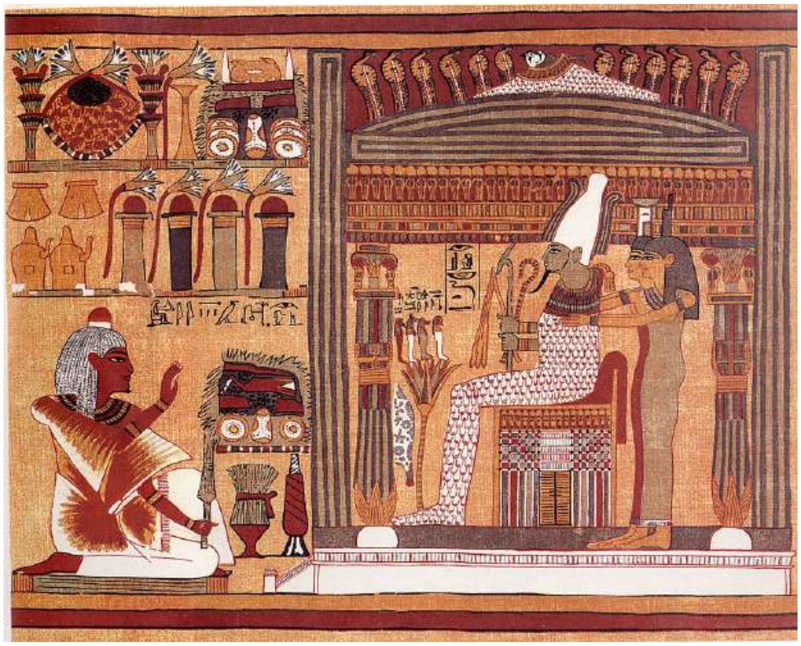

Figure 1.7: **Facsimile of a vignette from the Book of the Dead of Ani. The deceased Ani kneels before Osiris, judge of the dead. Behind Osiris stand his sisters Isis and Nephthys, and in front of him is a lotus on which stand the four sons of Horus.**

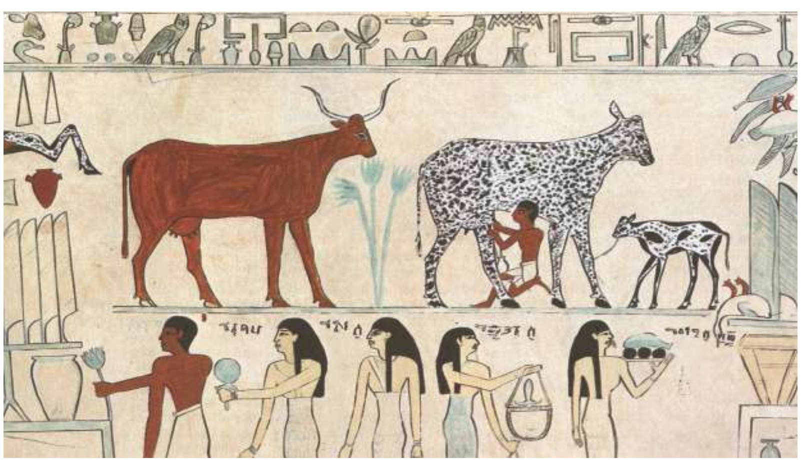

Figure 1.8: **Old Egyptian hieroglyphic painting showing an early instance of a domesticated animal (cow being milked).**

Figure 1.9: **A view of the well preserved and beautifully painted Tomb TT3 from Deir el-Medina on the West Bank of Luxor. This scene depicts the god Osiris with the Mountains of the West behind him. It belonged to Pashedu who served as an Ancient Egyptian artist and foreman at Deir el-Medina under pharaoh Seti I.**

immortal like him through a magical ceremony of mummification and entombment. As part of the ceremony, the following words were spoken: "Horus opens the mouth and eyes of the deceased, as he opened the mouth and eyes of his father. He walks! He speaks! He has become immortal! ... As Osiris lives, the king lives; as he does not die, the king does not die; as he does not perish, the king does not perish!" Later the policy became more democratic, and ordinary citizens were allowed mummification.

Imhotep

The tradition of careful mummification and preservation of the pharaohs led to the most impressive and characteristic expression of Egyptian civilization: the construction of colossal stone temples, tombs and pyramids. Ordinary houses in Egypt were made of brick, but since the tombs, in theory, had to last forever, they could not use brick or even the finest imported ceder wood. They had to be made entirely of stone.

The advanced use of stone in architecture began quite suddenly during the reign of Djoser in the Third Dynasty, in about 2,950 B.C.. During the Second Dynasty, a few tentative and crude attempts had been made to use stone in building, but these can hardly be thought of as leading to the revolutionary breakthrough in technique which can be seen in the great step pyramid of Djoser, surrounded by an amazing series of stone temples, and enclosed by a wall 33 feet high and nearly a mile long.

It is tempting to believe that this sudden leap forward in architectural technique was due to the genius of a single man, the first engineer whose name we know: Imhotep. The ancient Egyptians certainly believed that the whole technique of cutting and laying massive blocks of stone was invented entirely by Imhotep, and they raised him to the status of a god. Besides being King Djoser's chief architect, Imhotep was also a physician credited with miraculous cures. After his deification, he became the god of medicine, and his tomb became a place of pilgrimage for sick people seeking to be cured, more or less in the manner of Lourdes.

The craftsmanship of the pyramid builders has never been surpassed in any country. No scholar has been able to explain fully the methods by which they were able to fit enormous blocks of stone together with such astonishing accuracy. However, it is known that their method of quarrying was as follows: Along the line where a limestone block was to be split away from a cliff, a V-shaped groove was cut with copper tools. Along the bottom of the groove, wedge-holes were drilled, and wooden wedges were hammered into the holes. The wedges were soaked in water, and the force of expansion split the block away from the cliff face. Obviously, this is a slow and laborious method of quarrying, and therefore from the standpoint of economy it was better to cut one huge block rather than a hundred small ones. Also, from the standpoint of achieving enormous size and permanence in the finished structure, large blocks were by far the best.

In building the great pyramid of Cheops (c. 2,600 B.C.), on which 100,000 men were said to have worked 30 years, 2,300,000 blocks were used. The average weight of the stones was two and one half tons, but many of them weighed as much as fifteen tons, and the enormous slabs of granite which form the roof of the king's chamber weigh almost fifty tons apiece.

The blocks were dragged from the quarries on sleds pulled with ropes by teams of men. On the front of each sled stood a man, pouring water in front of the runners, so that the clay on which they slid would be made slippery. Also standing on the sled, was a foreman who clapped his hands rhythmically to coordinate the movements of the workmen. His clapping was amplified by a second foreman, who banged two blocks of wood together in the same rhythm.

Figure 1.10: **Statuette of Imhotep, chancellor to the pharaoh, priest of Ra and architect.**

Figure 1.11: **The step-pyramid of Djoser was designed by Imhotep, and built between 2667 and 2648 BC.**

Figure 1.12: **The great pyramids at Giza.**

1.3 The great wall of China

The art of working in bronze was developed in China during the Shang dynasty (1,500 B.C. - 1,100 B.C.) and it reached a high pitch of excellence in the Chou dynasty (1,100 B.C. - 250 B.C.).

In the Chou period, many of the cultural characteristics which we recognize as particularly Chinese were de- veloped. During this period, the Chinese evolved a code of behavior based on politeness and ethics. Much of this code of behavior is derived from the teachings of K'ung Fu-tzu (Confucius), a philosopher and government official who lived between 551 B.C. and 479 B.C.. In his writings about ethics and politics, K'ung Fu-tzu advocated respect for tradition and authority, and the effect of his teaching was to strengthen the conservative tendencies in Chinese civiliza- tion. He was not a religious leader, but a moral and political philosopher, like the philosophers of ancient Greece. He is traditionally given credit for the compilation of the Five Classics of Chinese Literature, which include books of history, philosophy and poetry, together with rules for religious ceremonies.

The rational teachings of K'ung Fu-tzu were complemented by the more mystical and intuitive doctrines of Lao-tzu and his followers. Lao-tzu lived at about the same time as K'ung Fu-tzu, and he founded the Taoist religion. The Taoists believed that unity with nature could be achieved by passively blending oneself with the forces of nature.

On the whole, politicians and scholars followed the practical teachings of K'ung Fu-tzu, while poets and artists be- came Taoists. The intuitive sensitivity to nature inspired by Taoist beliefs allowed these artists and poets to achieve literature and art of unusual vividness and force with great economy of means. The Taoist religion has much in common with Buddhism, and its existence in China paved the way for the spread of Buddhism from India to China and Japan.

From 800 B.C. onwards, the central authority of the Chou dynasty weakened, and China was ruled by local landlords. This period of disunity was ended in 246 B.C. by Shih Huang Ti, a chieftain from the small northern state of Ch'in, who became the first real emperor of China. (In fact, China derives its name from the state of Ch'in).

Shih Huang Ti was an effective but ruthless ruler. It was during his reign (246 B.C. -210 B.C.) that the great wall of China was built. This wall, built to protect China from the savage attacks of the mounted Mongolian hordes, is one of the wonders of the world. It runs 1,400 miles, over all kinds of terrain, marking a rainfall boundary between the rich agricultural land to the south and the arid steppes to the north.

In most places, the great wall is 25 feet high and 15 feet thick. To complete this fantastic building project, Shih Huang Ti carried absolutism to great extremes, uprooting thousands of families and transporting them to the comfort- less north to work on the wall. He burned all the copies of the Confucian classics which he could find, since his opponents quoted these classics to show that his absolutism had exceeded proper bounds.

Soon after the death of Shih Huang Ti, there was a popular reaction to the harshness of his government, and Shih's heirs were overthrown. However, Shih Huang Ti's unification of China endured, although the Ch'in dynasty (250 B.C. - 202 B.C.) was replaced by the Han dynasty (202 B.C. - 220 A.D.). The Han emperors extended the boundaries of China to the

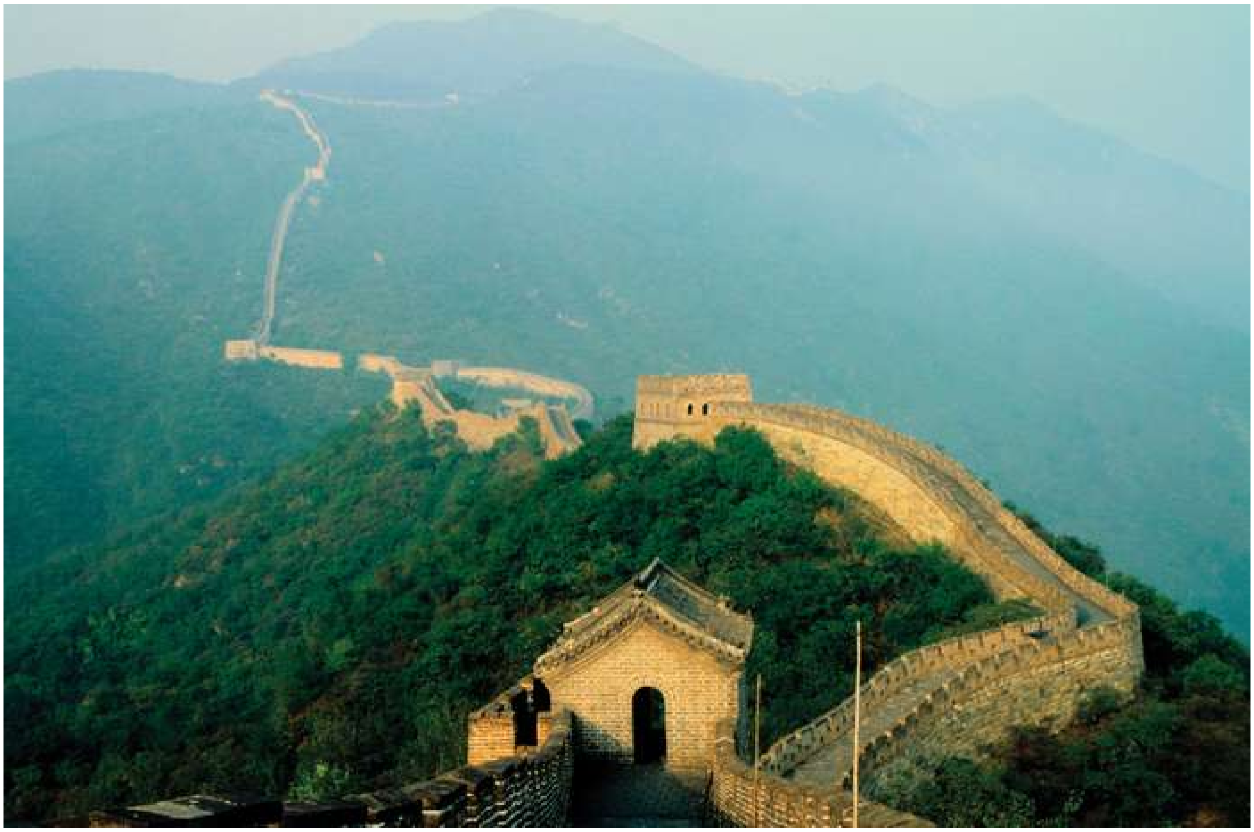

Figure 1.13: **The Great Wall of China near Beijing.**

west into Turkestan, and thus a trade route was opened, through which China exported silk to Persia and Rome.

Figure 1.14: **The Great Wall of China at Shanhaiguan, Hebei province, China.**

Figure 1.15: **The Great Wall of China at Mutianyu, northeast of Beijing..**

1.4 The Americas

Agriculture in the western hemisphere

During a glacial period between 20,000 and 10,000 years before the present, there was a land bridge across the Bering Strait. There is evidence that humans crossed this land bridge from Siberia and followed a coastal route past the glaciated regions of what is now Canada, finally reaching South America. Humans were able to build boats at that time, as evidenced by traces of very early settlements on islands off the coast of South America.

In a May 24, 2017 article in *Science*, Lizzie Wade wrote:

"About 600 kilometers north of Lima, an imposing earthen mound looms over the sea. People began building the ceremonial structure, called Huaca Prieta, about 7800 years ago. But according to a new study, the true surprise lies buried deep beneath the 30-meter-tall mound: stone tools, animal bones, and plant remains left behind by some of the earliest known Americans nearly 15,000 years ago. That makes Huaca Prieta one of the oldest archaeological sites in the Americas and suggests that the region's first migrants may have moved surprisingly slowly down the coast.

"The evidence of early human occupation stunned Tom Dillehay, an archaeologist at Vanderbilt University in Nashville who led the new study. Initially, he was interested in examining the mound itself. But geologists on his team wanted to study the landform under the mound, so 'we just kept going down,' he says. The deepest pit, which took 5 years to excavate, reached down 31 meters. Shockingly, those deep layers contained telltale signs of human occupation, Dillehay's team reports today in Science Advances: evidence of hearth fires, animal bones, plant remains, and simple but unmistakable stone tools. Radiocarbon dates from charcoal place the earliest human occupation at nearly 15,000 years ago.

"That's made some researchers say Huaca Prieta should join the small but growing list of pre-14,000-year-old sites that have revolutionized scientists' vision of the earliest Americans. Archaeologists used to think that people walked from Siberia through an ice-free passage down Alaska and Canada, reaching the interior of the United States about 13,000 years ago. In recent years, however, well documented earlier sites like Chile's Monte Verde have convinced most archaeologists that humans made it deep into the Americas by 14,500 years ago, meaning that they would have had to cross Canada long before an ice-free corridor existed. That would have left them with one logical route into the Americas: down the Pacific coast. But direct evidence for such a migration is lacking."

Another site that shows evidence of early human presence is Piki Mach'ay cave in Peru Radiocarbon dates from this cave give a human presence ranging from 22,200 to 14,700 years ago, but this evidence has been disputed. Wikipedia states that "Piki Mach'ay yielded some of the oldest plant remains in Peru, including an 11,000 year old bottle gourd. Strata from later periods at the site revealed fishtail points, manos, and metates. Plant remains indicate that, before 3,000 years BCE, amaranth, cotton, gourds, lucuma, quinoa, and squash were cultivated in the Ayacucho Basin before 3,000 years BCE. By

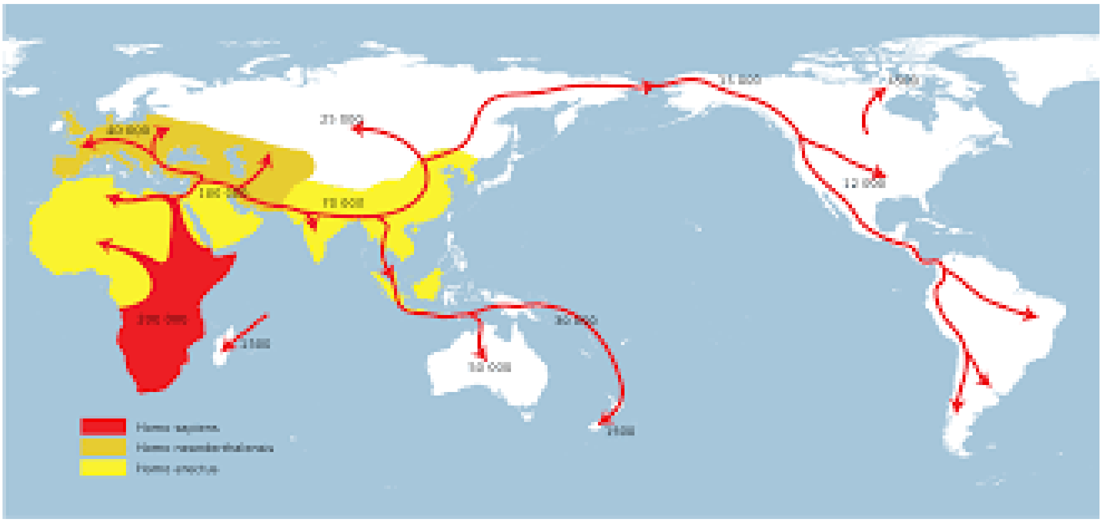

Figure 1.16: **Modern humans crossed the Bering Straits during a glacial period between 20,000 and 10,000 years before the present.**

4,000 years BCE corn (Zea mays) and common beans were grown. Chili remains date from 5,500 to 4,300 years BCE. The large amounts of guinea pig bones suggest possible domestication, and llamas may have been domesticated by 4,300 to 2,800 years BCE."

Peru gives potatoes to the world

Wikipedia states that "Cultivation of potatoes in South America may go back 10,000 years, yet the tubers do not preserve well in archaeological record, and there are problems with exact identification of those that are found... In the Altiplano, potatoes provided the principal energy source for the Inca Empire, its predecessors, and its Spanish successor... Potato was the staple food of most Pre-Columbian Mapuches[2], 'specially in the southern and coastal [Mapuche] territories where maize did not reach maturity'"

[2]The Mapuche are a group of indigenous inhabitants of south-central Chile and southwestern Argentina, including parts of present-day Patagonia.

Figure 1.17: **The "three sisters", maize, squash and beans, traditionally grown by tribes of the first people in North America.**

Figure 1.18: **An artist's guess at what the inhabitants of Piki Mach'ay cave in Peru might have looked like.**

Figure 1.19: **In the mountainous regions of Peru, the ancient Incas built terraces for the cultivation of potatoes.**

Figure 1.20: **A Mayan temple that dominates the archaeological site of Chichen Itza. The design of the temple has special astronomical significance. Each face of the pyramid has a stairway with 91 steps, which together with the shared step at the top, add up to 365, the number of days in a year.**

Figure 1.21: **Panoramic view of Machu Picchu.**

Figure 1.22: **Incan stonework. It is impossible to fit a knifeblad between the stones. We do not know how they achieved this degree of accuracy in cutting the blocks.**

1.5 Angkor Wat

Here is a quotation from a SpringerLink article on the hydrolic engineering near to Angkor Wat.

The network of water management infrastructure that was developed in the heartland of the Khmer Empire during the classical Angkor Period (approximately ninth to fifteenth centuries AD) is one of the signal engineering achievements of the preindustrial world. Over several centuries, an elaborate and sophisticated water management system was developed over an area of approximately 1,500 km 2 around the great monuments of Angkor. The network integrated and sustained a thriving metropolis of several hundred thousand people, located at the heart of an Empire that dominated mainland Southeast Asia for half a millennium. At the same time, it may have created a range of challenges to the long-term viability of that urban complex and to the Angkorian civilization itself.

Another article[3] states that

Angkor Wat is one of the most ancient and original hydraulic cities on earth. A hydraulic city is described as a highly productive system of irrigation carefully adapted to the region. The hydraulic cities of Angkor established a "Baray", or large reservoir, to ensure optimal storage of water for cultivating rice. With the help of gravity, the baray collected the maximum amount of water onto a large surface to create permanent rice fields. During the monsoon seasons, the baray would fill with water, allowing for rice cultivation during the dry season. Even if the monsoon season brought little rain, the design of the baray allowed for the rice fields to be filled with water when necessary, using an engineering process to overcome unforeseen shortcomings of water supply. Unfortunately, the decline of the Angkor Wat civilization remains a mystery today; however, some historians believe the fall of the empire was a result of the very hydraulic system created, which most likely caused intense water blockage overtime, eventually halting the natural flow of water

[3]https://thesisisfun.wordpress.com/thesis-prep/angkor-wat-hydraulic-city/

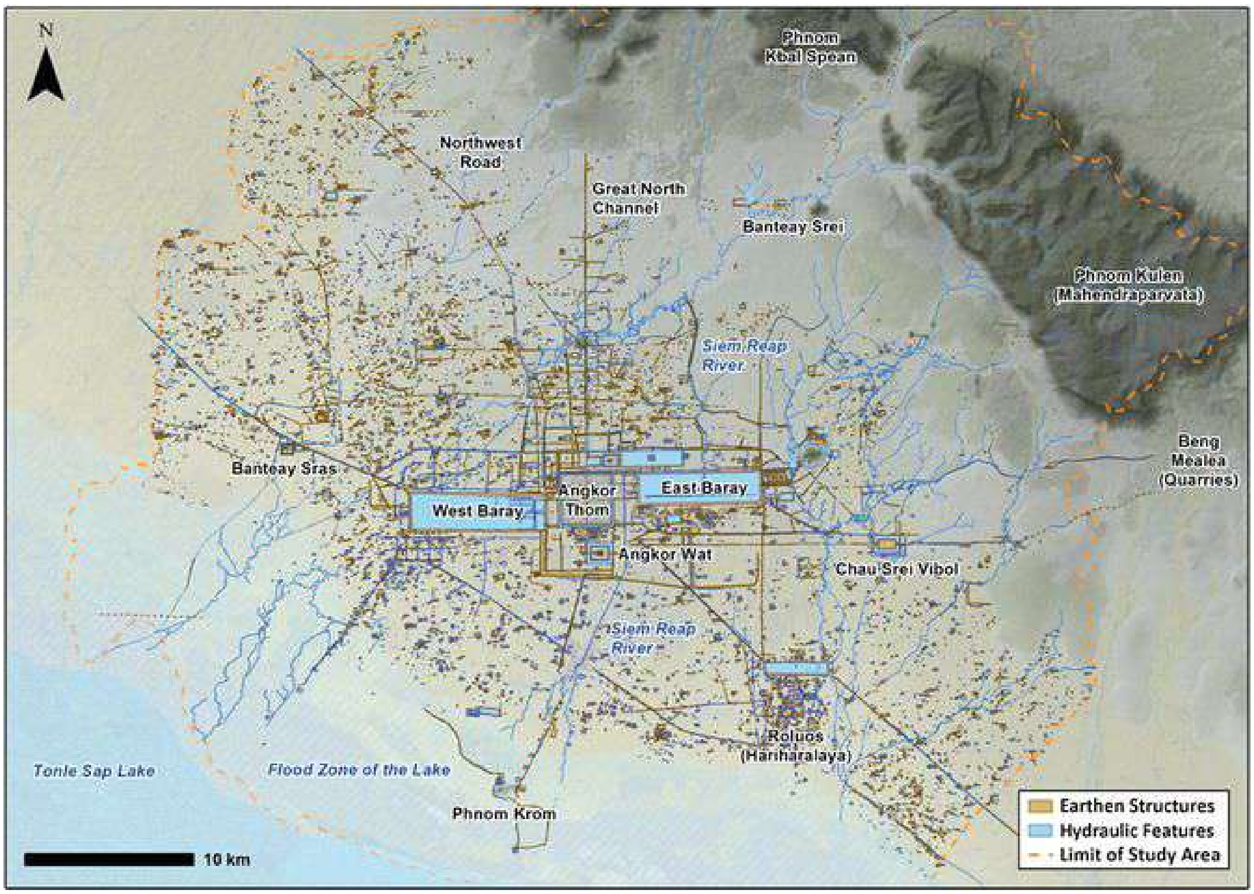

Figure 1.23: **A map of the hydrolic engineering system near Angkor Wat.**

Figure 1.24: **Temples at Angkor Wat.**

Figure 1.25: **Another view of Angkor Wat's temples.**

Figure 1.26: **The Roman Baths in the city of Bath, England.**

Figure 1.27: **The Alcántara Bridge, Spain, a masterpiece of ancient bridge building.**

Figure 1.28: **A Roman aqueduct: The multiple arches of the Pont du Gard in Roman Gaul (modern-day southern France). The upper tier encloses an aqueduct that carried water to Nimes in Roman times; its lower tier was expanded in the 1740s to carry a wide road across the river.**

Figure 1.29: **The exterior of the Colosseum, showing the partially intact outer wall (left) and the mostly intact inner wall (center and right). The outer wall is estimated to have required over 100,000 cubic meters (3,531,467 cubic feet) of travertine stone which were set without mortar; they were held together by 300 tons of iron clamps.**

Figure 1.30: **A Roman street in Pompeii. At the peak of Rome's development, the late Empire's 113 provinces were interconnected by 372 great roads. The total length of these roads was more than 400,000 kilometers (250,000 miles).**

1.6 Roman engineering

During the period between 202 B.C. and 31 B.C., Rome gradually extended its control over the Hellenistic states. By intervening in a dynastic struggle between Cleopatra and her brother Ptolemy, Julius Caesar was able to obtain control of Egypt. He set fire to the Egyptian fleet in the harbor of Alexandria. The fire spread to the city. Soon the great library of Alexandria was in flames, and most of its 750,0000 volumes were destroyed. If these books had survived, our knowledge of the history, science and literature of the ancient world would be incomparably richer. Indeed, if the library had survived, the whole history of the world might have been very different.

The Roman conquest produced 600 years of political stability in the west, and it helped to spread civilization into northern Europe. The Roman genius was for practical organization, and for useful applications of knowledge such as engineering and public health.

Roman roads, bridges and aqueducts, many of them still in use, testify to the superb skill of Roman engineers. The great system of aqueducts which supplied Rome with water brought the city a million cubic meters every day. Under the streets of Rome, a system of sewers (*cloacae*), dating from the 6th century B.C., protected the health of the citizens.

The abacus was used in Rome as an aid to arithmetic. This device was originally a board with a series of groves in which pebbles (*calculi*) were slid up and down. Thus the English word "calculus" is derived from the Latin name for a pebble.

The impressive technical achievements of the Roman Empire were in engineering, public health and applied science, rather than in pure science. In the 5th century A.D., the western part of the Roman Empire was conquered by barbaric tribes from northern Europe, and the west entered a dark age.

Suggestions for further reading

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Chapter 2

LEONARDO AS AN ENGINEER

2.1 The life of Leonardo da Vinci

East-west contacts

Towards the end of the middle ages, Europe began to be influenced by the advanced Islamic civilization. European scholars were anxious to learn, but there was an "iron curtain" of religious intolerance which made travel in the Islamic countries difficult and dangerous for Christians. However, in the 12th century, parts of Spain, including the city of Toledo, were reconquered by the Christians. Toledo had been an Islamic cultural center, and many Moslem scholars, together with their manuscripts, remained in the city when it passed into the hands of the Christians. Thus Toledo became a center for the exchange of ideas between east and west; and it was in this city that many of the books of the classical Greek and Hellenistic philosophers were translated from Arabic into Latin.

In the 12th century, the translation was confined to books of science and philosophy. Classical Greek literature was forbidden by both the Christian and Moslem religions; and the beautiful poems and dramas of Homer, Sophocles and Euripides were not translated into Latin until the time of the Renaissance Humanists.

During the Mongol period (1279-1328), direct contact between Europe and China was possible because the Mongols controlled the entire route across central Asia; and during this period Europe received from China three revolutionary inventions: printing, gunpowder and the magnetic compass.

Another bridge between east and west was established by the crusades. In 1099, taking advantage of political divisions in the Moslem world, the Christians conquered Jerusalem and Palestine, which they held until 1187. This was the first of a series of crusades, the last of which took place in 1270. European armies, returning from the Middle East, brought with them a taste for the luxurious spices, textiles, jewelry, leatherwork and fine steel weapons of the orient; and their control of the Mediterranean sea routes made trade with the east both safe and profitable. Most of the profit from this trade went to a few cities, particularly to Venice and Florence.

At the height of its glory as a trading power, the Venetian Republic maintained six fleets of nationally owned ships, which could be chartered by private enterprise. All the ships of this fleet were of identical construction and rigged with identical components, so that parts could be replaced with ease at depots of the Venetian consular service abroad. The ships of these fleets could either serve as merchant ships, or be converted into warships by the addition of guns. Protected by a guard of such warships, large convoys of Venetian merchant ships could sail without fear of plunder by pirates.

In 1420, at the time of Venice's greatest commercial expansion, the doge, Tommaso Mocenigo, estimated the annual turnover of Venetian commerce to be ten million ducats, of which two million was profit. With this enormous income to spend, the Venetians built a city of splendid palaces, which rose like a shimmering vision above the waters of the lagoon.

The Venetians were passionately fond of pleasure, pageantry and art. The cross-shaped church of Saint Mark rang with the music of great composers, such as Gabrieli and Palestrina; and elegant triumphal music accompanied the doge as he went each year to throw a golden ring into the waters of the lagoon, an act which symbolized the marriage of Venice to the sea.

Like the Athenians after their victory in the Persian war, the Venetians were both rich and confident. Their enormous wealth allowed them to sponsor music, art, literature and science. The painters Titian, Veronese, Giorgione and Tintoretto, the sculptor Verrochio and the architect Palladio all worked in Venice at the height of the city's prosperity.

The self-confidence of the Venetians produced a degree of intellectual freedom which was not found elsewhere in Europe at that time, except in Florence. At the University of Padua, which was supported by Venetian funds, students from all countries were allowed to study regardless of their religious beliefs. It was at Padua that Copernicus studied, and there Andreas Vesalius began the research which led to his great book on anatomy. At one point in his career, Galileo also worked at the University of Padua.

The prosperity of 15th century Florence, like that of Venice, was based on commerce. In the case of Florence, the trade was not by sea, but along the main north-south road of Italy, which crossed the Arno at Florence. In addition to this trade, Florence also had an important textile industry. The Florentines imported wool from France, Flanders, Holland and England. They wove the wool into cloth and dyed it, using superior techniques, many of which had come to them from India by way of the Islamic civilization. Later, silk weaving (again using eastern techniques) became important. Florentine banking was also highly developed, and our present banking system is derived from Florentine commercial practices.

Humanism

In the 15th and 16th centuries, Florence was ruled by a syndicate of wealthy merchant families, the greatest of whom were the Medicis. Cosimo de' Medici, the unofficial ruler of Florence from 1429 to 1464, was a banker whose personal wealth exceeded that of most contemporary kings. In spite of his great fortune, Cosimo lived in a relatively modest style, not wishing to attract attention or envy; and in general, the Medici influence tended to make life in Florence more modest than life in Venice.

Cosimo de' Medici is important in the history of ideas as one of the greatest patrons of the revival of Greek learning. In 1439, the Greek Patriarch and the Emperor John Palaeologus attended in Florence a council for the reunification of the Greek and Latin churches. The Greek-speaking Byzantine scholars who accompanied the Patriarch brought with them a number of books by Plato which excited the intense interest and admiration of Cosimo de' Medici.

Cosimo immediately set up a Platonic Academy in Florence, and chose a young man named Marsilio Ficino as its director. In one of his letters to Ficino, Cosimo says:

"Yesterday I came to the villa of Careggi, not to cultivate my fields, but my soul. Come to us, Marsilio, as soon as possible. Bring with you our Plato's book *De Summo Bono*. This, I suppose, you have already translated from the Greek language into Latin, as you promised. I desire nothing so much as to know the road to happiness. Farewell, and do not come without the Orphian lyre!"

Cosimo's grandson, Lorenzo the Magnificent, continued his grandfather's policy of reviving classical Greek learning, and he became to the golden age of Florence what Pericles had been too the golden age of Athens. Among the artists whom Lorenzo sponsored were Michelangelo, Botticelli and Donatello. Lorenzo established a system of bursaries and prizes for the support of students. He also gave heavy financial support to the University of Pisa, which became a famous university under Lorenzo's patronage. (It was later to be the university of Galileo and Fermi.)

At Florence, Greek was taught by scholars from Byzantium; and Poliziano, who translated Homer into Latin could say with justice: "Greek learning, long extinct in Greece itself, has come to life and lives again in Florence. There Greek literature is taught and studied, so that Athens, root and branch, has been transported to make her abode - not in Athens in ruins and in the hands of barbarians, but in Athens as she was, with her breathing spirit and her very soul."

Leonardo da Vinci

Against this background, it may seem strange that Lorenzo the Magnificent did not form a closer relationship with Leonardo da Vinci, the most talented student of Verrocchio's school in Florence. One might have expected a close friendship between the two men, since Lorenzo, only four years older than Leonardo, was always quick to recognize exceptional ability.

The explanation probably lies in Leonardo's pride and sensitivity, and in the fact that, while both men were dedicated to knowledge, they represented different points of view. Lorenzo was full of enthusiasm for the revival of classical learning, while Leonardo had already taken the next step: Rejecting all blind obedience to authority, including the authority of the ancients, he relied on his own observations. Lorenzo was fluent in Latin and Greek, and was widely educated in Greek philosophy, while Leonardo was ignorant of both languages and was largely self-taught in philosophy and science (although he had studied mathematics at the school of Benedetto d'Abacco).

While he did not form a close friendship with Lorenzo the Magnificent, Leonardo was lucky in becoming the friend and protegé of the distinguished Florentine mathematician, physician, geographer and astronomer, Paolo Toscanelli, who was also the friend and advisor of Columbus. (Toscanelli furnished Columbus with maps of the world and encouraged him in his project of trying to reach India and China by sailing westward. Toscanelli's maps mistakenly showed the Atlantic Ocean with Europe on one side, and Asia on the other!)

Gradually, under Toscanelli's influence, young Leonardo's powerful and original mind was drawn away from the purely representational aspects of art, and he became more and more involved in trying to understand the underlying structure and mechanism of the things which he observed in nature - the bodies of men and animals, the flight of birds, the flow of fluids and the features of the earth.

Both in painting and in science, Leonardo looked directly to nature for guidance, rather than to previous masters. He wrote:

"The painter will produce pictures of small merit if he takes as his standard the pictures of others; but if he will study from natural objects, he will produce good fruits... And I would say about these mathematical studies, that those who study the authorities and not the works of nature are descendents but not sons of nature."

In another place, Leonardo wrote:

"But first I will test with experiment before I proceed further, because my intention is to consult experience first, and then with reasoning to show why such experience is bound to operate in such a way. And that is the true rule by which those who analyze the effects of nature must proceed; and although nature begins with the cause and ends with the experience, we must follow the opposite course, namely (as I said before) begin with the experience and by means of it investigate the cause."

Lorenzo the Magnificent finally did help Leonardo in a backhanded way: In 1481, when Leonardo was 29 years old, Lorenzo sent him as an emissary with a gift to the Duke of Milan, Ludovico Sforza. Although Milan was far less culturally developed than Florence, Leonardo stayed there for eighteen years under the patronage of Sforza. He seemed to work better in isolation, without the competition and criticism of the Florentine intellectuals.

In Milan, Leonardo began a series of anatomical studies which he developed into a book, intended for publication. Leonardo's anatomical drawings make previous work in this field seem like the work of children, and in many respects his studies were not surpassed for hundreds of years. Some of his anatomical drawings were published in a book by Fra Pacioli, and they were very influential; but most of the thousands of pages of notes which Leonardo wrote have only been published in recent years.

The notebooks of Leonardo da Vinci cover an astonishing range of topics: mathematics, physics, astronomy, optics, engineering, architecture, city planing, geology, hydrodynamics and aerodynamics, anatomy, painting and perspective, in addition to purely literary works. He was particularly interested in the problem of flight, and he made many studies of the flight of birds and bats in order to design a flying machine. Among his notes are designs for a helicopter and a parachute, as well as for a propeller-driven flying machine.

In astronomy, Leonardo knew that the earth rotates about its axis once every day, and he understood the physical law of inertia which makes this motion imperceptible to us except through the apparent motion of the stars. In one of his notebooks, Leonardo wrote: "The sun does not move." However, he did not publish his ideas concerning astronomy. Leonardo was always planning to organize and publish his notes, but he was so busy with his many projects that he never finished the task. At one point, he wrote what sounds like a cry of despair: "Tell me, tell me if anything ever was finished!"

Leonardo ended his life in the court of the king of France, Francis I. The king gave him a charming chateau in which to live, and treated him with great respect. Francis I visited Leonardo frequently in order to discuss philosophy, science and art; and when Leonardo died, the king is said to have wept openly.

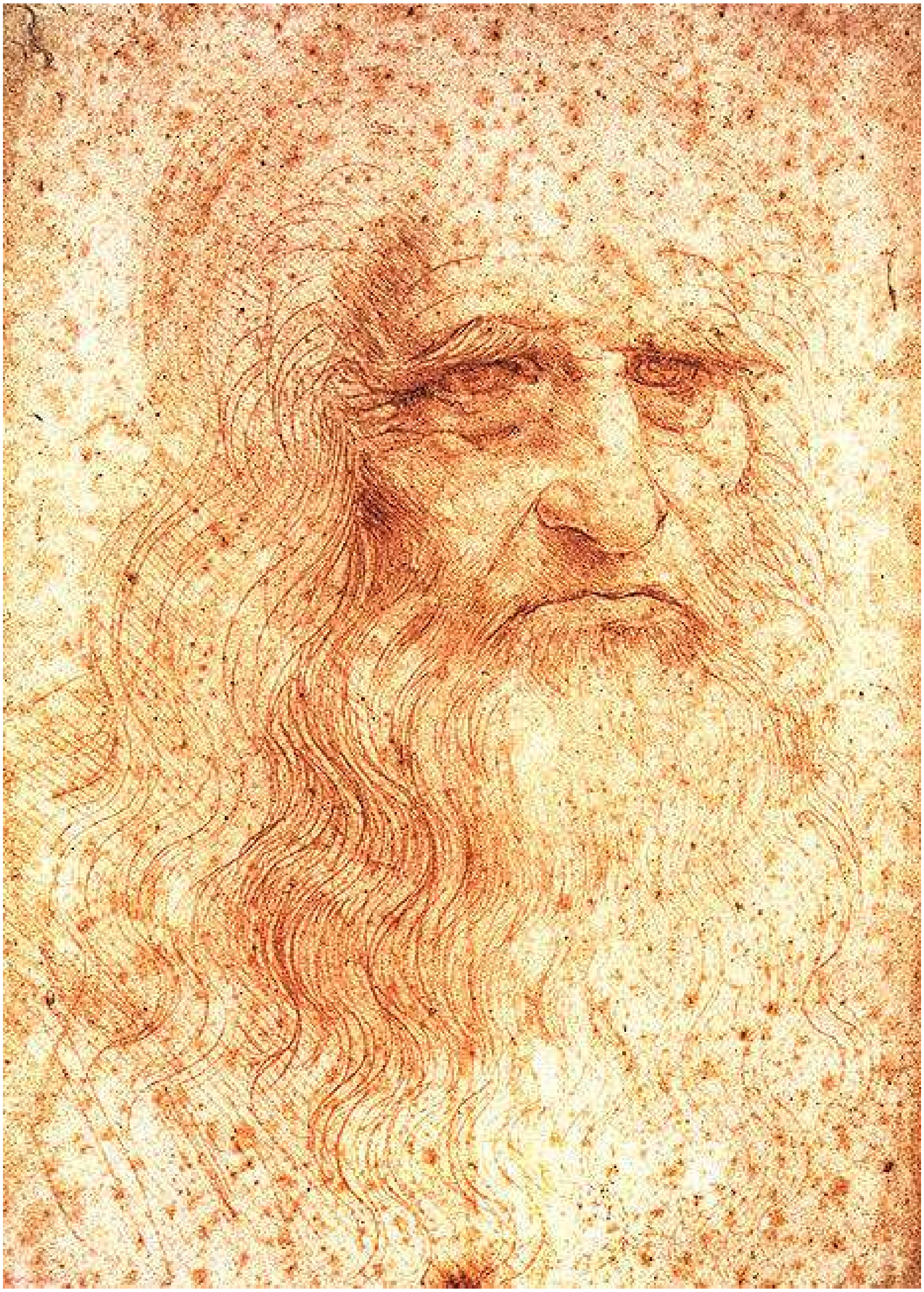

Figure 2.1: **Leonardo da Vinci's self portrait as an old man.**

Figure 2.2: **Leonardo's portrait of a lady with an ermine, painted in 1489-1490. The painting is now at the National Museum in Krakow, Poland.**

Figure 2.3: **Head of a Woman, a drawing by Leonardo.**

2.2 Some of Leonardo's engineering drawings

According to Wikipedia,

> **Leonardo was a master of mechanical principles. He utilized leverage and cantilevering, pulleys, cranks, gears, including angle gears and rack and pinion gears; parallel linkage, lubrication systems and bearings. He understood the principles governing momentum, centripetal force, friction and the aerofoil and applied these to his inventions. His scientific studies remained unpublished with, for example, his manuscripts describing the processes governing friction predating the introduction of Amontons' laws of friction by 150 years.**
>
> **It is impossible to say with any certainty how many or even which of his inventions passed into general and practical use, and thereby had impact over the lives of many people. Among those inventions that are credited with passing into general practical use are the strut bridge, the automated bobbin winder, the rolling mill, the machine for testing the tensile strength of wire and the lens-grinding machine pictured at right. In the lens-grinding machine, the hand rotation of the grinding wheel operates an angle-gear, which rotates a shaft, turning a geared dish in which sits the glass or crystal to be ground. A single action rotates both surfaces at a fixed speed ratio determined by the gear.**

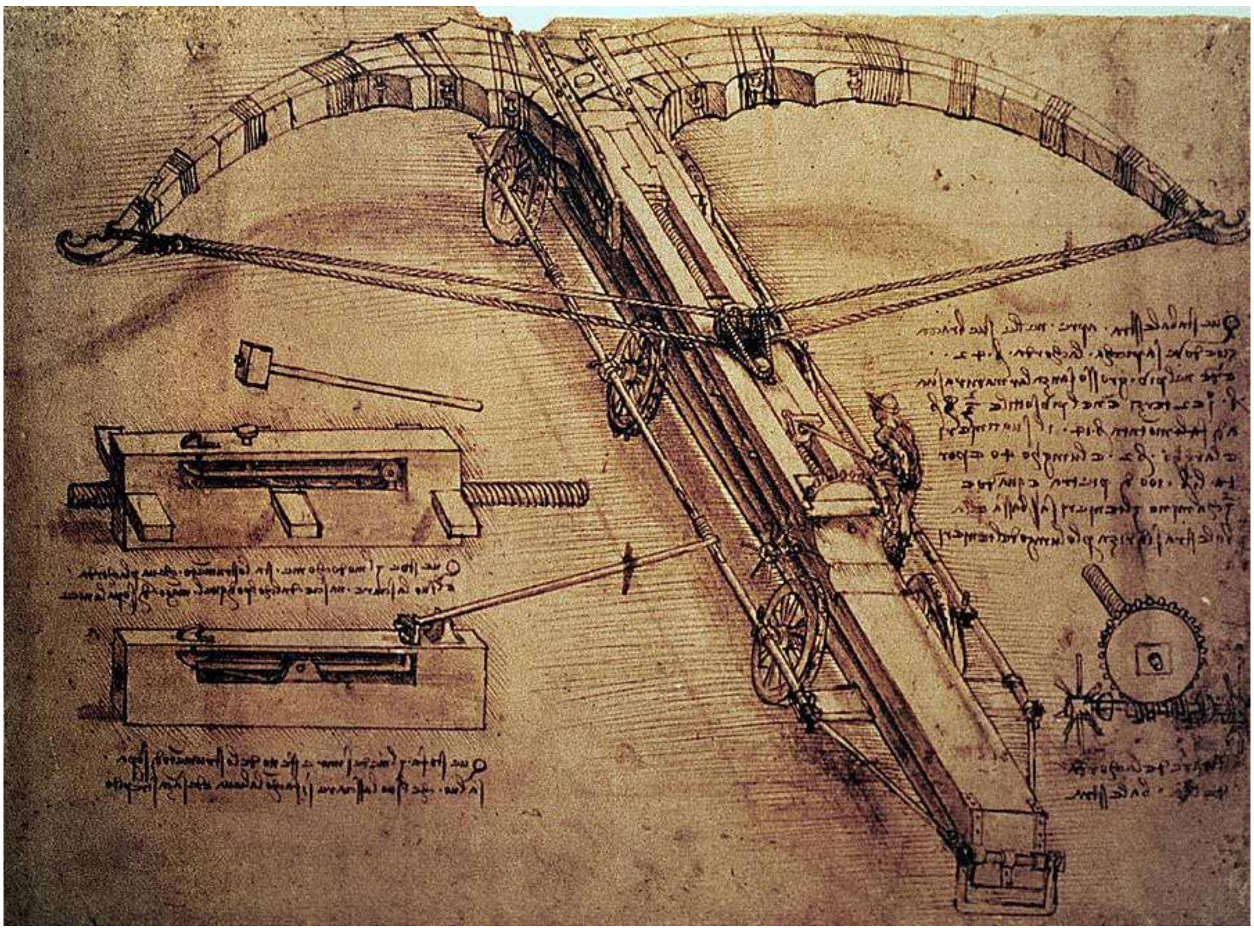

Figure 2.4: **Design for a crossbow.**

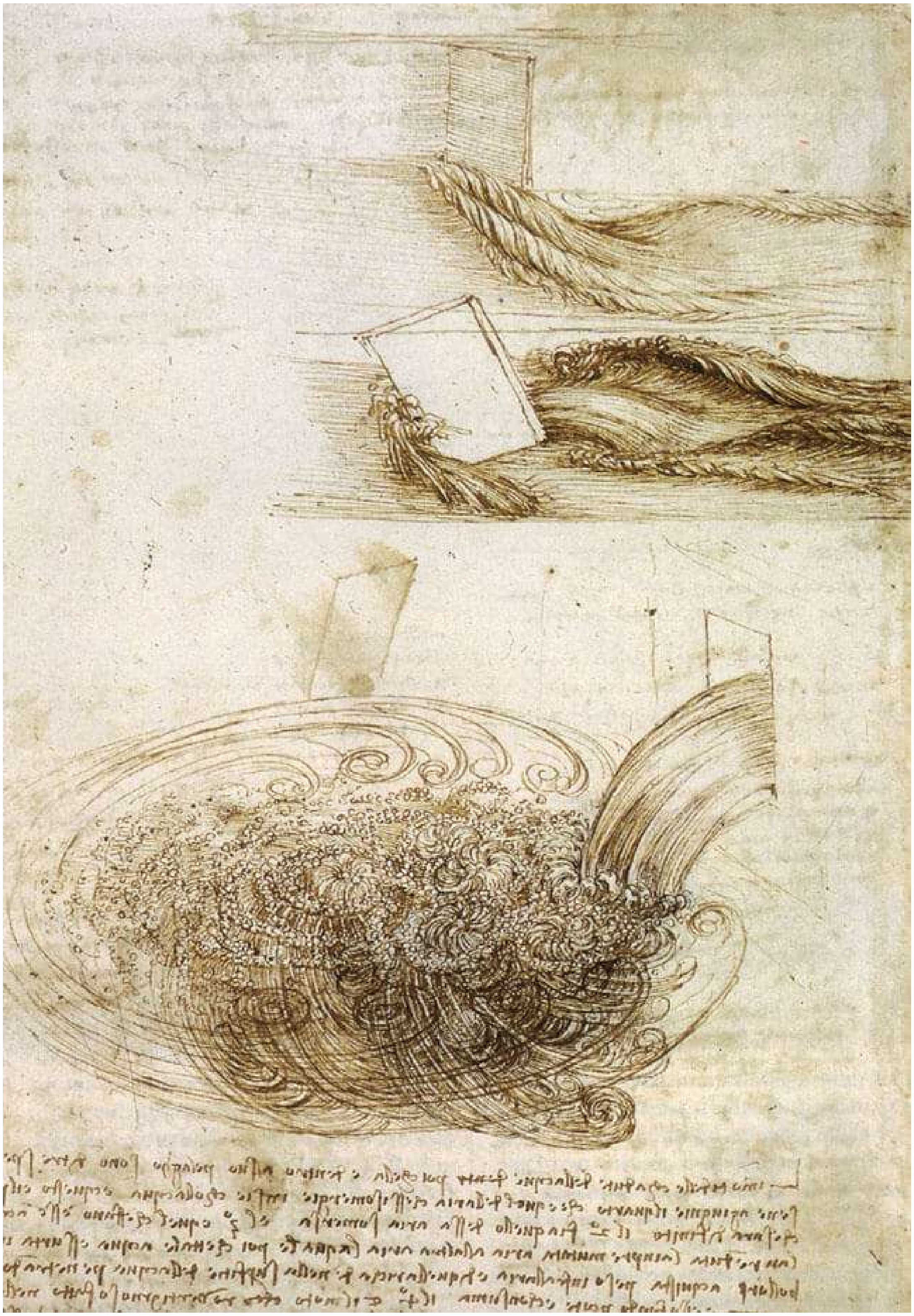

Figure 2.5: **Studies of Water Passing Obstacles.**

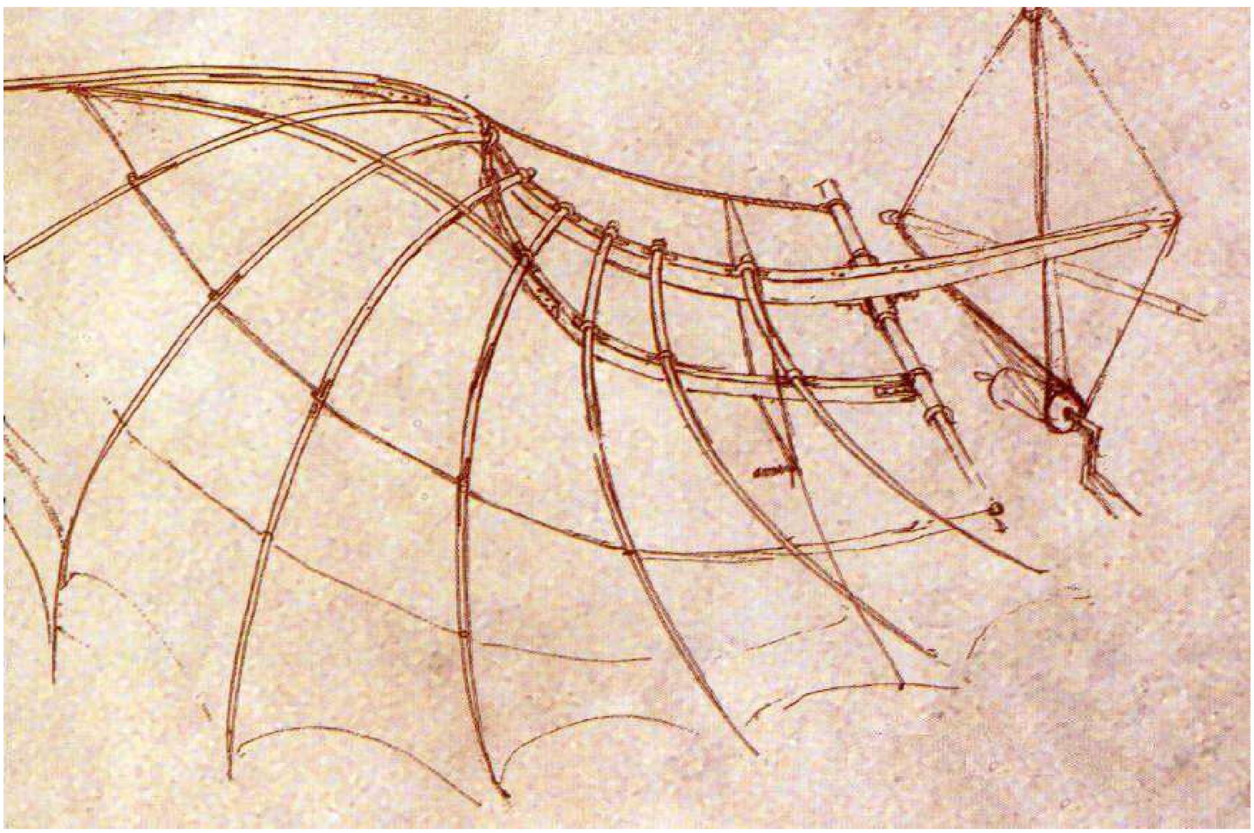

Figure 2.6: **Wing Construction with Engineering Design.**

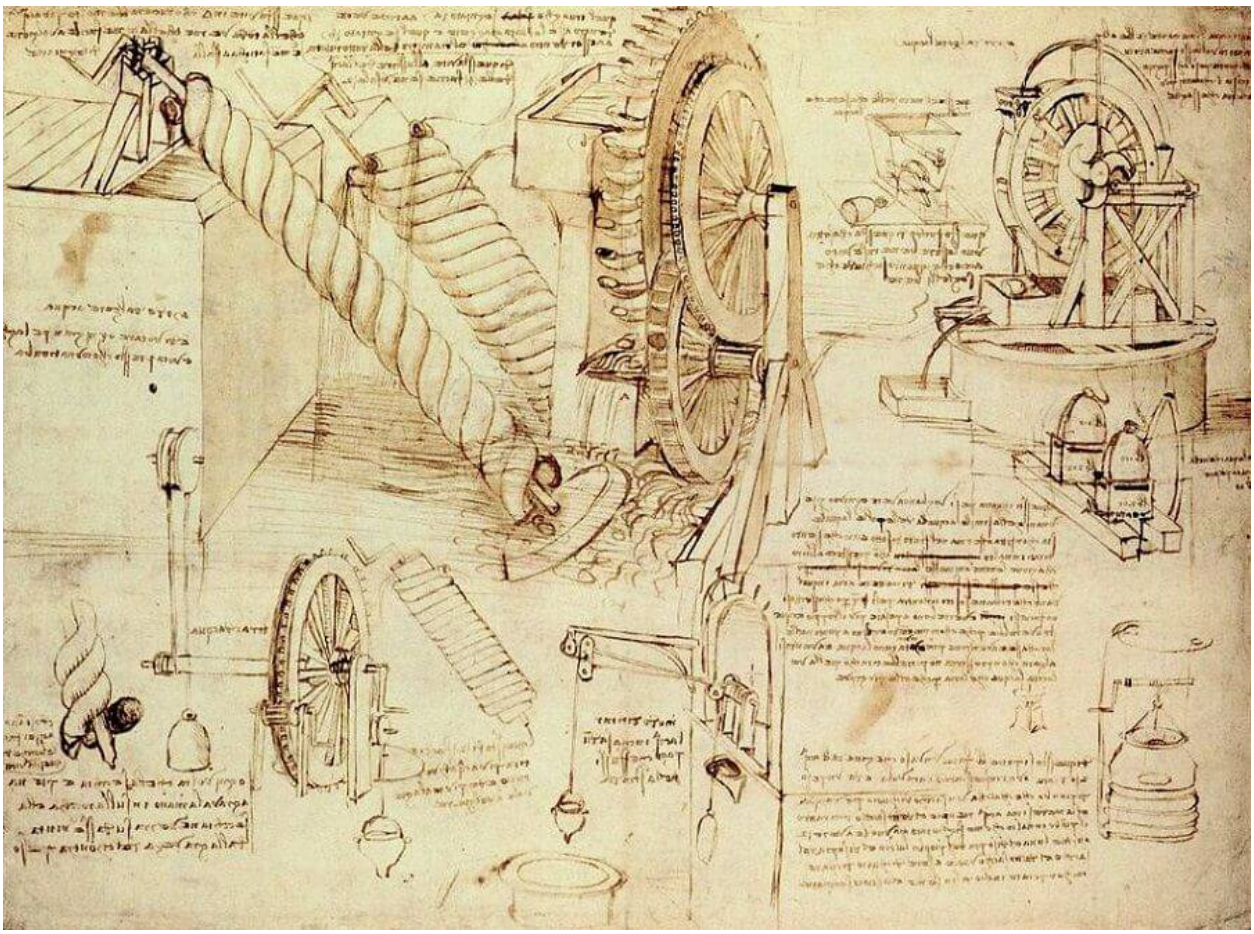

Figure 2.7: **Water Lifting Devices.**

Figure 2.8: **A Plan of Imola.**

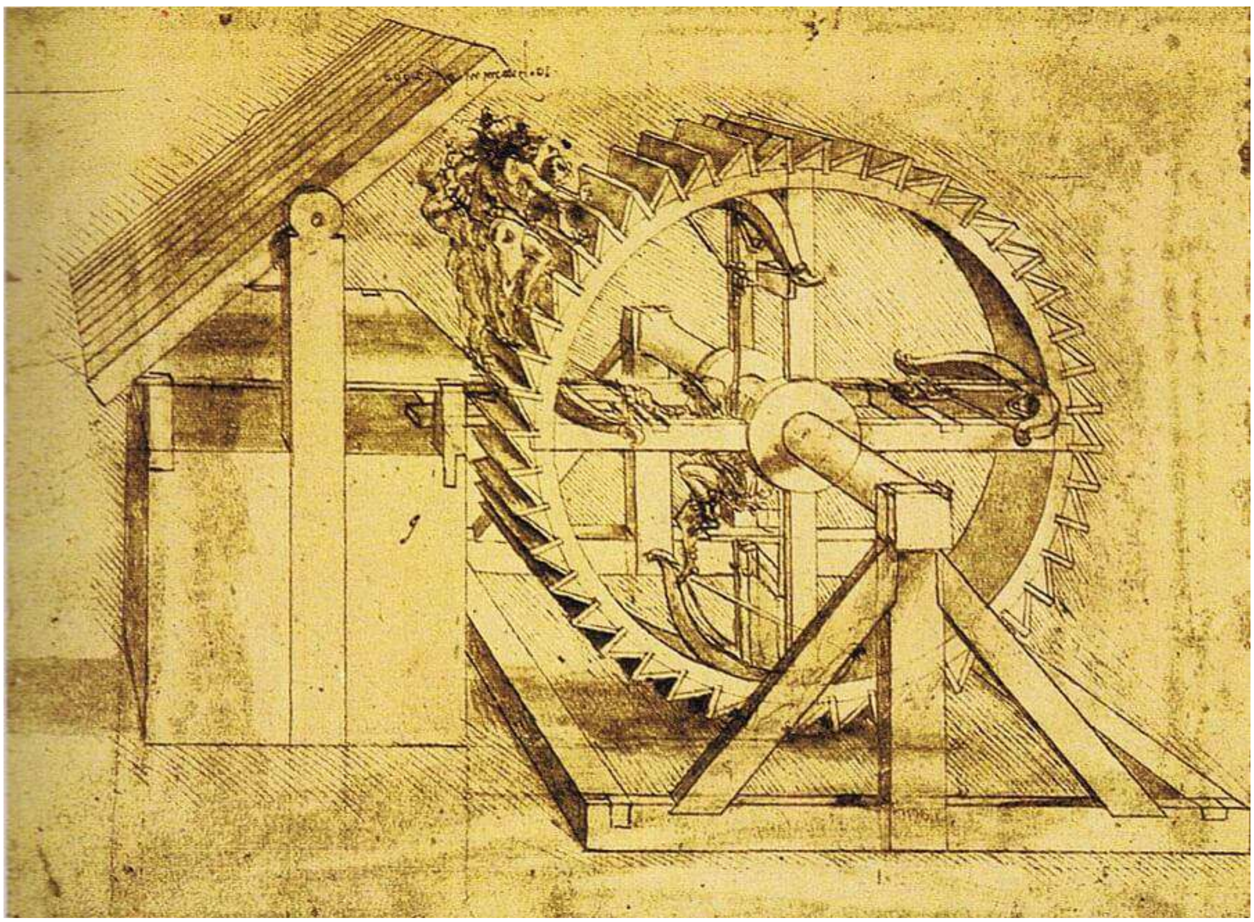

Figure 2.9: **Machine Gun.**

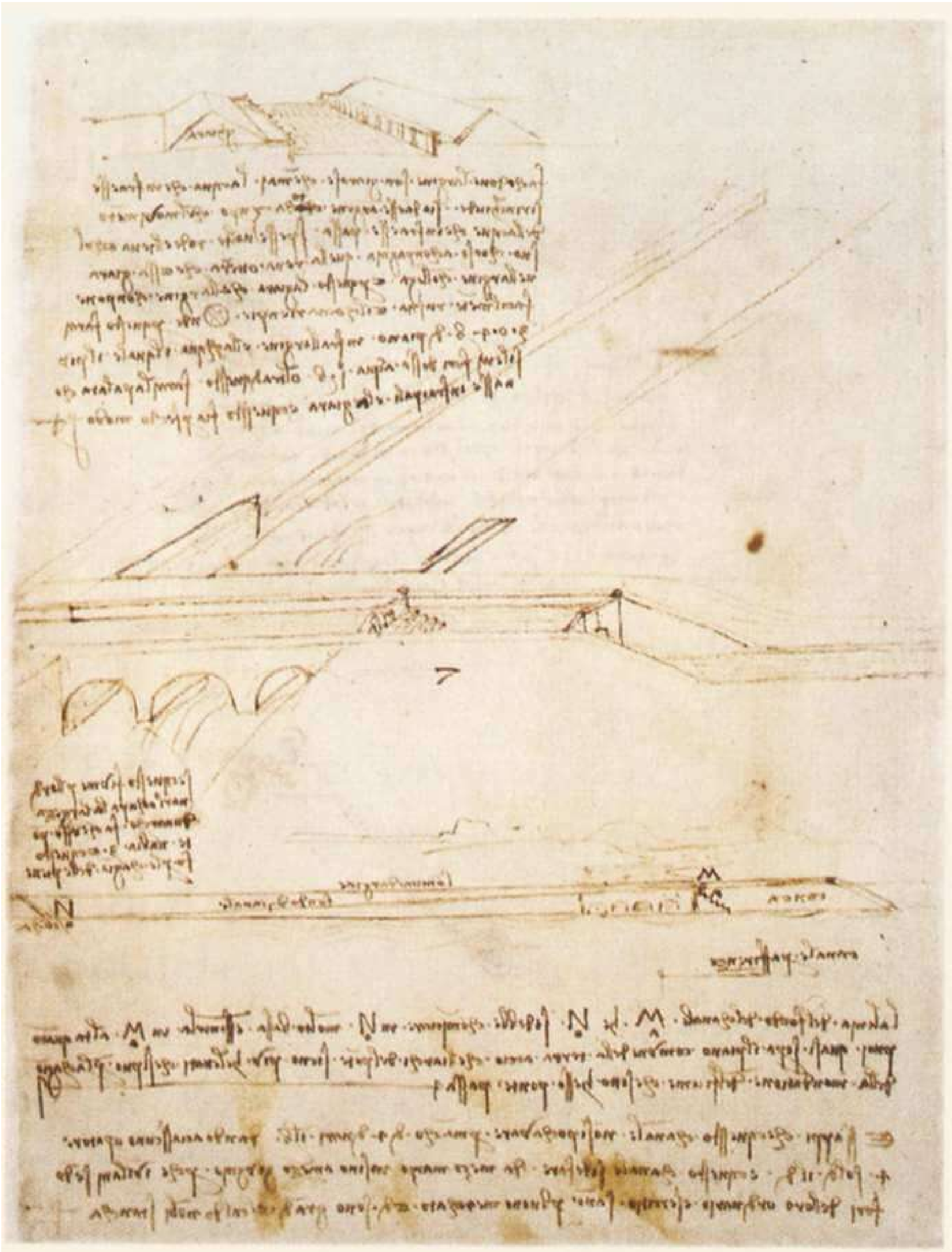

Figure 2.10: **Canal bridge.**

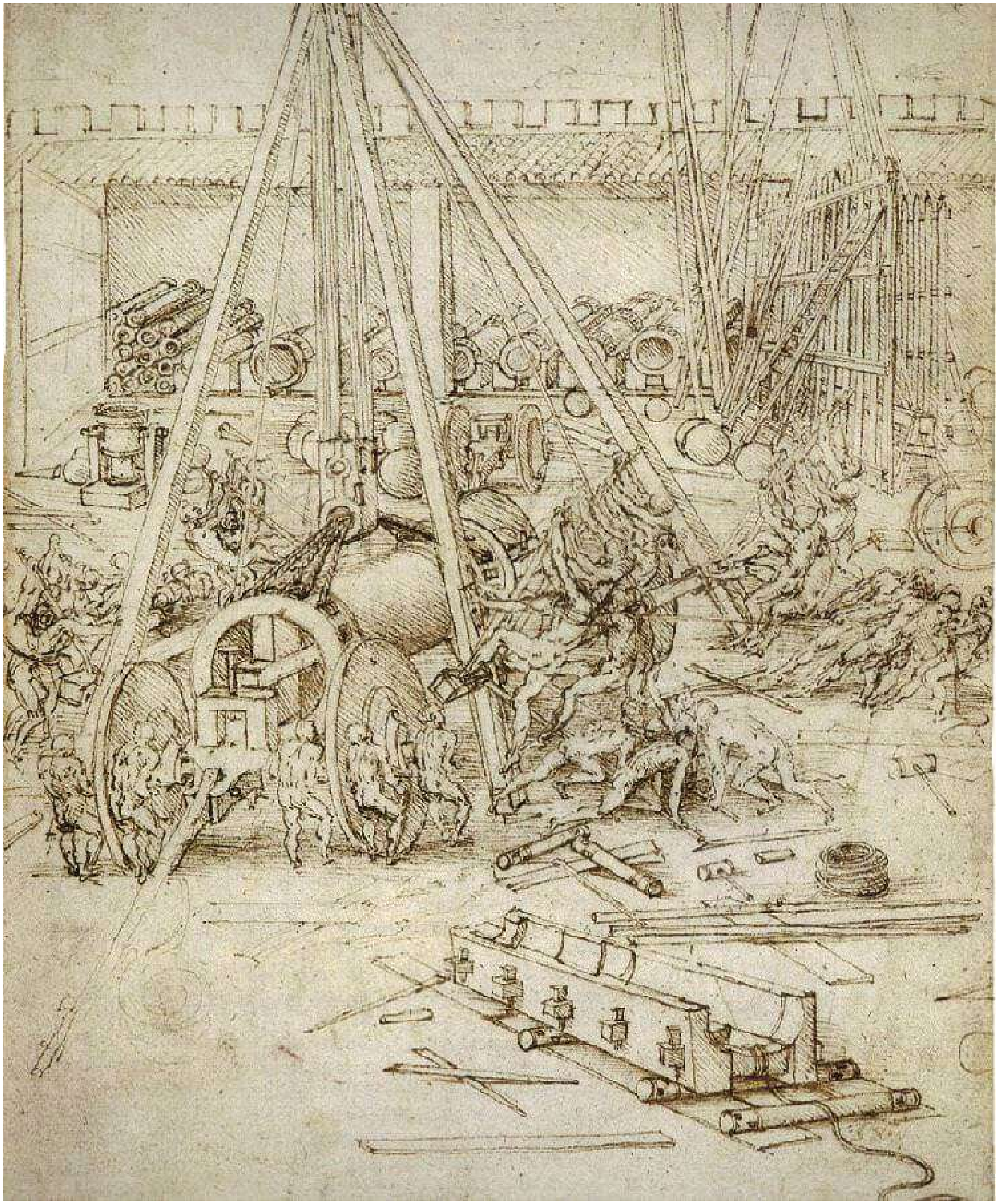

Figure 2.11: **Cannon Foundry, 1488.**

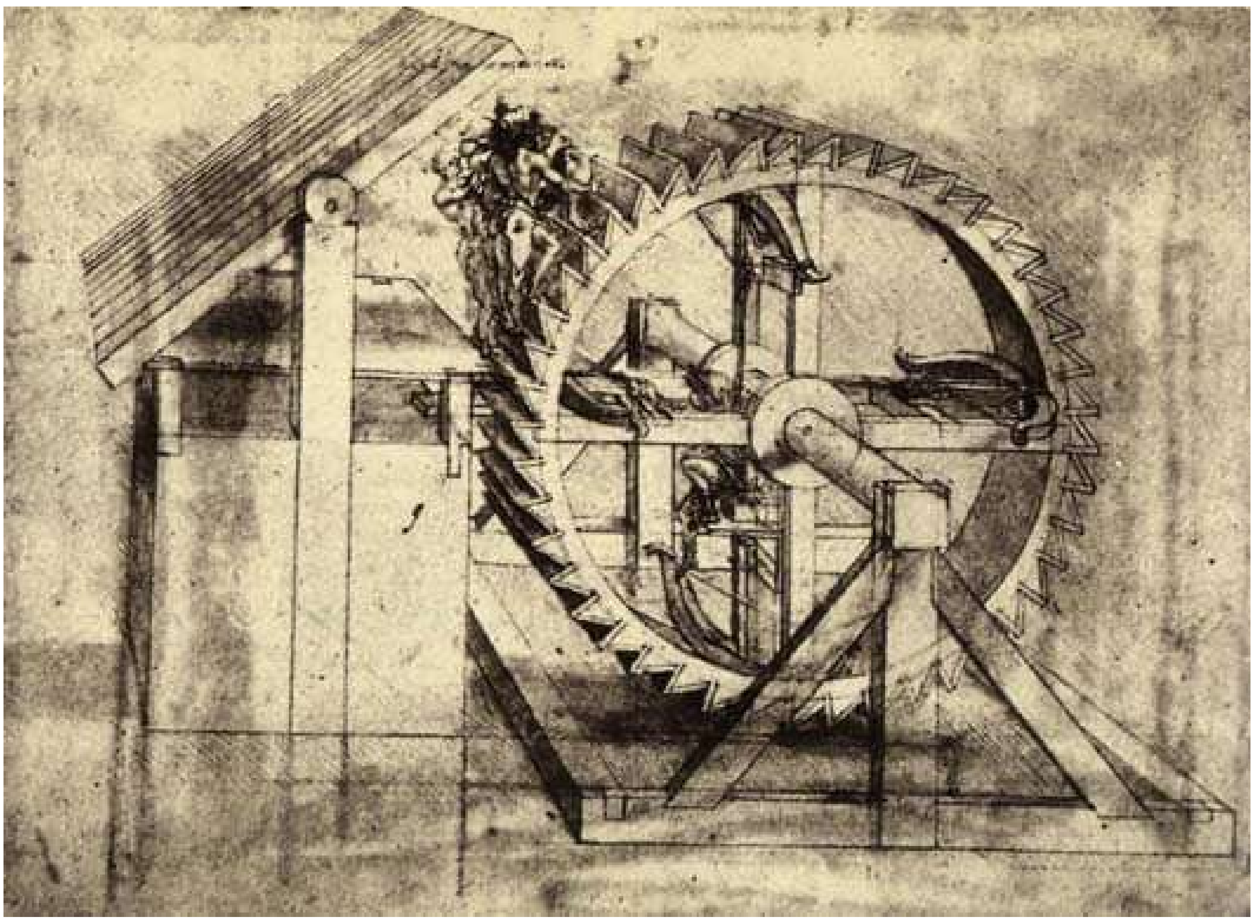

Figure 2.12: **Crossbow machine.**

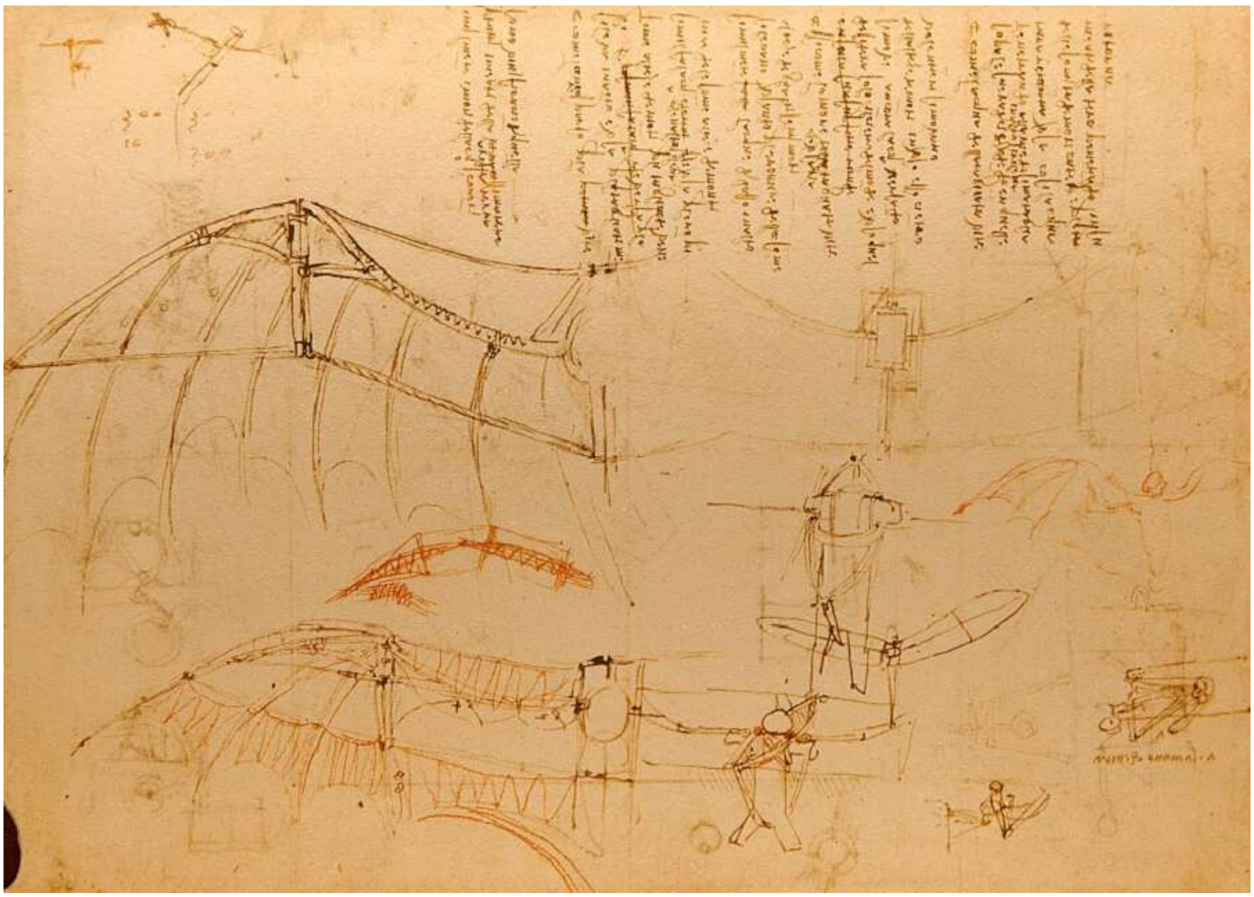

Figure 2.13: **Design for a flying machine.**

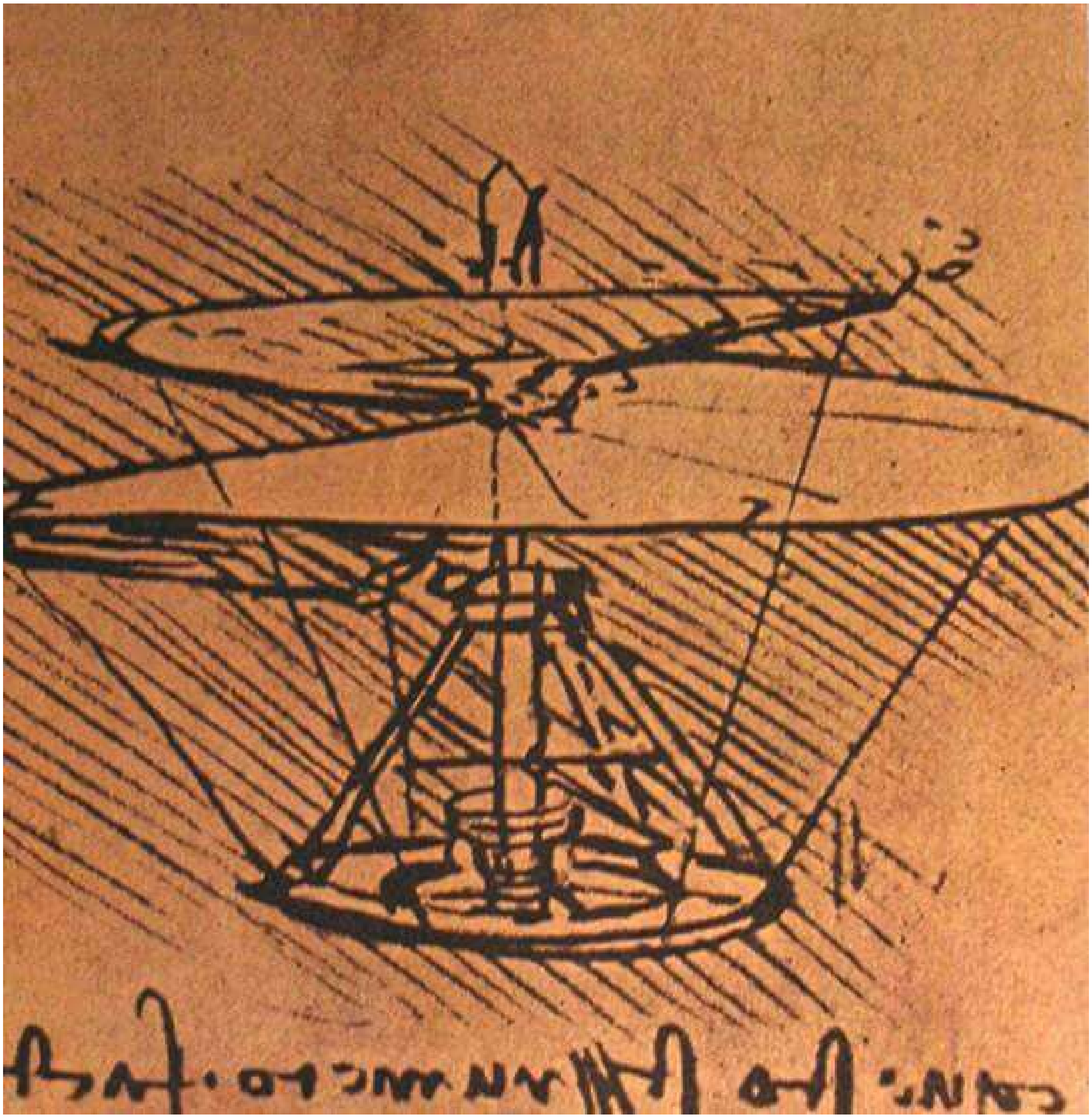

Figure 2.14: **Design for a helicopter.**

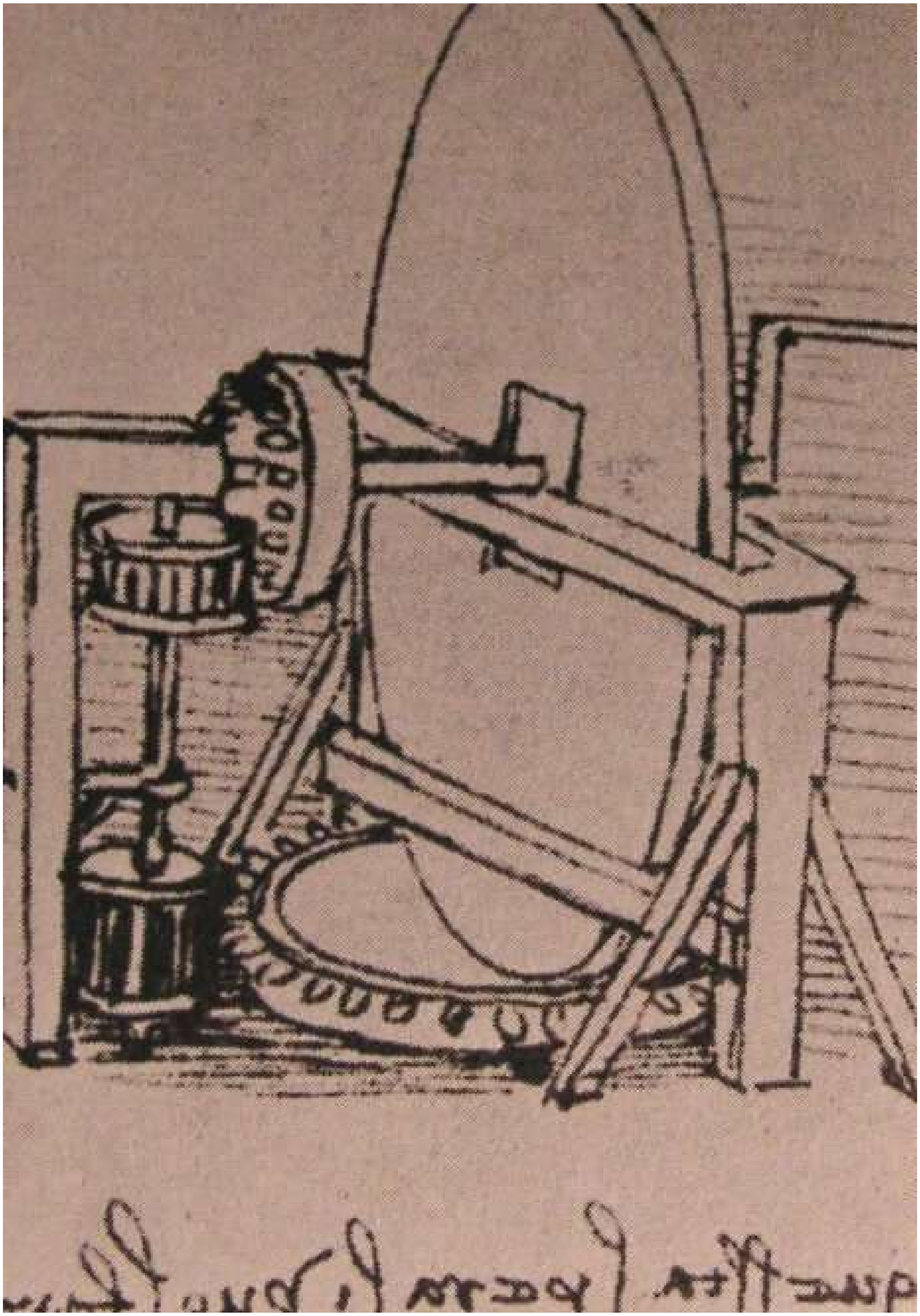

Figure 2.15: **Design for a machine for grinding convex lenses.**

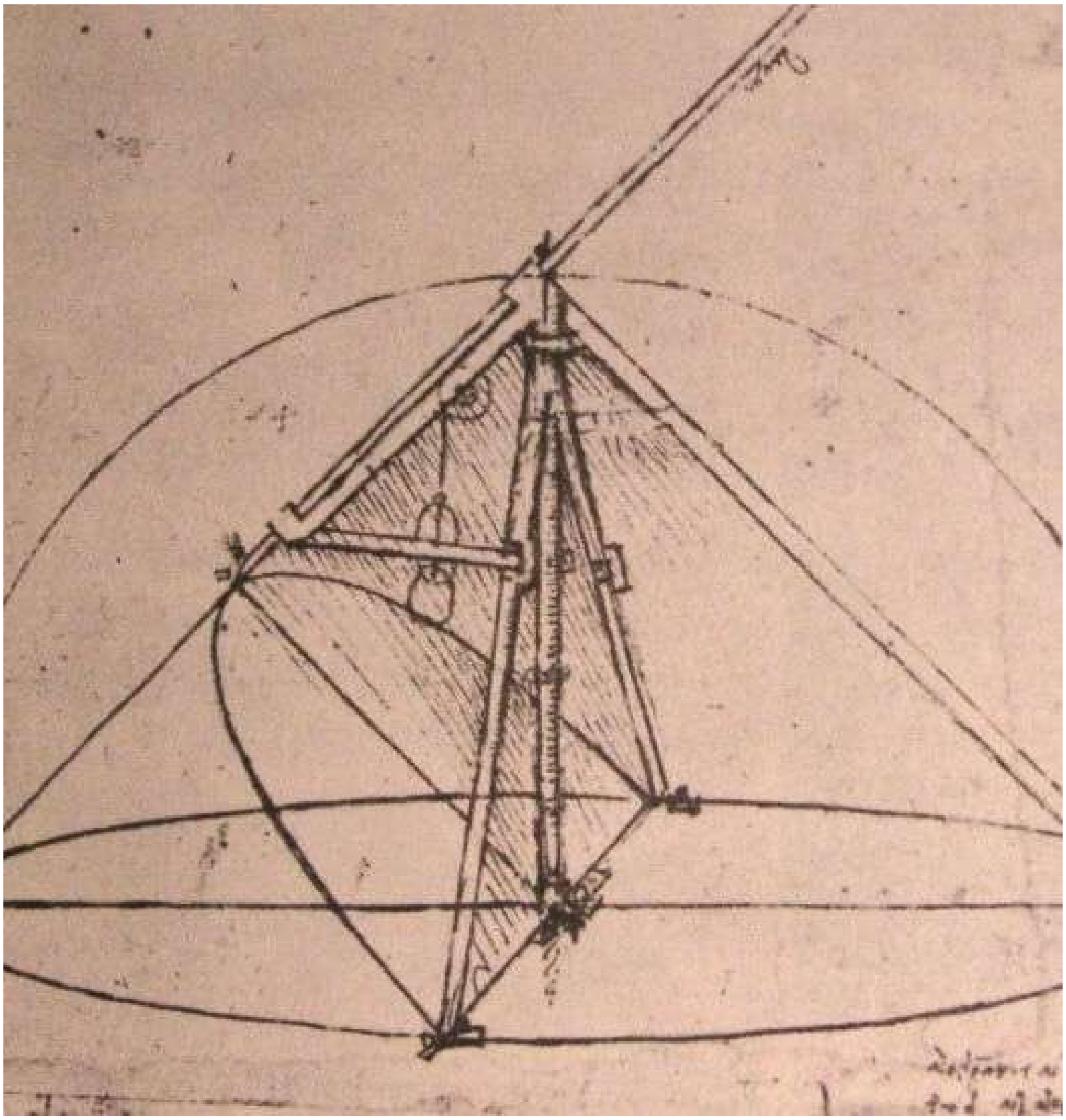

Figure 2.16: **Design for a parabolic compass.**

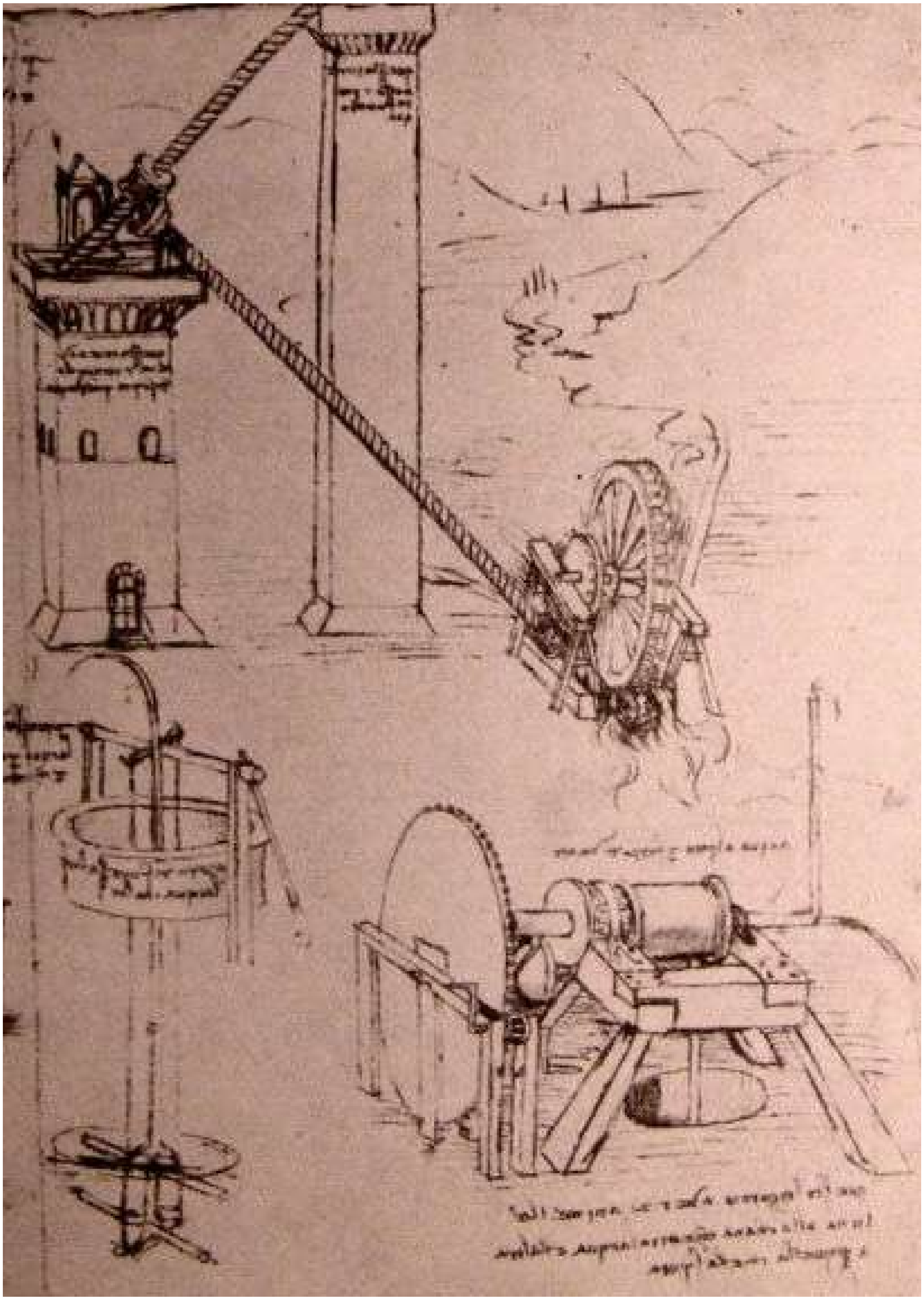

Figure 2.17: **Drawings of machines.**

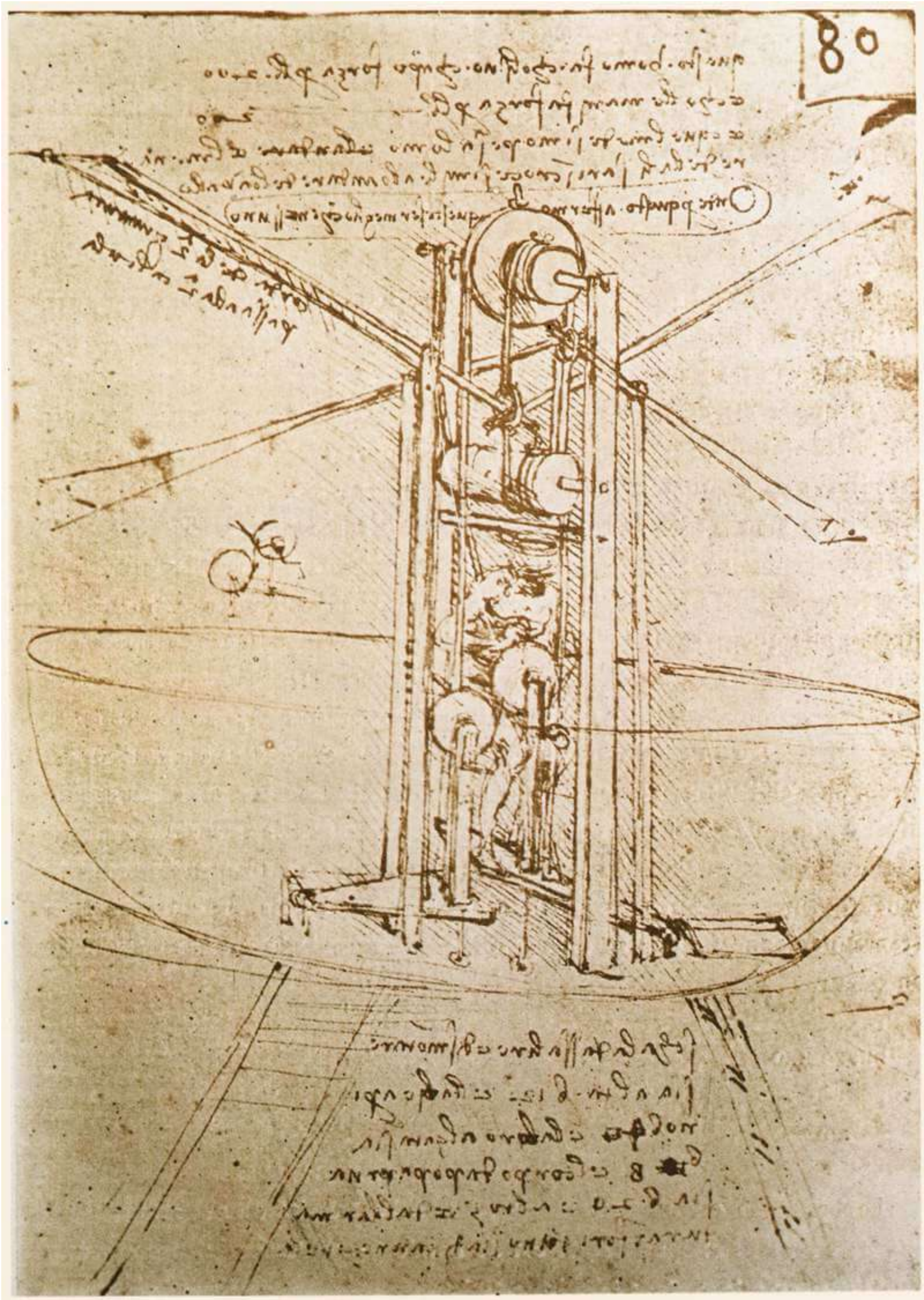

Figure 2.18: **Flying machine.**

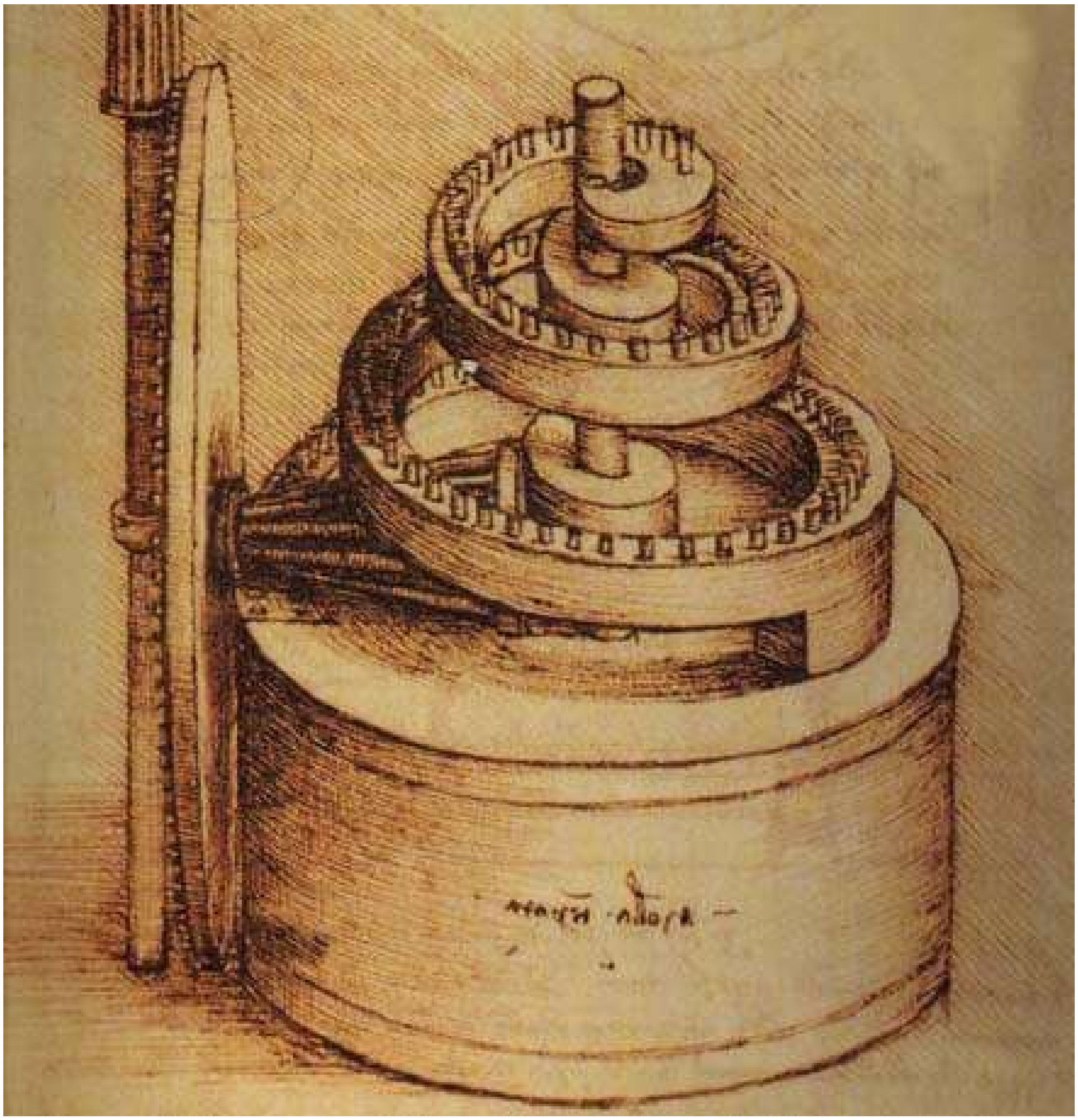

Figure 2.19: **Spring device.**

Suggestions for further reading

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Chapter 3

THE INVENTION OF PRINTING

3.1 China

It was during the T'ang period that the Chinese made an invention of immense importance to the cultural evolution of mankind. This was the invention of printing. Together with writing, printing is one of the key inventions which form the basis of human cultural evolution.

Printing was invented in China in the 8th or 9th century A.D., probably by Buddhist monks who were interested in producing many copies of the sacred texts which they had translated from Sanskrit. The act of reproducing prayers was also considered to be meritorious by the Buddhists.

The Chinese had for a long time followed the custom of brushing engraved official seals with ink and using them to stamp documents. The type of ink which they used was7 made from lamp-black, water and binder. In fact, it was what we now call "India ink". However, in spite of its name, India ink is a Chinese invention, which later spread to India, and from there to Europe.

We mentioned that paper of the type which we now use was invented in China in the first century A.D.. Thus, the Buddhist monks of China had all the elements which they needed to make printing practical: They had good ink, cheap, smooth paper, and the tradition of stamping documents with ink-covered engraved seals. The first block prints which they produced date from the 8th century A.D.. They were made by carving a block of wood the size of a printed page so that raised characters remained, brushing ink onto the block, and pressing this onto a sheet of paper.

The oldest known printed book, the "Diamond Sutra", is dated 868 A.D.., and it consists of only six printed pages. In was discovered in 1907 by an English scholar who obtained permission from Buddhist monks in Chinese Turkestan to open some walled-up monastery rooms, which were said to have been sealed for 900 years. The rooms were found to contain a library of about 15,000 manuscripts, among which was the Diamond Sutra.

Block printing spread quickly throughout China, and also reached Japan, where woodblock printing ultimately reached great heights in the work of such artists as Hiroshige and Hokusai. The Chinese made some early experiments with movable type, but movable type never became popular in China, because the Chinese written language contains 10,000 characters. However, printing with movable type was highly successful in Korea as early as the 15th century A.D..

The unsuitability of the Chinese written language for the use of movable type was the greatest tragedy of the Chinese civilization. Writing had been developed at a very early stage in Chinese history, but the system remained a pictographic system, with a different character for each word. A phonetic system of writing was never developed.

The failure to develop a phonetic system of writing had its roots in the Chinese imperial system of government. The Chinese empire formed a vast area in which many different languages were spoken. It was necessary to have a universal language of some kind in order to govern such an empire. The Chinese written language solved this problem admirably.

Suppose that the emperor sent identical letters to two officials in different districts. Reading the letters aloud, the officials might use entirely different words, although the characters in the letters were the same. Thus the Chinese written language was a sort of "Esperanto" which allowed communication between various language groups, and its usefulness as such prevented its replacement by a phonetic system.

The invention of block printing during the T'ang dynasty had an enormously stimulating effect on literature, and the T'ang period is regarded as the golden age of Chinese lyric poetry. A collection of T'ang poetry, compiled in the 18th century, contains 48,900 poems by more than 2,000 poets.

Figure 3.1: **The Diamond Sutra, 868 A.D., is the first known printed book.**

3.2 Islamic civilization and printing

Some Islamic contributions to civilization

In the 5th century A.D., there was a split in the Christian church of Byzantium;and the Nestorian church, separated from the official Byzantine church. The Nestorians were bitterly persecuted by the Byzantines, and therefore they migrated, first to Mesopotamia, and later to south-west Persia. (Some Nestorians migrated as far as China.)

During the early part of the middle ages, the Nestorian capital at Gondisapur was a great center of intellectual activity. The works of Plato, Aristotle, Hippocrates, Euclid, Archimedes, Ptolemy, Hero and Galen were translated into Syriac by Nestorian scholars, who had brought these books with them from Byzantium.

Among the most distinguished of the Nestorian translators were the members of a family called Bukht-Yishu (meaning "Jesus hath delivered"), which produced seven generations of outstanding scholars. Members of this family were fluent not only in Greek and Syriac, but also in Arabic and Persian.

In the 7th century A.D., the Islamic religion suddenly emerged as a conquering and proselytizing force. Inspired by the teachings of Mohammad (570 A.D. - 632 A.D.), the Arabs and their converts rapidly conquered western Asia, northern Africa, and Spain. During the initial stages of the conquest, the Islamic religion inspired a fanaticism in its followers which was often hostile to learning. However, this initial fanaticism quickly changed to an appreciation of the ancient cultures of the conquered territories; and during the middle ages, the Islamic world reached a very high level of culture and civilization.

Thus, while the century from 750 to 850 was primarily a period of translation from Greek to Syriac, the century from 850 to 950 was a period of translation from Syriac to Arabic. It was during this latter century that Yuhanna Ibn Masawiah (a member of the Bukht-Yishu family, and medical advisor to Caliph Harun al-Rashid) produced many important translations into Arabic.

The skill of the physicians of the Bukht-Yishu family convinced the Caliphs of the value of Greek learning; and in this way the family played an extremely important role in the preservation of the western cultural heritage. Caliph al-Mamun, the son of Harun al-Rashid, established at Baghdad a library and a school for translation, and soon Baghdad replaced Gondisapur as a center of learning.

The English word "chemistry" is derived from the Arabic words *"al-chimia"*, which mean "the changing". The earliest alchemical writer in Arabic was Jabir (760-815), a friend of Harun al-Rashid. Much of his writing deals with the occult, but mixed with this is a certain amount of real chemical knowledge. For example, in his *Book of Properties*, Jabir gives the following recipe for making what we now call lead hydroxycarbonate (white lead), which is used in painting and pottery glazes: "Take a pound of litharge, powder it well and heat it gently with four pounds of vinegar until the latter is reduced to half its original volume. The take a pound of soda and heat it with four pounds of fresh water until the volume of the latter is halved. Filter the two solutions until they are quite clear, and then gradually add the solution of soda to that of the litharge. A white substance is formed, which settles to the bottom. Pour off the supernatant water, and leave the residue to dry. It will become a salt as white as snow."

Another important alchemical writer was Rahzes (c. 860 - c. 950). He was born in the ancient city of Ray, near Teheran, and his name means "the man from Ray". Rahzes studied medicine in Baghdad, and he became chief physician at the hospital there. He wrote the first accurate descriptions of smallpox and measles, and his medical writings include methods for setting broken bones with casts made from plaster of Paris. Rahzes was the first person to classify substances into vegetable, animal and mineral. The word *"al-kali"*, which appears in his writings, means "the calcined" in Arabic. It is the source of our word "alkali", as well as of the symbol K for potassium.

The greatest physician of the middle ages, Avicenna, (Abu-Ali al Hussein Ibn Abdullah Ibn Sina, 980-1037), was also a Persian, like Rahzes. More than a hundred books are attributed to him. They were translated into Latin in the 12th century, and they were among the most important medical books used in Europe until the time of Harvey. Avicenna also wrote on alchemy, and he is important for having denied the possibility of transmutation of elements.

In mathematics, one of the most outstanding Arabic writers was al-Khwarizmi (c. 780 - c. 850). The title of his book, *Ilm al-jabr wa'd muqabalah*, is the source of the English word "algebra". In Arabic *al-jabr* means "the equating". Al-Khwarizmi's name has also become an English word, "algorism", the old word for arithmetic. Al-Khwarizmi drew from both Greek and Hindu sources, and through his writings the decimal system and the

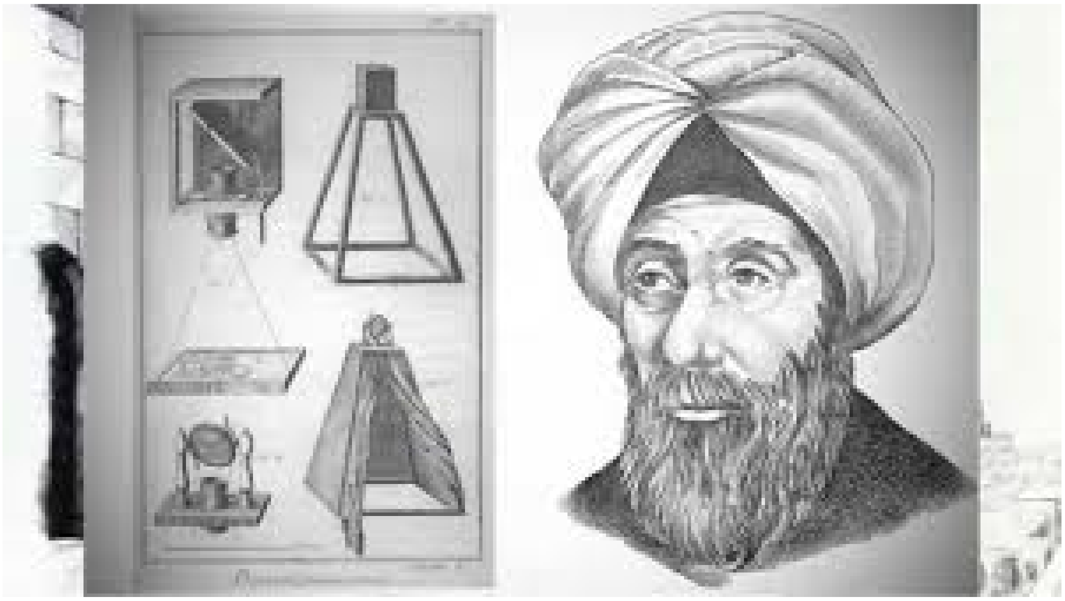

Figure 3.2: **Al-Hazen invented the camera-obscura during the years 1012-1021. It was a forerunner of the modern camera.**

use of zero were transmitted to the west.

One of the outstanding Arabic physicists was al-Hazen (965-1038). He made the mistake of claiming to be able to construct a machine which could regulate the flooding of the Nile. This claim won him a position in the service of the Egyptian Caliph, al-Hakim. However, as al-Hazen observed Caliph al-Hakim in action, he began to realize that if he did not construct his machine immediately, he was likely to pay with his life! This led al-Hazen to the rather desperate measure of pretending to be insane, a ruse which he kept up for many years. Meanwhile he did excellent work in optics, and in this field he went far beyond anything done by the Greeks.

Al-Hazen studied the reflection of light by the atmosphere, an effect which makes the stars appear displaced from their true positions when they are near the horizon; and he calculated the height of the atmospheric layer above the earth to be about ten miles. He also studied the rainbow, the halo, and the reflection of light from spherical and parabolic mirrors. In his book, *On the Burning Sphere*, he shows a deep understanding of the properties of convex lenses. Al-Hazen also used a dark room with a pin-hole opening to study the image of the sun during an eclipses. This is the first mention of the *camera obscura*, and it is perhaps correct to attribute the invention of the *camera obscura* to al-Hazen.

Another Islamic philosopher who had great influence on western thought was Averröes, who lived in Spain from 1126 to 1198. His writings took the form of thoughtful commentaries on the works of Aristotle. He shocked both his Moslem and his Christian readers by maintaining that the world was not created at a definite instant, but that it instead evolved over a long period of time, and is still evolving.

Like Aristotle, Averröes seems to have been groping towards the ideas of evolution which were later developed in geology by Steno, Hutton and Lyell and in biology by Darwin and Wallace. Much of the scholastic philosophy which developed at the University of Paris during the 13th century was aimed at refuting the doctrines of Averröes; but nevertheless, his ideas survived and helped to shape the modern picture of the world.

Muslims in Egypt and probably elsewhere were using printing to mass-produce texts as early as the 10th century. Dozens of examples of their output are preserved in museums and libraries, but have, until recently, been overlooked and neglected by scholars. This phenomenon is yet another example of the 1000-year missing history of science and technology.

It is, however, true that Muslims did not use printing to produce books, nor extended texts in any form, until the 18th century. This challenge was taken up by Europeans from the 15th century onwards, and it would not have been possible there, without the availability of another gift from the Muslims, paper, which had earlier reached Europe from the Muslim world, via Spain and Italy.

Figure 3.3: **A handwritten Islamic manuscript: Qazwini, 'Ajaib al-makhluqat, MS probably from Mosul, ca.1305. British Library.**

3.3 Gutenberg

Johannes Gensfleisch zur Laden zum Gutenberg (c.1400-1468) was born in the German city of Mainz. He was the youngest son of an upper-class merchant, Friele Gensfleisch zur Laden, whose long-established family traced its roots back to the 13th century.

Johannes Gutenberg was educated as a goldsmith and blacksmith, and may also have attended the University of Erfurt. In 1440, while he was living in Strassburg. he is said to have perfected and unveiled his system of printing with movable type.

By 1448, he was back in Mainz, where he took a loan from his brother-on-law to meet the expenses of setting up a printing press.In 1450, the press was in operation, and Gutenberg took a further loan, 800 guilders, from the moneylender Johann Fust. Peter Schöffer, who became Fust's son-in-law also joined the enterprise, and is believed to have designed the type faces.

Among the many technical innovations introduced by Gutenberg are the invention of a process for mass-producing movable type; the use of oil-based ink for printing books; adjustable molds; mechanical movable type; and the use of a wooden printing press similar to the agricultural screw presses of the period. The alloy which he used was a mixture of lead, tin, and antimony that melted at a relatively low temperature for faster and more economical casting, cast well, and created a durable type. The combination of all these elements made the mass production of books both practical and economically feasible.

Gutenberg's greatest artistic achievement was his printed Bible, but this project also cost so much that it left him with debts of more than 20,000 guilders. A court order gave Fust control of the Bible printing project, and half of the printed Bibles.

Although he had suffered bankruptcy, the aging Gutenberg's greatness was acknowledged in 1465. He was given the tithe "Hofmann" (Gentleman of the Court) and awarded a yearly stipend, as well as 2,180 liters of grain and 2,000 liters of wine tax-free. He died in 1468, having enjoyed this official recognition for only three years.

Printing quickly affected both religion and science in Europe. By 1517, when Martin Luther posted his Ninety-Five Theses on the door of All Saint's Church in Wittenburg, many cities has printing presses. The theses were quickly reprinted and translated, and they spread throughout Europe. This initiated a pamphlet war, in which both sides used printing to spread their views. The impact of Luther's German translation of the Bible was greatly increased by the fact that inexpensive printed copies were widely available.

Science was Similarly revolutionized. Nicolaus Copernicus (1473-1543) had a far greater impact on the history of science than his near contemporary Leonardo da Vinci (1452-1519) because of printing. Leonardo's thousands of pages of notes and his innovations in virtually all the fields of human knowledge have only recently become available in printed form. By contrast, the publication Copernicus' great book, *De revolutionibus orbium coelestium* (On the Revolutions of the Celestial Spheres) initiated a sequence of discoveries by Tycho Brahe, Galileo, Johannes Kepler and Isaac Newton, discoveries upon which the modern world is built.

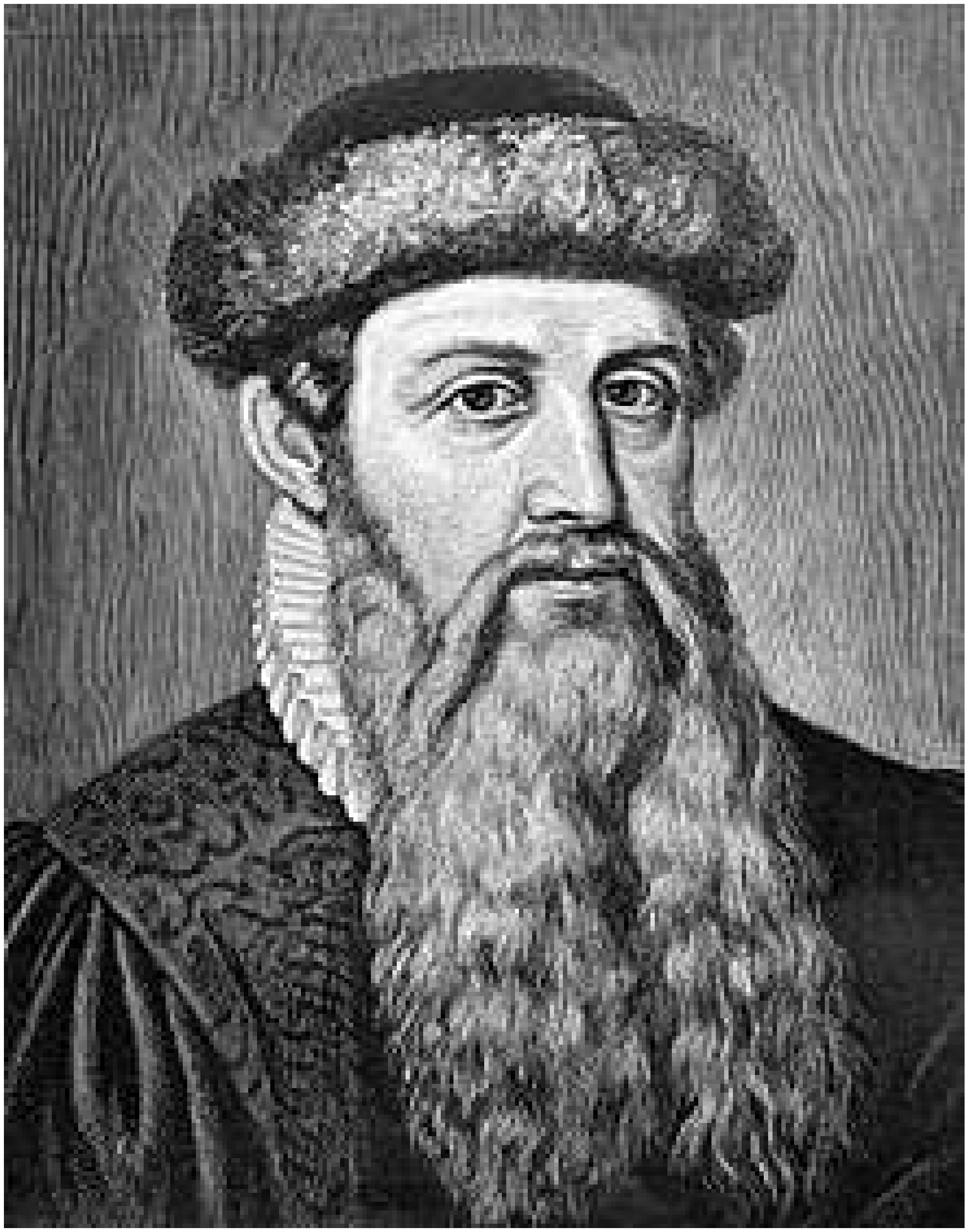

Figure 3.4: **Gutenberg is credited with introducing printing with movable type into Europe, with many improvements of technique. His inventions were a turning point in European history, and ushered in the modern era, the Reformation, the Age of Reason and the Industrial Revolution.**

Figure 3.5: **Gutenberg's printing press**

Figure 3.6: **Gutenberg's bible**

3.4 The Enlightenment

Political philosophy of the Enlightenment

The 16th, 17th and 18th centuries have been called the "Age of Discovery", and the "Age of Reason", but they might equally well be called the "Age of Observation". On every side, new worlds were opening up to the human mind. The great voyages of discovery had revealed new continents, whose peoples demonstrated alternative ways of life. The telescopic exploration of the heavens revealed enormous depths of space, containing myriads of previously unknown stars; and explorations with the microscope revealed a new and marvelously intricate world of the infinitesimally small.

In the science of this period, the emphasis was on careful observation. This same emphasis on observation can be seen in the Dutch and English painters of the period. The great Dutch masters, such as Jan Vermeer (1632-1675), Frans Hals (1580-1666), Pieter de Hooch (1629-1678) and Rembrandt van Rijn (1606-1669), achieved a careful realism in their paintings and drawings which was the artistic counterpart of the observations of the pioneers of microscopy, Anton van Leeuwenhoek and Robert Hooke. These artists were supported by the patronage of the middle class, which had become prominent and powerful both in England and in the Netherlands because of the extensive world trade in which these two nations were engaged.

Members of the commercial middle class needed a clear and realistic view of the world in order to succeed with their enterprises. (An aristocrat of the period, on the other hand, might have been more comfortable with a somewhat romanticized and out-of-focus vision, which would allow him to overlook the suffering and injustice upon which his privileges were based.) The rise of the commercial middle class, with its virtues of industriousness, common sense and realism, went hand in hand with the rise of experimental science, which required the same virtues for its success.

In England, the House of Commons (which reflected the interests of the middle class), had achieved political power, and had demonstrated (in the Puritan Rebellion of 1640 and the Glorious Revolution of 1688) that Parliament could execute or depose any monarch who tried to rule without its consent. In France, however, the situation was very different.

After passing through a period of disorder and civil war, the French tried to achieve order and stability by making their monarchy more absolute. The movement towards absolute monarchy in France culminated in the long reign of Louis XIV, who became king in 1643 and who ruled until he died in 1715.

The historical scene which we have just sketched was the background against which the news of Newton's scientific triumph was received. The news was received by a Europe which was tired of religious wars; and in France, it was received by a middle class which was searching for an ideology in its struggle against the *ancien régime*.

To the intellectuals of the 18th century, the orderly Newtonian cosmos, with its planets circling the sun in obedience to natural law, became an imaginative symbol representing rationality. In their search for a society more in accordance with human nature, 18th century Europeans were greatly encouraged by the triumphs of science. Reason had shown itself to be an adequate guide in natural philosophy. Could not reason and natural law also be made the basis of moral and political philosophy? In attempting to carry out this program, the philosophers of the Enlightenment laid the foundations of psychology, anthropology, social science, political science and economics.

One of the earliest and most influential of these philosophers was John Locke (1632-1705), a contemporary and friend of Newton. In his *Second Treatise on Government*, published in 1690, John Locke's aim was to refute the doctrine that kings rule by divine right, and to replace that doctrine by an alternative theory of government, derived by reason from the laws of nature. According to Locke's theory, men originally lived together without formal government:

"Men living together according to reason," he wrote, "without a common superior on earth with authority to judge between them, is properly the state of nature... A state also of equality, wherein all the power and jurisdiction is reciprocal, no one having more than another; there being nothing more evident than that creatures of the same species, promiscuously born to all the same advantages of nature and the use of the same facilities, should also be equal amongst one another without subordination or subjection..."

"But though this be a state of liberty, yet it is not a state of licence... The state of nature has a law to govern it, which obliges every one; and reason, which is that law, teaches all mankind who will but consult it, that being equal and independent, no one ought to harm another in his life, health, liberty or possessions."

In Locke's view, a government is set up by means of a social contract. The government is given its powers by the consent of the citizens in return for the services which it renders to them, such as the protection of their lives and property. If a government fails to render these services, or if it becomes tyrannical, then the contract has been broken, and the citizens must set up a new government.

Locke's influence on 18th century thought was very great. His influence can be seen, for example, in the wording of the American Declaration of Independence. In England, Locke's political philosophy was accepted by almost everyone. In fact, he was only codifying ideas which were already in wide circulation and justifying a revolution which had already occurred. In France, on the other hand, Locke's writings had a revolutionary impact.

Credit for bringing the ideas of both Newton and Locke to France, and making them fashionable, belongs to Francois Marie Arouet (1694-1778), better known as "Voltaire". Besides persuading his mistress, Madame de Chatelet, to translate Newton's *Principia* into French, Voltaire wrote an extremely readable commentary on the book; and as a result, Newton's ideas became highly fashionable among French intellectuals. Voltaire lived with Madame du Chatelet until she died, producing the books which established him as the leading writer of Europe, a prophet of the Age of Reason, and an enemy of injustice, feudalism and superstition.

The Enlightenment in France is considered to have begun with Voltaire's return from England in 1729; and it reached its high point with the publication of of the *Encyclopedia* between 1751 and 1780. Many authors contributed to the *Encyclopedia*, which was an enormous work, designed to sum up the state of human knowledge.

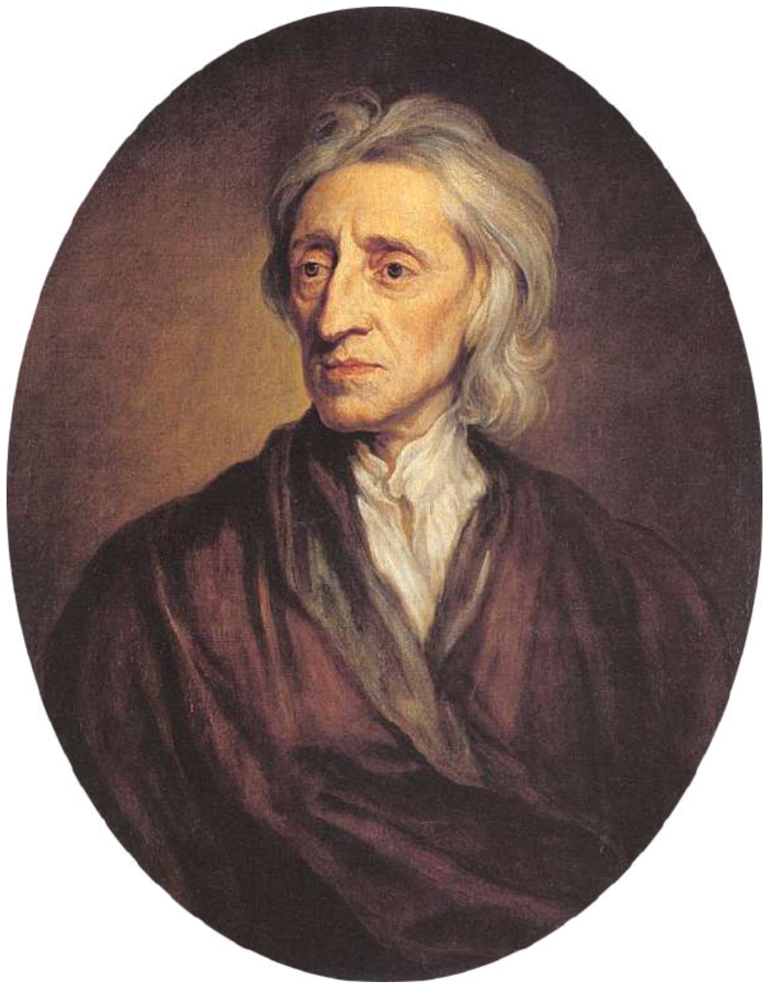

Figure 3.7: **John Locke (1632-1705): "Men living together according to reason, without a common superior on earth with authority to judge between them, is properly the state of nature... A state also of equality, wherein all the power and jurisdiction is reciprocal, no one having more than another; there being nothing more evident than that creatures of the same species, promiscuously born to all the same advantages of nature and the use of the same facilities, should also be equal amongst one another without subordination or subjugation..."**

Turgot and Montesquieu wrote on politics and history; Rousseau wrote on music, and Buffon on natural history; Quesnay contributed articles on agriculture, while the Baron d'Holbach discussed chemistry. Other articles were contributed by Condorcet, Voltaire and d'Alembert. The whole enterprise was directed and inspired by the passionate faith of Denis Diderot (1713-1784). The men who took part in this movement called themselves *"philosophes"*. Their creed was a faith in reason, and an optimistic belief in the perfectibility of human nature and society by means of education, political reforms, and the scientific method.

The *philosophes* of the Enlightenment visualized history as a long progression towards the discovery of the scientific method. Once discovered, this method could never be lost; and it would lead inevitably (they believed) to both the material and moral improvement of society. The *philosophes* believed that science, reason, and education, together with the principles of political liberty and equality, would inevitably lead humanity forward to a new era of happiness. These ideas were the faith of the Enlightenment; they influenced the French and American revolutions; and they are still the basis of liberal political belief.

Voltaire and Rousseau

Voltaire (1694-1778)

Francois-Marie Arouet, who later changed his name to Voltaire, was born in Paris. His father was a lawyer and a minor treasury official, while his mother's family was on the lowest rank if the French nobility. He was educated by Jesuits at Collège Louis-le-Grande, where he learned Latin theology and rhetoric. He later became fluent in Italian, Spanish and English.

Despite his father's efforts to make him study law, the young Voltaire was determined to become a writer. He eventually became the author of more than 2,000 books and pamphlets and more than 20,000 letters. His works include many forms of writing, including plays, poems, novels, essays and historical and scientific works. His writings advocated civil liberties, and he used his satirical and witty style of writing to criticize intolerance, religious dogma and absolute monarchy. Because of the intolerance and censorship of his day, he was frequently in trouble and sometimes imprisoned. Nevertheless, his works were very popular, and he eventually became extremely rich, partly through clever investment of money gained through part ownership of a lottery.

During a period of forced exile in England, Voltaire mixed with the English aristocracy, meeting Alexander Pope, John Gay, Jonathan Swift, Lady Mary Wortley Montagu, Sarah, Duchess of Marlborough, and many other members of the nobility and royalty. He admired the English system of constitutional monarchy, which he considered to be far superior to the absolutism then prevailing in France. In 1733, he published a book entitled *Letters concerning the English Nation*, in London. When French translation was published in 1734, Voltaire was again in deep trouble. In order to avoid arrest, he stayed in the country château belonging to Émilie du Châtelet and her husband, the Marquis du Châtelet.

As a result, Madame du Châtelet became his mistress and the relationship lasted for

16 years. Her tolerant husband, the Marquis, who shared their intellectual and scientific interests, often lived together with them. Voltaire paid for improvements to the château, and together, the Marquis and Voltaire collected more than 21,000 books, and enormous number for that time. Madame du Châtelet translated Isaac Newton's great book, *Principia Mathematica*, into French, and her translation was destined to be the standard one until modern times. Meanwhile, Voltaire wrote a French explanation of the ideas of the *Principia*, which made these ideas accessible to a wide public in France. Together, the Marquis, his wife and Voltaire also performed many scientific experiments, for example experiments designed to study the nature of fire.

Voltaire's vast literary output is available today in approximately 200 volumes, published by the University of Oxford, where the Voltaire Foundation is now established as a research department.

Rousseau (1712-1778)

In 1754 Rousseau wrote: "The first man who, having fenced in a piece of land, said 'This is mine', and found people naïve enough to believe him, that man was the true founder of civil society. From how many crimes, wars, and murders, from how many horrors and misfortunes might not any one have saved mankind, by pulling up the stakes, or filling up the ditch, and crying to his fellows: Beware of listening to this impostor; you are undone if you once forget that the fruits of the earth belong to us all, and the earth itself to nobody."

Later, he began his influential book *The Social Contract*, published in 1752, with the dramatic words: "Man is born free, and everywhere he is in chains. Those who think themselves the masters of others are indeed greater slaves than they." Rousseau concludes Chapter 3 of this book with the words: "Let us then admit that force does not create right, and that we are obliged to obey only legitimate powers". In other words, the ability to coerce is not a legitimate power, and there is no rightful duty to submit to it. A state has no right to enslave a conquered people.

These ideas, and those of John Locke, were reaffirmed in 1776 by the American Declaration of Independence: "We hold these truths to be self-evident: That all men are created equal. That they are endowed by their Creator with certain inaliable rights, and the among these are the rights to life, liberty and the pursuit of happiness; and that to pursue these rights, governments are instituted among men, deriving their just powers from the consent of the governed."

Today, in an era of government tyranny and subversion of democracy, we need to remember that the just powers of any government are not derived from the government's ability to use of force, but exclusively from the consent of the governed.

Figure 3.8: **Voltaire used his satirical and witty style of writing to criticize intolerance, religious dogma and absolute monarchy. He wrote more than 2,000 books and pamphlets and more than 20,000 letters. His writings made a significant contribution to the Enlightenment, and paved the way for revolutions both in France and America.**

Figure 3.9: **The frontpiece of Voltaire's book popularizing Newton's ideas for French readers. Madame du Châtelet appears as a muse, reflecting Newton's thoughts down to Voltaire.**

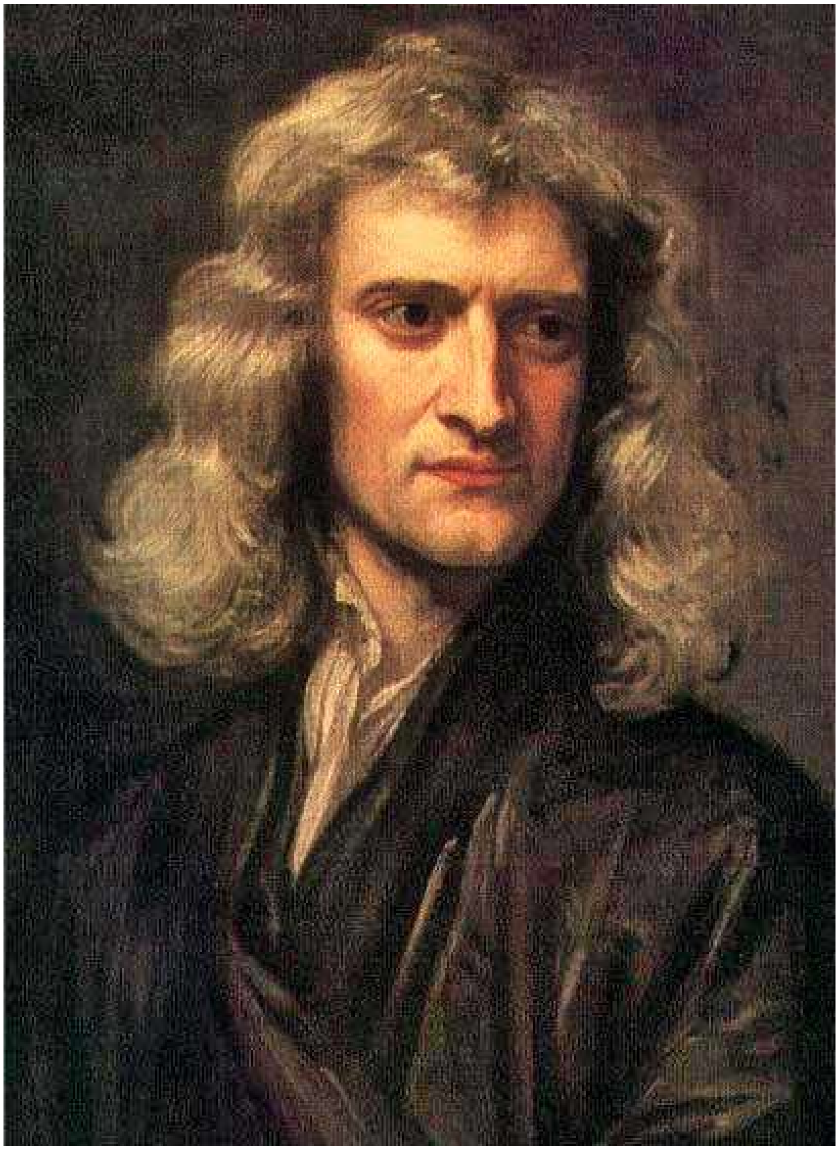

Figure 3.10: **The work of Sir Isaac Newton (1642-1726) illustrates a key aspect of human cultural evolution: Because of the introduction of printing in Europe, Newton was able to build on the work of his predecessors, Copernicus, Brahe, Galileo and Kepler. He could never have achieved his great synthesis alone. During the Enlightenment, Newton became a symbol of rationality and reason. Alexander Pope wrote: "Nature, and nature's laws, lay hid in night. God said 'Let Newton be', and all was light!"**

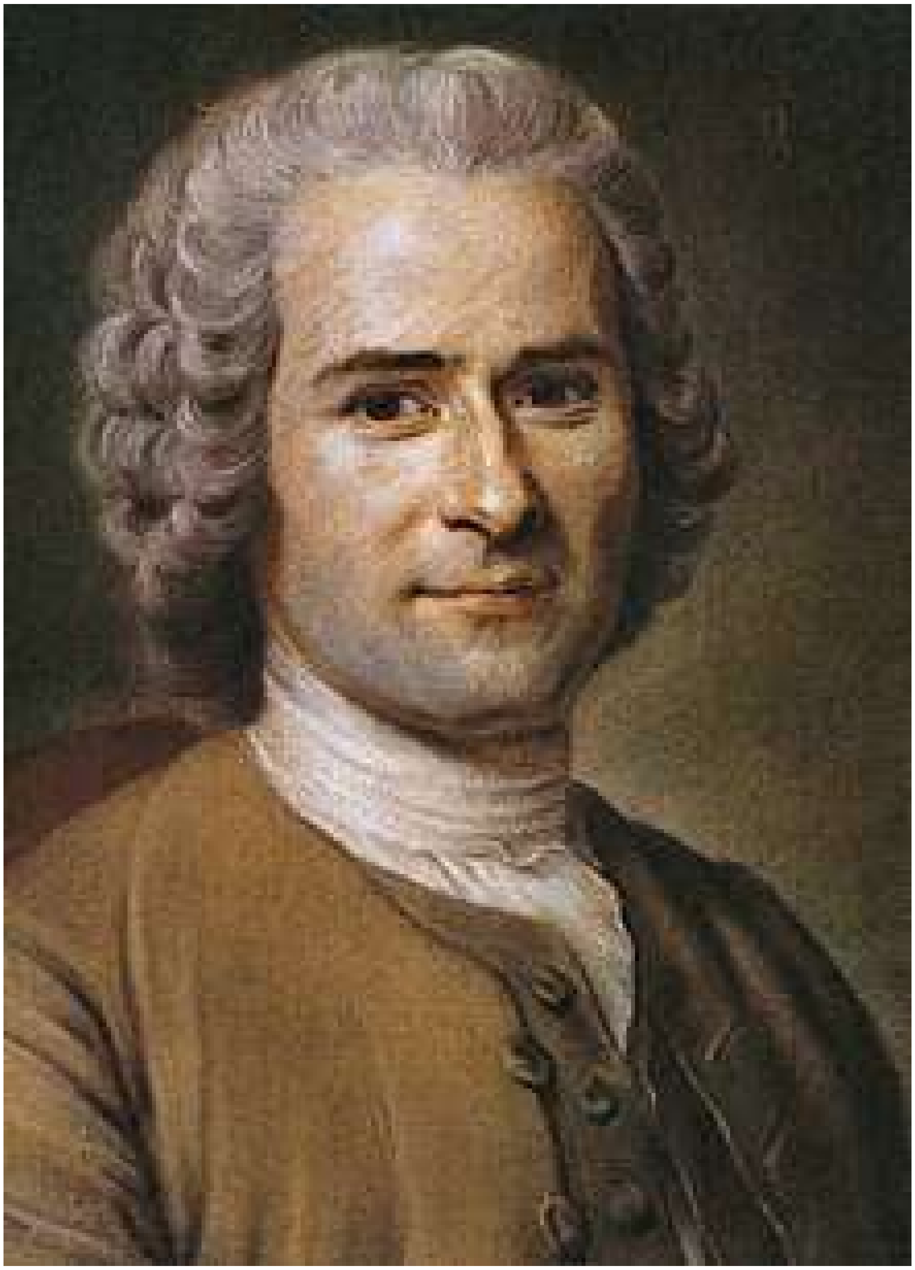

Figure 3.11: **Unlike Voltaire, Rousseau was not an advocate of science, but instead believed in the importance of emotions. He believed that civilization has corrupted humans rather than making them better. Rousseau was a pioneer of the romantic movement. His book, *The Social Contract*, remains influential today.**

Figure 3.12: **The printer and publisher Joseph Johnson (1738-1809).**

The printer and publisher Joseph Johnson

As an example of the influence of printing on the liberation of ideas, we can consider the circle of important authors that formed around the English printer and publisher Joseph Johnson (1738-1809). His weekly dinners for authors were famous. Among the many great thinkers. artists, scientists, writers and religious dissenters who attended these dinners, or whose works he published, were William Cowper, Erasmus Darwin, William Blake, Henry Fuselli, Mary Wollstonecraft, William Godwin, Thomas Robert Malthus, Thomas Paine, Pricilla Wakefield, Gilbert Wakefield. Benjamin Franklin, Richard Price and Joseph Priestly.

Throughout her career, the pioneering feminist writer Mary Wollstonecraft was aided by Johnson. As she wrote to her sister, she had decided to become the first of a new genus: a professional female writer. Having learned French and German, she translated Necker's *Of the Importance of Religious Opinions* and Saltzman's *Elements of Morality for the Use of Children.* Mary was helped in her new career by the liberal publisher, Joseph Johnson, who was also the publisher of Thomas Paine and William Godwin. Mary met these already famous authors at Johnson's dinner parties, and conversations with them helped to expand her knowledge and ambitions. Joseph Johnson was a very brave man. By publishing the works of radical authors, he was risking arrest by England's repressive government. In her letters, Mary described Johnson as "a father and brother".

At Johnson's parties Mary met, for the second time, the famous novelist and philosopher William Godwin. This time, they both formed a higher opinion of each other than at their first meeting. A passionate love affair developed between them, and when Mary became pregnant, they were married. Tragically, Mary Wollstonecraft died in childbirth. Her daughter Mary would later become the wife of Godwin's admirer, the poet Percy Bysshe Shelley, and Mary Shelly created the enduring masterpiece *Frankenstein.*

Figure 3.13: **Mary Wollstonecraft in a painting by John Opie. She called Joseph Johnson "my father and brother".**

Figure 3.14: **The famous scientist and dissenter, Joseph Priestly, in a portrait by Henry Fuselli, commissioned by Joseph Johnson. Priestly and Fuselli were among Johnson's closest friends.**

3.5 Universal education

Today, there is some form of compulsory education in most countries. However, regional differences are still very great, as shown in the maps below.

The percentage of the global population without any schooling decreased from 36% in 1960 to 25% in 2000. In the developed countries, illiteracy rates and the number of children without schooling both were approximately halved between 1970 and 2000. However, illiteracy in the less developed countries exceeded that of the developed ones by a factor of ten in 1970. By 2000, this factor had increased to approximately 20.

As economies become more and more knowledge-based, high and higher educational levels of education are required. For many modern professions, students may be 30 years old before they complete their doctoral and post-doctoral educations. For this reason high educational levels are linked with lower fertility rates. Teenagers are biologically ready to have children, but in modern societies, they are not yet sufficiently educated to obtain well-paid work.

The Human Development Report

Since 1990, the Human Development Report has been published annually by the United Nations. It was launched jointly by the Pakistani economist Mahbub ul Haq and Indian Nobel laureate Amartya Sen. The purpose of the report has been to place people rather that material goods at the center of evaluations of economic progress. As Mahbub ul Haq put it, “People are the real wealth of a nation. The basic objective of development is to create an enabling environment for people to enjoy long, healthy and creative lives. This may appear to be a simple truth. But it is often forgotten in the immediate concern with the accumulation of commodities and financial wealth.”

Among the Human Development Index indicators used by the report is based on life expctancy, education and per-capita income. In 2010, the Human Development Report also introduced a Inequality Adjusted Human Development Index (IHDI).

In a recent ranking of countries according to their Human Development Indices, the highest ranked countries were Norway, Australia, Switzerland, Germany, Denmark, Singapore, Netherlands, Ireland, Iceland, Canada, Hong Kong, United States, New Zealand, Sweden, Lichtenstein, United Kingdom, Japan, South Korea, Israel, Luxembourg, France, Belgium, Switzerland, Austria, Slovenia and Italy in that order.

The lowest ranked countries were Swaziland, Syria, Angola, Tanzania, Nigeria, Cameroon, Papua New Guinea, Zimbabwe, Solomon Islands, Mauritania, Madagascar, Rwanda, Comoros, Lethoso, Senegal, Haiti, Uganda, Sudan, Togo, Benin and Yemen, with Yemen having the lowest human development index of all the world’s countries. In fact Yemen is currently experiencing a humanitarian crisis of huge proportions, and immediate international help is urgently needed.

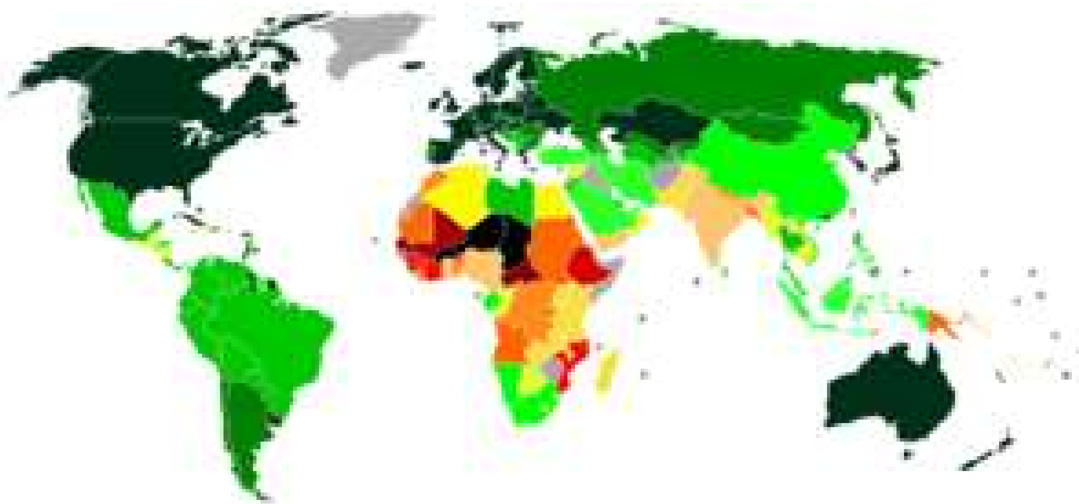

Figure 3.15: **A map showing global educational indices based on data from 2006 and 2007. Progressively darker shades of green indicate very high indices, while yellow, orange and red represent the low indices, red being the lowest.**

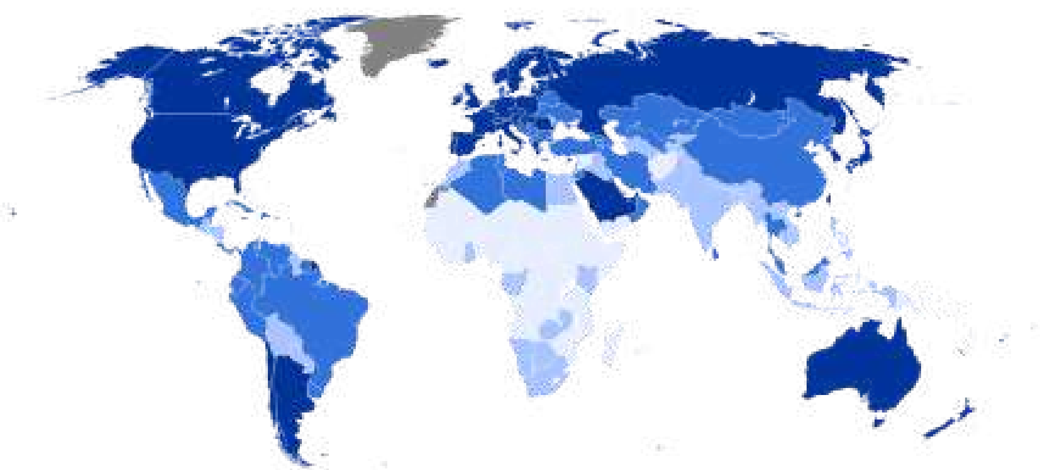

Figure 3.16: **A map showing the Human Development Index based on data from 2015 and 2016. The dark shades of blue indicate a very high index, while white indicates very low values. Grey indicates that data were not available.**

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Chapter 4

THE INDUSTRIAL REVOLUTION

We have seen how the development of printing in Europe produced a brilliant, chainlike series of scientific discoveries. During the 17th century, the rate of scientific progress gathered momentum, and in the 18th and 19th centuries, the practical applications of scientific knowledge revolutionized the methods of production in agriculture and industry.

During the Industrial Revolution, feudal society, with its patterns of village life and its traditional social obligations, was suddenly replaced by a money-dominated society whose rules were purely economic, and in which labor was regarded as a commodity. The changes produced by the industrial revolution at first resulted in social chaos - enormous wealth in some classes of society, and great suffering in other classes; but later, after the appropriate social and political adjustments had been made, the improved methods of production benefited all parts of society in a more even way.

4.1 Development of the steam engine

The discovery of atmospheric pressure

Early steam engines made use of the pressure of the atmosphere, and in fact it was the discovery of atmospheric pressure that led to the invention of the steam engine. Aristotle had maintained "nature abhors a vacuum", but this doctrine was questioned by the Italian physicist Evangelesta Torricelli (1608-1647), who invented the barometer in 1643.

Pump makers working for the Grand Duke of Tuscany had found that suction pumps were unable to raise water to heights greater than 10 meters (in today's units). Attempting to understand why this should be the case, Torricelli filled an approximately 1-meter-long glass tube with mercury, which is 14 times denser than water. The tube was sealed at one end, and open at the other. He then immersed the open end in a dish of mercury, and raised the sealed end, so that the tube was in a vertical position. Part of the mercury flowed out of the tube into the dish, leaving a 76-centimeter-high column of mercury, and 24 centimeters of empty space at the top. The empty space contained what we now call a Torricellian vacuum.

This experiment enabled Torricelli to understand why the Grand Duke's suction pumps were unable to raise water to a height greater than 10 meters. Torricelli realized that both the 10 meter column of water (the maximum that could be achieved), and the (equally heavy) 76 centimeter column of mercury, were held in place by the weight of the atmosphere, which they exactly balanced. Later experiments soon demonstrated that the height of the column of mercury in Torricelli's barometer depended on the weather, and on height above sea level. Summarizing his experiments, Torricelli wrote: "We live submerged at the bottom of an ocean of elementary air, which is known by incontestable experiments to have weight."

Torricelli's experiments marked the start of period where, throughout Europe, much interest was focused on experiments with gases. In 1650 Otto von Guericke, the Mayor of Magdeburg Germany, invented the first vacuum pump. In a dramatic experiment, performed in 1663 in the presence of Frederick Wilhelm I of Brandenburg, von Guericke's assistants fitted two large copper hemispheres together, after the joining surfaces had been carefully greased to make the junction airtight. Von Guericke's pump was then used to evacuate the volume within the hemispheres. To the amazement of the watching crowd, a team of 24 horses, 12 on each side, strained at the hemispheres but failed to separate them. Von Guericke explained that it was the pressure of the atmosphere that held the hemispheres so tightly together, and he demonstrated that when air was allowed to enter the interior volume, the hemispheres could be separated without effort.

Steam engines using atmospheric pressure

Continuing the vogue for experiments with gases and pumps that was sweeping across Europe, Edward Somerset, the 2nd Marquess of Worcester, designed steam-powered pumps to bring water from wells to fountains. He published the designs for his engines in 1663, and he may have installed pumps built according to these designs at Vauxhall House in London. In the 1680's a number of steam-powered pumps were constructed for Louis XIV of France by Sir Samuel Morland (1625-1695), who lived in Vauxhall and may have been influenced by Somerset's ideas.

Meanwhile, in France, the physicist Denis Papin (1647-1712) had become interested in the motive force of steam. Together with Gottfried Leibniz he invented the pressure cooker, and he also invented designs for steam engines. Some of Papin's steam engine designs were presented to the Royal Society between 1707 and 1712, without acknowledgment or payment, and this caused Papin to complain bitterly. He died soon afterward.

In 1698, the English inventor Thomas Savery (1650-1715) patented a steam engine for pumping water. It had no piston, but used condensing steam and atmospheric pressure to bring up the water by means of a siphon principle. It was therefore useless for pumping water from very deep mines, although Savery described it as the "Miner's Friend". Savery's design was so similar to Somerset's that it was probably a direct copy.

The ironmonger Thomas Newcomen's "atmospheric-engine" of 1712 proved to be much more practical for pumping water from the deep mines of Cornwall. Newcomen was forced to go into a partnership with Savery because of the latter's patent, and he also used some

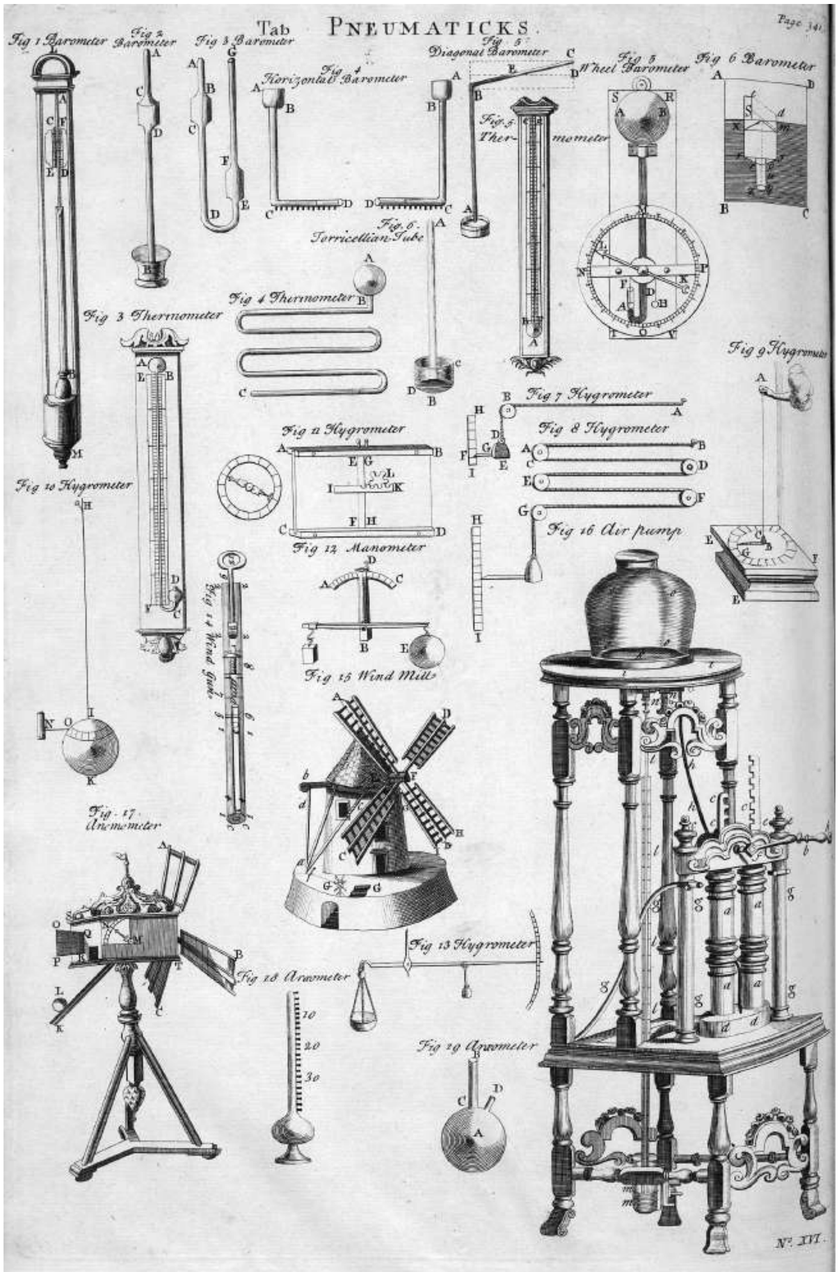


Figure 4.1: **"Table of Pneumaticks" (1728).**

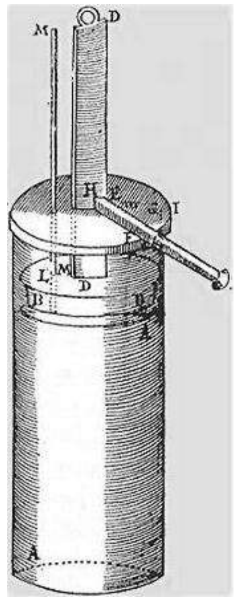


Figure 4.2: **The French physicist Papin's design for a steam engine (1690).**

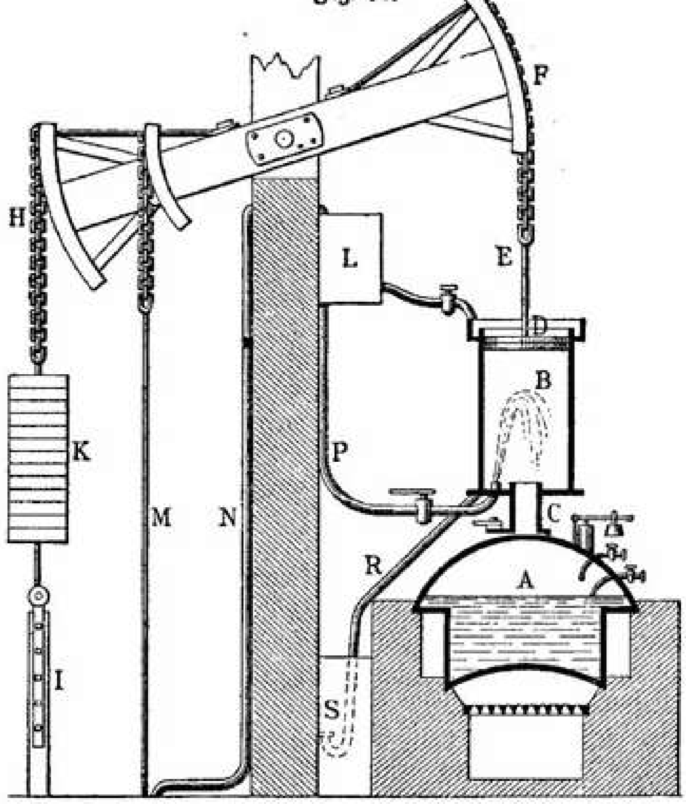
of Papin's ideas. An important feature of Newcomen's engine was a beam that transmitted power from the working piston to a pump at the base of the mineshaft. In Newcomen's engine, steam entered the cylinder, driving the piston upward. A jet of water was then sprayed into the interior of the cylinder, condensing the steam and allowing atmospheric pressure to drive the piston down. Early models of the engine operated slowly, and the valves were opened and closed by hand. Later, the opening and closing of the valves was performed automatically by means of the "potter cord". According to legend this device is named after a boy, Humphrey Potter, who in 1713 had been given the job of opening and closing the valves. Wishing to play with his friends, he invented the automatic mechanism.

The main problem with Newcomen's engine was that its fuel use was enormously wasteful. This was because, with every cycle, the cylinder was cooled by water, and then heated again by steam.

At Glasgow University, where Adam Smith was Professor of Moral Philosophy, there was a shop where scientific instruments were made and sold. The owner of the shop was a young man named James Watt (1736-1819), who came from a family of ship builders and teachers of mathematics and navigation. Besides being an extremely competent instrument maker, Watt was a self-taught scientist of great ability, and his shop became a meeting place for scientifically inclined students.

James Watt tried to repair the university's small-scale model of the Newcomen engine, but he failed to make it work well. He could see that it was extraordinarily inefficient in its use of fuel, and he began making experiments to find out why it was so wasteful. James Watt quickly found the answer: The engine was inefficient because of the large amounts of energy needed to heat the iron cylinder. In 1765, Watt designed an improved engine with a separate condenser. The working cylinder could then be kept continuously hot.

Fig. 30.



Newcomens Dampfmaschine.

Figure 4.3: **Newcomen's steam engine.**

To have an idea for a new, energy-saving engine was one thing, however, and to make the machine practical was another. James Watt had experience as an instrument maker, but no experience in large-scale engineering. However, Watt formed a partnership with Mathew Boulton, who was the most talented and progressive manufacturer in England.

Boulton was more interested in applying art and science to manufacturing than he was in simply making money. His idea was to bring together under one roof the various parts of the manufacturing process which had been scattered among many small workshops by the introduction of division of labor. He believed that improved working conditions would result in an improved quality of products.

With these ideas in mind, Matthew Boulton built a large mansion-like house on his property at Soho, outside Birmingham, and installed in it all the machinery necessary for the complete production of a variety of small steel products. Because of his personal charm, and because of the comfortable working conditions at the Soho Manufactory, Boulton was able to attract the best and most skillful craftsmen in the region; and by 1765, the number of the staff at Soho had reached 600.

At this point, Erasmus Darwin (the grandfather of Charles Darwin) introduced James Watt to Matthew Boulton, and they formed a partnership for the development of the steam engine. The high quality of craftsmanship and engineering skill which Matthew Boulton was able to put at Watt's disposal allowed the young inventor to turn his great idea into a reality. However, progress was slow, and the original patent was running out.

Boulton skillfully lobbied in Parliament for an extension of the patent and, as James Watt put it, "Mr. Boulton's amiable and friendly character, together with his fame as an ingenious and active manufacturer procured me many and very active friends in both houses of Parliament".

In 1775, the firm of Boulton and Watt was granted an extension of the master steam engine patent until 1800. From a legal and financial standpoint, the way was now clear for the development of the engine; and a major technical difficulty was overcome when the Birmingham ironmaster and cannon-maker, John Wilkinson, invented a method for boring large cylinders accurately by fixing the cutting tool to a very heavy and stable boring shaft.

By 1780, Boulton and Watt had erected 40 engines, about half of which pumped water from the deep Cornish tin mines. Even their early models were at least four times as efficient as the Newcomen engine, and Watt continually improved the design. At Boulton's urging, James Watt designed rotary engines, which could be used for driving mills; and he also invented a governor to regulate the speed of his engines, thus becoming a pioneer of automation. By the time its patent of the separate condenser had run out in 1800, the firm of Boulton and Watt had made 500 engines. After 1800, the rate of production of steam engines became exponential, and when James Watt died in 1819, his inventions had given employment, directly or indirectly, to an estimated two million people.

The Soho manufactory became an almost obligatory stop on any distinguished person's tour of England. Samuel Johnson, for example, wrote that he was received at Soho with great civility; and Boswell, who visited Soho on another occasion, was impressed by "the vastness and contrivance" of the machinery. He wrote that he would never forget Matthew Boulton's words to him as they walked together through the manufactory: "I sell here, Sir, what all the world desires to have - Power!"

4.2 Working conditions

Both Matthew Boulton and James Watt were model employers as well as pioneers of the factory system. Boulton had a pension scheme for his men, and he made every effort to insure that they worked under comfortable conditions. However, when he died in 1809, the firm of Boulton and Watt was taken over by his son, Matthew Robbinson Boulton, in partnership with James Watt Jr. The two sons did not have their fathers' sense of social responsibility; and although they ran the firm very efficiently, they seemed to be more interested in profit-making than in the welfare of their workers.

A still worse employer was Richard Arkwright (1732-1792), who held patents on a series of machines for carding, drawing and spinning silk, cotton, flax and wool. He was a rough, uneducated man, who rose from humble origins to become a multimillionaire by driving himself almost as hard as he drove his workers. Arkwright perfected machines (invented by others) which could make extremely cheap and strong cotton thread; and as a result, a huge cotton manufacturing industry grew up within the space of a few years. The growth of the cotton industry was especially rapid after Arkwright's patent expired in 1785.

Crowds of workers, thrown off the land by the Enclosure Acts and by the Clearances in Scotland, flocked to the towns, seeking work in the new factories[1]. Wages fell to a near-starvation level, hours of work increased, and working conditions deteriorated. Dr. Peter Gaskell, writing in 1833, described the condition of the English mill workers as follows:

"The vast deterioration in personal form which has been brought about in the manufacturing population during the last thirty years... is singularly impressive, and fills the mind with contemplations of a very painful character... Their complexion is sallow and pallid, with a peculiar flatness of feature caused by the want of a proper quantity of adipose substance to cushion out the cheeks. Their stature is low - the average height of men being five feet, six inches... Great numbers of the girls and women walk lamely or awkwardly... Many of the men have but little beard, and that in patches of a few hairs... (They have) a spiritless and dejected air, a sprawling and wide action of the legs..."

"Rising at or before daybreak, between four and five o'clock the year round, they swallow a hasty meal or hurry to the mill without taking any food whatever... At twelve o'clock the engine stops, and an hour is given for dinner... Again they are closely immured

[1]During the Highland Clearances, families that had farmed the land for generations were violently forced to leave their houses, which were then burned to prevent return. The land was afterward used as pasturage for sheep, which had been found to be more profitable. Donald McLeod, a crofter (small farmer) in Sutherland, has left the following account of the Clearances in his district: "The consternation and confusion were extreme. Little or no time was given for the removal of persons or property; the people striving to remove the sick and helpless before the fire should reach them; next, struggling to save the most valuable of their effects. The cries of the women and children, the roaring of the affrighted cattle, hunted at the same time by the yelling dogs of the shepherds amid the smoke and fire, altogether presented a scene that completely baffles description - it required to be seen to be believed... The conflagration lasted six days, until the whole of the dwellings were reduced to ashes or smoking ruins."

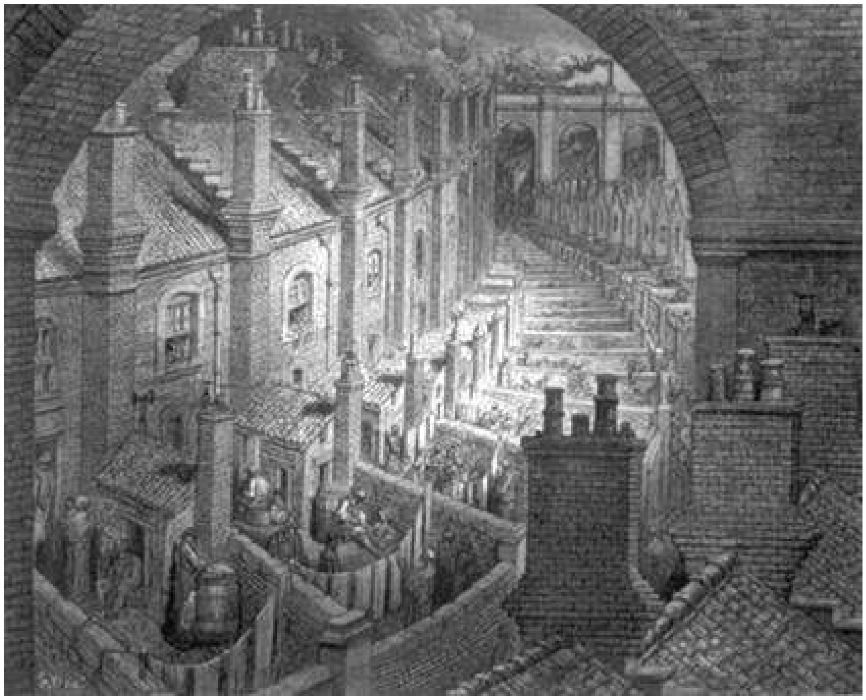


Figure 4.4: **London during the industrial revolution.**

from one o'clock till eight or nine, with the exception of twenty minutes, this being allowed for tea. During the whole of this long period, they are actively and unremittingly engaged in a crowded room at an elevated temperature."

Dr. Gaskell described the housing of the workers as follows:

"One of the circumstances in which they are especially defective is that of drainage and water-closets. Whole ranges of these houses are either totally undrained, or very partially... The whole of the washings and filth from these consequently are thrown into the front or back street, which, often being unpaved and cut into deep ruts, allows them to collect into stinking and stagnant pools; while fifty, or even more than that number, having only a single convenience common to them all, it is in a very short time choked with excrementous matter. No alternative is left to the inhabitants but adding this to the already defiled street."

"It frequently happens that one tenement is held by several families... The demoralizing effects of this utter absence of domestic privacy must be seen before they can be thoroughly appreciated. By laying bare all the wants and actions of the sexes, it strips them of outward regard for decency - modesty is annihilated - the father and the mother, the brother and the sister, the male and female lodger, do not scruple to commit acts in front of each other which even the savage keeps hid from his fellows."

"Most of these houses have cellars beneath them, occupied - if it is possible to find a lower class - by a still lower class than those living above them."

The following extract from John Fielden's book, *The Curse of the Factory System*

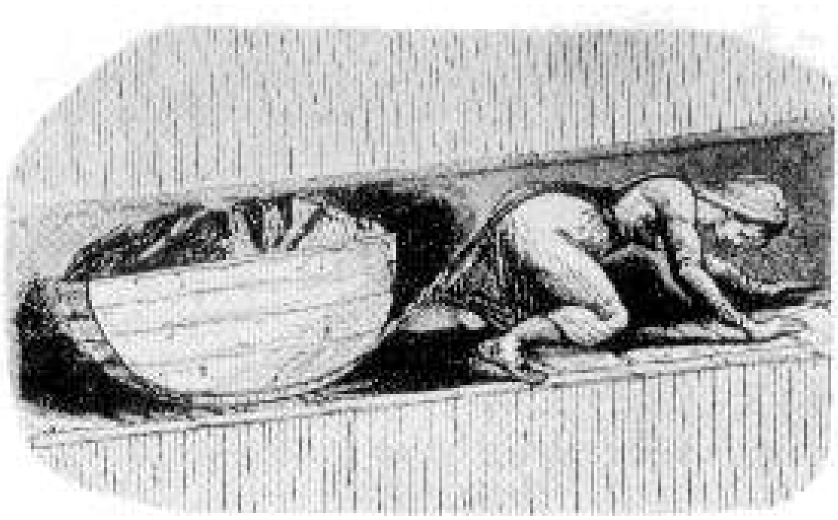


Figure 4.5: **A girl pulling a coal tub up a narrow passage in a British mine.**

Figure 4.6: **A child working in a South Carolina mill in 1908.**

(1836), describes the condition of young children working in the cotton industry:

"It is well known that Arkwright's (so called at least) inventions took manufactures out of the cottages and farmhouses of England... and assembled them in the counties of Derbyshire, Nottinghamshire and more particularly, in Lancashire, where the newly-invented machinery was used in large factories built on the side of streams capable of turning the water wheel. Thousands of hands were suddenly required in these places, remote from towns."

"The small and nimble fingers of children being by far the most in request, the custom instantly sprang up of procuring 'apprentices' from the different parish workhouses of London, Birmingham and elsewhere... Overseers were appointed to see to the works, whose interest it was to work the children to the utmost, because their pay was in proportion to the quantity of work which they could exact."

"Cruelty was, of course, the consequence; and there is abundant evidence on record to show that in many of the manufacturing districts, the most heart-rending cruelties were practiced on the unoffending and friendless creatures... that they were flogged, fettered and tortured in the most exquisite refinement of cruelty, that they were, in many cases, starved to the bone while flogged to their work, and that even in some instances they were driven to commit suicide... The profits of manufacture were enormous; but this only whetted the appetite it should have satisfied."

The misery of factory workers in England during the early phases of the Industrial Revolution prompted the writings of Karl Marx (1818-1883) and Frederich Engels (1820-1895). Engels' book, *The condition of the Working Class in England*, was published in 1844. *The Communist Manifesto*, (*Manifest der Komunistischen Partei*), on which Marx and Engels collaborated, was published in 1848, while Marx's large book, *Das Kapital. Kritik der politischen Oekonomie* was printed in 1867.

One of the arguments which was used to justify the abuse of labor was that the alternative was starvation. The population of Europe had begun to grow rapidly for a variety of reasons: - because of the application of scientific knowledge to the prevention of disease; because the potato had been introduced into the diet of the poor; and because bubonic plague had become less frequent after the black rat had been replaced by the brown rat, accidentally imported from Asia.

It was argued that the excess population could not be supported unless workers were employed in the mills and factories to produce manufactured goods, which could be exchanged for imported food. In order for the manufactured goods to be competitive, the labor which produced them had to be cheap: hence the abuses. (At least, this is what was argued).

4.3 The slow acceptance of birth control in England

Industrialization benefited England, but in a very uneven way, producing great wealth for some parts of society, but also extreme misery in other social classes. For many, technical progress by no means led to an increase of happiness. The persistence of terrible poverty in 19th-century England, and the combined pessimism of Ricardo and Malthus, caused Thomas Carlyle to call economics “the Dismal Science”.

Fortunately, Ricardo’s “Iron Law of Wages” seems to have rusted over the years. Apparently it was not an eternal law, but only a description of a passing phase of industrialism, before the appropriate social and legislative adjustments had been made. Among the changes which were needed to insure that the effects of technical progress became beneficial rather than harmful, the most important were the abolition of child labor, the development of unions, the minimum wage law, and the introduction of birth control.

Francis Place (1771-1854), a close friend of William Godwin and James Mill, was one of the earliest and most courageous pioneers of these needed changes. Place had known extreme poverty as a child, but he had risen to become a successful businessman and a leader of the trade union movement.

Place and Mill were Utilitarians, and like other members of this movement they accepted the demographic studies of Malthus while disagreeing with Malthus’ rejection of birth control. They reasoned that since abortion and infanticide were already widely used by the poor to limit the size of their families, it was an indication that reliable and humane methods of birth control would be welcome. If marriage could be freed from the miseries which resulted from excessive numbers of children, the Utilitarians believed, prostitution would become less common, and the health and happiness of women would be improved.

Francis Place and James Mill decided that educational efforts would be needed to make the available methods of birth control more widely known and accepted. In 1818, Mill cautiously wrote “The great problem of a real check to population growth has been miserably evaded by all those who have meddled with the subject... And yet, if the superstitions of the nursery were discarded, and the principle of utility kept steadily in view, a solution might not be very difficult to be found.”

A few years later, Mill dared to be slightly more explicit: “The result to be aimed at”, he wrote in his *Elements of Political Economy* (1821), “is to secure to the great body of the people all the happiness which is capable of being derived from the matrimonial union, (while) preventing the evils which the too rapid increase of their numbers would entail. The progress of legislation, the improvement of the education of the people, and the decay of superstition will, in time, it may be hoped, accomplish the difficult task of reconciling these important objects.”

In 1822, Francis Place took the considerable risk of publishing a four-page pamphlet entitled *To the Married of Both Sexes of the Working People*, which contained the following passages:

“It is a great truth, often told and never denied, that when there are too many working people in any trade or manufacture, they are worse paid than they ought to be paid, and are compelled to work more hours than they ought to work. When the number of working people in any trade or manufacture has for some years been too great, wages are reduced very low, and the working people become little better than slaves.”

“When wages have thus been reduced to a very small sum, working people can no longer maintain their children as all good and respectable people wish to maintain their children, but are compelled to neglect them; - to send them to different employments; - to

Mills and Manufactories, at a very early age. The miseries of these poor children cannot be described, and need not be described to you, who witness them and deplore them every day of your lives."

"The sickness of yourselves and your children, the privation and pain and premature death of those you love but cannot cherish as you wish, need only be alluded to. You know all these evils too well."

"And what, you will ask, is the remedy? How are we to avoid these miseries? The answer is short and plain: the means are easy. Do as other people do, to avoid having more children than they wish to have, and can easily maintain."

"What is to be done is this. A piece of soft sponge is tied by a bobbin or penny ribbon, and inserted just before the sexual intercourse takes place, and is withdrawn again as soon as it has taken place. Many tie a sponge to each end of the ribbon, and they take care not to use the same sponge again until it has been washed. If the sponge be large enough, that is, as large as a green walnut, or a small apple, it will prevent conception... without diminishing the pleasures of married life..."

"You cannot fail to see that this address is intended solely for your good. It is quite impossible that those who address you can receive any benefit from it, beyond the satisfaction which every benevolent person and true Christian, must feel, at seeing you comfortable, healthy and happy."

The publication of Place's pamphlet in 1822 was a landmark in the battle for the acceptance of birth control in England. Another important step was taken in 1832, when a small book entitled *The Fruits of Philosophy or, the Private Companion of Young Married People* was published by a Boston physician named Dr. Charles Knowlton. The book contained simple contraceptive advice. It reviewed the various methods of birth control available at the time. In order for the sponge method to be reliable, Knowlton's book pointed out, use of a saline douching solution was necessary.

For a number of years, a reprinted edition of Knowlton's book was sold openly in London. However, in 1876 a new law against obscene publications was passed, and a bookseller was sentenced to two year's imprisonment for selling *The Fruits of Philosophy.* Charles Bradlaugh, a liberal politician and editor, and his friend, the feminist author Mrs. Annie Besant, then decided to sell the book themselves in order to provoke a new trial. The Chief Clerk of the Magistrates, the Detective Department, and to the City Solicitor, were all politely informed of the time and place where Charles Bradlaugh and Annie Besant intended to sell Knowlton's book, and the two reformers asked to be arrested.

In the historic trial that followed, the arguments of Malthus were used, not only by Charles Bradlaugh, who conducted his own defense, but also by the Lord Chief Justice, who instructed the jury to acquit the defendants. In the end, the jury ruled that the motives of Besant and Bradley were above reproach. However, the issue was made less clear when the jury also ruled Knowlton's book to be obscene. The enormous publicity that accompanied the trial certainly did not harm the sales of the book!

As birth control was gradually accepted in England, the average number of children per marriage fell from 6.16 in the 1860's to 2.43 in 1915. At the same time, trade unions developed, and improved social legislation was enacted.

Figure 4.7: **Annie Besant (1847-1933).**

4.4 The Industrial Revolution

The development of printing in Europe produced a brilliant, chainlike series of scientific discoveries. During the 17th century, the rate of scientific progress gathered momentum, and in the 18th and 19th centuries, the practical applications of scientific knowledge revolutionized the methods of production in agriculture and industry.

The changes produced by the Industrial Revolution at first resulted in social chaos - enormous wealth in some classes of society, and great suffering in other classes; but later, after the appropriate social and political adjustments had been made, the improved methods of production benefited all parts of society in a more even way.

The Industrial Revolution marked the start of massive human use of fossil fuels. The stored energy from several hundred million years of plant growth began to be used at roughly a million times the rate at which it had been formed. The effect on human society was like that of a narcotic. There was a euphoric (and totally unsustainable) surge of growth of both population and industrial production. Meanwhile, the carbon released into the atmosphere from the burning of fossil fuels began to duplicate the conditions which led to the 5 geologically-observed mass extinctions, during each of which more than half of all living species disappeared forever.

Figure 4.8: **And was Jerusalem builded here, among these dark Satanic mills?**

4.5 Technical change

We have just seen how the development of printing in Europe produced a brilliant, chainlike series of scientific discoveries. During the 17th century, the rate of scientific progress gathered momentum, and in the 18th and 19th centuries, the practical applications of scientific knowledge revolutionized the methods of production in agriculture and industry.

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There is, in fact, a general pattern which we can notice in the social impact of technology: Technical changes usually occur rapidly, while social and political adjustments take more time. The result is an initial period of social disruption following a technical change, which continues until the structure of society has had time to adjust. Thus, for example, the introduction of a money-based economy into a society which has previously been based on a pattern of traditional social duties always creates an initial period of painful disruption.

In the case of the Industrial Revolution, feudal society, with its patterns of village life and its traditional social obligations, was suddenly replaced by an industrial society whose rules were purely economic, and in which labor was regarded as a commodity. At first, the change produced severe social disruption and suffering; but now, after two centuries of social and political adjustment, the industrialized countries are generally considered to have benefited from the change.

Cullen, Black and Watt

The two driving forces behind the Industrial Revolution were world trade and scientific discovery. During the 18th century, both these forces were especially strongly felt in Scotland and in the north-western part of England. The distilling industry in Scotland grew enormously because of world trade; and the resulting interest in what happens when liquids are vaporized and condensed produced one of the major scientific and technical developments of the Industrial Revolution.

The first step in this development was taken by William Cullen, a professor of medicine at the universities of Glasgow and Edinburgh. In a paper entitled *Of the Cold Produced by Evaporation* (1749), Cullen wrote that he had noticed that "...water and some other liquids, in evaporating, produce some degree of cold".

Cullen therefore began to make experiments in which he dipped a thermometer in and out of a liquid and observed the drop in temperature. He noticed that the effect was increased by "...moving the thermometer very nimbly to and fro in the air; or if, while the ball was wet with spirit of wine, it was blown upon with a pair of bellows". In this way, Cullen achieved a temperature 44 degrees below the freezing point of water. He next tried producing vacuums above various liquids with the help of an air pump:

"We set the vessel containing the ether", Cullen wrote, "In another a little larger, containing water. Upon exhausting the receiver and the vessel's remaining a few minutes *in vacuo*, we found the most part of the water frozen, and the vessel containing the ether surrounded with a thick crust of ice."

One of Cullen's favorite students at Edinburgh was Joseph Black (1728-1799). He became Cullen's scientific assistant, and later, in 1756, he was elected to the Chair of Medicine at Glasgow University. Continuing Cullen's work on the cold produced by evaporating liquids, Black discovered and studied quantitatively the phenomenon of latent heats, e.g., the very large quantities of heat which are necessary to convert ice into water, or to convert water into steam.

Black was led to his discovery of latent heats not only by Cullen's work, but also by his own observations on Scottish weather. Writing of the discovery, one of Black's friends at Glasgow recorded that "...since a fine winter day of sunshine did not at once clear the hills of snow, nor a frosty night suddenly cover the ponds with ice, Dr. Black was already convinced that much heat was absorbed and fixed in the water which slowly trickled from the wreaths of snow; and on the other hand, that much heat emerged from it while it was slowly changing into ice. For, during a thaw, a thermometer will always sink when removed from the air into melting snow; and during a severe frost it will rise when plunged into freezing water. Therefore in the first case, the snow is receiving heat, and in the last, the water is allowing it to emerge again."

At Glasgow University, where Joseph Black was Professor of Medicine, there was a shop where scientific instruments were made and sold. The owner of the shop was a young man named James Watt (1736-1819), who came from a family of ship builders and teachers of mathematics and navigation. Besides being an extremely competent instrument maker, Watt was a self-taught scientist of great ability, and his shop became a meeting place for scientifically inclined students. Dr. Black was also a frequent visitor to Watt's shop, and a strong friendship formed between the professor and the highly intelligent young instrument maker.

In 1763, Glasgow University asked James Watt to repair a model of a Newcomen steam engine. This type of steam engine had been used for several years to pump water out of mines. It had a single cylinder which filled with steam so that the piston was driven to one end. Then water was sprayed into the cylinder, condensing the steam; and the vacuum drew the piston back to the other end of the cylinder, thus completing the cycle.

James Watt tried to repair the university's small-scale model of the Newcomen engine, but he failed to make it work well. He could see that it was extraordinarily inefficient in its use of fuel, and he began making experiments to find out why it was so wasteful. Because of James Watt's friendship with Joseph Black, he quickly found the answer in the phenomena of latent heats and specific heats: The engine was inefficient because of the large amounts of energy needed to convert water into steam and to heat the iron cylinder.

In 1765, Watt designed an improved engine with a separate condenser. The working cylinder could then be kept continuously hot, and the condensing steam could be returned through the boiler, so that its latent heat could be used to preheat the incoming water. To have an idea for a new, energy-saving engine was one thing, however, and to make the machine practical was another. James Watt had experience as instrument maker, but no experience in large-scale engineering.

In 1767, Watt was engaged to make a survey for a canal which was to join the Forth and the Clyde through Loch Lomond. Because of this work, he had to make a trip to London to explain the canal project to a parliamentary committee; and on the return trip he met Dr. Erasmus Darwin in Birmingham. Darwin, who was interested in steam engines, quickly recognized Watt's talent and the merit of his idea.

Erasmus Darwin (1731-1802) was the most famous physician of the period, but his interests were by no means confined to medicine. He anticipated his grandson, Charles Darwin, by developing the first reasonably well thought-out theory of evolution; and, at the time when he met James Watt he was enthusiastically trying to design a steam locomotive. His collaborators in this project were Benjamin Franklin and the pioneering Birmingham industrialist, Matthew Boulton.

In August, 1767, Erasmus Darwin wrote to Watt: "The plan of your steam improvements I have religiously kept secret, but begin to see myself some difficulties in your execution, which did not strike me when you were here. I have got another and another hobby horse since I saw you. I wish that the Lord would send you to pass a week with me, and Mrs. Watt with you; - a week, a month, a year!"

Dr. Darwin introduced James Watt to Matthew Boulton, and a famous partnership was formed. The partnership of Boulton and Watt was destined to make the steam engine practical, and thus to create a new age - an age in which humans would would rely for power neither on their own muscles nor on the muscles of slaves, but would instead control almost unlimited power through their engines.

James Watt was lucky to meet Erasmus Darwin and to be introduced to Matthew Boulton, since Boulton was the most talented and progressive manufacturer in England - the best possible man to understand the significance of Watt's great invention and to help in its development.

Boulton

Matthew Boulton was the son of a Birmingham manufacturer, and at the age of seventeen, he had invented a type of metal buckle inlaid with glass, which proved to be extremely popular and profitable. By the time that he was twenty-one, his father had made him manager of the business. At twenty-eight, Matthew Boulton married an heiress, receiving a very large dowry. When his wife died four years later, Boulton married her younger sister, and he was given a second large fortune.

Instead of retiring from manufacturing and becoming a country gentleman, as most of his contemporaries would have done, Boulton used his wealth to try out new ideas. He tried especially to improve the quality of the goods manufactures in Birmingham. Since he was already an extremely rich man, he was more interested in applying art and science to manufacturing than he was in simply making money.

Boulton's idea was to bring together under one roof the various parts of the manufacturing process which had been scattered among many small workshops by the introduction of division of labor. He believed that improved working conditions would result in an improved quality of products.

With these ideas in mind, Matthew Boulton built a large mansion-like house on his property at Soho, outside Birmingham, and installed in it all the machinery necessary for the complete production of a variety of small steel products. Because of his personal charm, and because of the comfortable working conditions at the Soho Manufactory, Boulton was able to attract the best and most skillful craftsmen in the region; and by 1765, the number of the staff at Soho had reached 600.

Boulton continued to manufacture utilitarian goods, on which he made a profit, but he also introduced a line of goods of high artistic merit on which he gained prestige but lost money. He made fine gilt brass candelabra for both George III and Catherine the Great; and he was friendly with George III, who consulted him on technical questions.

At this point, Erasmus Darwin introduced James Watt to Matthew Boulton, and they formed a partnership for the development of the steam engine. The high quality of craftsmanship and engineering skill which Matthew Boulton was able to put at Watt's disposal allowed the young inventor to turn his great idea into a reality. However, progress was slow, and the original patent was running out.

Boulton skillfully lobbied in Parliament for an extension of the patent and, as James Watt put it, "Mr. Boulton's amiable and friendly character, together with his fame as an ingenious and active manufacturer procured me many and very active friends in both houses of Parliament".

In 1775, the firm of Boulton and Watt was granted an extension of the master steam engine patent until 1800. From a legal and financial standpoint, the way was now clear for the development of the engine; and a major technical difficulty was overcome when the Birmingham ironmaster and cannon-maker, John Wilkinson, invented a method for boring large cylinders accurately by fixing the cutting tool to a very heavy and stable boring shaft.

By 1780, Boulton and Watt had erected 40 engines, about half of which pumped water from the deep Cornish tin mines. Even their early models were at least four times as efficient as the Newcomen engine, and Watt continually improved the design. At Boulton's urging, James Watt designed rotary engines, which could be used for driving mills; and he also invented a governor to regulate the speed of his engines, thus becoming a pioneer of automation. By the time its patent of the separate condenser had run out in 1800, the firm of Boulton and Watt had made 500 engines. After 1800, the rate of production of steam engines became exponential, and when James Watt died in 1819, his inventions had given employment, directly or indirectly, to an estimated two million people.

The Soho manufactory became an almost obligatory stop on any distinguished person's tour of England. Samuel Johnson, for example, wrote that he was received at Soho with great civility; and Boswell, who visited Soho on another occasion, was impressed by "the vastness and contrivance" of the machinery. He wrote that he would never forget Matthew Boulton's words to him as they walked together through the manufactory: "I sell here, Sir, what all the world desires to have - Power!"

4.6 The Lunar Society

Matthew Boulton loved to entertain; and he began to invite his friends in science and industry to regular dinners at his home. At these dinners, it was understood by all the guests that science and philosophy were to be the topics of the conversation. This group of friends began to call themselves the "Lunar Society", because of their habit of meeting on nights when the moon was full so that they could find their way home easily afterwards.

During the early stages of the Industrial Revolution, the Lunar Society of Birmingham played a role in the development of scientific ideas which was almost as important as the role played by the Royal Society of London at the time of Isaac Newton. Among the members of this group of friends, besides Erasmus Darwin and James Watt, were the inventive and artistic pottery manufacturer, Josiah Wedgwood (the other grandfather of Charles Darwin), and the author, chemist and Unitarian minister, Joseph Priestley (1733-1804).

Joseph Priestley's interests were typical of the period: The center of scientific attention had shifted from astronomy to the newly-discovered phenomena of electricity, heat and chemistry, and to the relationship between them. Priestly, who was a prolific and popular author of books on many topics, decided to write a *History of Electricity.* He not only collected all the results of previous workers in an organized form, but also, while repeating their experiments, he made a number of original discoveries. For example, Joseph Priestley was the first to discover the inverse square law of attraction and repulsion between electrical charges, a law which was later verified by the precise experiments of Henry Cavendish

(1731-1810) and Charles Coulomb (1736-1806).

The chemistry of gases was also very much in vogue during this period. Joseph Black's medical thesis at Edinburgh University had opened the field with an elegant quantitative treatment of chemical reactions involving carbon dioxide. Black had shown that when chalk (calcium carbonate) is heated, it is changed into a caustic residue (calcium oxide) and a gas (carbon dioxide).

Black had carefully measured the weight lost by the solid residue when the gas was driven off, and he had shown that precisely the same weight was regained by the caustic residue when it was exposed to the atmosphere and reconverted to chalk. His work suggested not only that weight is conserved in chemical reactions, but also that carbon dioxide is present in the atmosphere. Black's work had initiated the use of precise weighing in chemistry, a technique which later was brought to perfection by the great French chemist, Anton Lavoisier (1743-1794).

Joseph Priestley, (who had been supplied with a large burning-glass by his brother-in-law, the wealthy ironmaster, John Wilkinson), carried out an experiment similar to Black's. He used the glass to focus the rays of the sun on a sample of what we now call red oxide of mercury. He collected the gas which was driven off, and tested its properties, recording that "...what surprized me more than I can well express was that a candle burned in this air with a remarkably vigorous flame". He also found that a mouse could live much longer in the new gas than in ordinary air.

On a trip to France, Priestley communicated these results to Anton Lavoisier, who named the gas "oxygen" and established fully its connection with combustion and respiration. At almost the same time, the Swedish chemist, Karl Wilhelm Scheele (1742-1786), discovered oxygen independently.

Joseph Priestley isolated and studied nine other new gases; and he invented the technique of collecting gases over mercury. This was much better than collecting them over water, since the gases did not dissolve in mercury. He extended Joseph Black's studies of carbon dioxide, and he invented a method for dissolving carbon dioxide in beverages under pressure, thus becoming the father of the modern soft drink industry!

The tremendous vogue for gas chemistry in the late 18th century can also be seen in the work of the eccentric multimillionaire scientist, Henry Cavendish, who discovered hydrogen by dissolving metals in acids, and then showed that when hydrogen is burned in oxygen, the resulting compound is pure water. Cavendish also combined the nitrogen in the atmosphere with oxygen by means of electrical sparks. The remaining bubble of atmospheric gas, which stubbornly refused to combine with oxygen, was later shown to be a new element - argon.

The great interest in gas chemistry shown by intelligent people of the period can be seen in Josiah Wedgwood's suggestions to the painter, George Stubbs, who was commissioned to make a portrait of Wedgwood's children:

"The two family pieces I have hinted at, I mean to contain the children only, and grouped perhaps in some such manner as this - Sukey playing upon her harpsichord with Kitty singing to her, as she often does, and Sally and Mary Ann upon the carpet in some employment suitable to their ages. This to be one picture. The pendant to be Jack standing at a table making fixable air with the glass apparatus etc., and his two brothers accompanying him, Tom jumping up and clapping his hands in joy, and surprized at seeing the stream of bubbles rise up just as Jack has put a little chalk to the acid. Jos with the chemical dictionary before him in a thoughtful mood; which actions will be exactly descriptive of their respective characters."

The force of feudal traditions was still so strong, however, that in spite of Josiah Wedgwood's suggestions, George Stubbs painted the children on horseback, looking precisely like the children of a traditional landlord. The "fixable air" which Wedgwood mentions was the contemporary word for carbon dioxide. Josiah Wedgwood's daughter, Sukey (Susannah), was destined to become the mother of the greatest biologist of all time, Charles Darwin.

4.7 Adam Smith

One of Joseph Black's best friends at Glasgow University was the Professor of Moral Philosophy, Adam Smith. In 1759, Smith published a book entitled *The Theory of Moral Sentiments*, which was subtitled: *An Essay towards an Analysis of the Principles by which Men naturally judge concerning the Conduct and Character, first of their Neighbors, and afterwards of themselves.*

In this book, Adam Smith pointed out that people can easily judge the conduct of their neighbors. They certainly know when their neighbors are treating them well, or badly. Having learned to judge their neighbors, they can, by analogy, judge their own conduct. They can tell when they are mistreating their neighbor or being kind by asking themselves: "Would I want him to do this to me?" As Adam Smith put it:

"Our continual observations upon the conduct of others insensibly lead us to form to ourselves certain general rules concerning what is fit and proper to be done or avoided... It is thus the general rules of morality are formed."

When we are kind to our neighbors, they maintain friendly relations with us; and to secure the benefits of their friendship, we are anxious to behave well towards other people. Thus, according to Adam Smith, enlightened self-interest leads men and women to moral behaviour.

In 1776, Adam Smith published another equally optimistic book, with a similar theme: *The Wealth of Nations*. In this book, he examined the reasons why some nations are more prosperous than others. Adam Smith concluded that the two main factors in prosperity are division of labor and economic freedom.

As an example of the benefits of division of labor, he cited the example of a pin factory, where ten men, each a specialist in a particular manufacturing operation, could produce 48,000 pins per day. One man drew the wire, another straightened it, a third pointed the pins, a fourth put on the heads, and so on. If each man had worked separately, doing all the operations himself, the total output would be far less. The more complicated the manufacturing process (Smith maintained), the more it could be helped by division of labor. In the most complex civilizations, division of labor has the greatest utility.

Adam Smith believed that the second factor in economic prosperity is economic freedom, and in particular, freedom from mercantilist government regulations. He believed that natural economic forces tend to produce an optimum situation, in which each locality specializes in the economic operation for which it is best suited.

Smith believed that when each individual aims at his own personal prosperity, the result is the prosperity of the community. A baker does not consciously set out to serve society by baking bread - he only intends to make money for himself; but natural economic forces lead him to perform a public service, since if he were not doing something useful, people would not pay him for it. Adam Smith expressed this idea in the following way:

"As every individual, therefore, endeavours as much as he can, both to employ his capital in support of domestic industry, and so to direct that industry that its produce may be of greatest value, each individual necessarily labours to render the annual revenue of the Society as great as he can."

"He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain; and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention. Nor is it always the worse for Society that it was no part of it. By pursuing his own interest, he frequently promotes that of society more effectively than when he really intends to promote it."

In Adam Smith's optimistic view, an "invisible hand" guides individuals to promote the public good, while they consciously seek only their own gain. This vision was enthusiastically adopted adopted by the vigorously growing industrial nations of the west. It is the basis of much of modern history; but there proved to be shortcomings in Smith's theory. A collection of individuals, almost entirely free from governmental regulation, each guided only by his or her desire for personal gain - this proved to be a formula for maximum economic growth; but certain modifications were needed before it could lead to widely shared happiness and social justice.

The dark, Satanic mills

Both Matthew Boulton and Josiah Wedgwood were model employers as well as pioneers of the factory system. Matthew Boulton had a pension scheme for his men, and he made every effort to insure that they worked under comfortable conditions. However, when he died in 1809, the firm of Boulton and Watt was taken over by his son, Matthew Robbinson Boulton, in partnership with James Watt Jr.. The two sons did not have their fathers' sense of social responsibility; and although they ran the firm very efficiently, they seemed to be more interested in profit-making than in the welfare of their workers.

A still worse employer was Richard Arkwright (1732-1792), who held patents on a series of machines for carding, drawing and spinning silk, cotton, flax and wool. He was a rough, uneducated man, who rose from humble origins to become a multimillionaire by driving himself almost as hard as he drove his workers. Arkwright perfected machines (invented by others) which could make extremely cheap and strong cotton thread; and as a result, a huge cotton manufacturing industry grew up within the space of a few years. The growth of the cotton industry was especially rapid after Arkwright's patent expired in 1785.

Crowds of workers, thrown off the land by the Enclosure Acts, flocked to the towns, seeking work in the new factories. Wages fell to a near-starvation level, hours of work increased, and working conditions deteriorated. Dr. Peter Gaskell, writing in 1833, described the condition of the English mill workers as follows:

"The vast deterioration in personal form which has been brought about in the manufacturing population during the last thirty years... is singularly impressive, and fills the mind with contemplations of a very painful character... Their complexion is sallow and pallid, with a peculiar flatness of feature caused by the want of a proper quantity of adipose substance to cushion out the cheeks. Their stature is low - the average height of men being five feet, six inches... Great numbers of the girls and women walk lamely or awkwardly... Many of the men have but little beard, and that in patches of a few hairs... (They have) a spiritless and dejected air, a sprawling and wide action of the legs..."

"Rising at or before daybreak, between four and five o'clock the year round, they swallow a hasty meal or hurry to the mill without taking any food whatever... At twelve o'clock the engine stops, and an hour is given for dinner... Again they are closely immured from one o'clock till eight or nine, with the exception of twenty minutes, this being allowed for tea. During the whole of this long period, they are actively and unremittingly engaged in a crowded room at an elevated temperature."

Dr. Gaskell described the housing of the workers as follows:

"One of the circumstances in which they are especially defective is that of drainage and water-closets. Whole ranges of these houses are either totally undrained, or very partially... The whole of the washings and filth from these consequently are thrown into the front or back street, which, often being unpaved and cut into deep ruts, allows them to collect into stinking and stagnant pools; while fifty, or even more than that number, having only a single convenience common to them all, it is in a very short time choked with excrementous matter. No alternative is left to the inhabitants but adding this to the already defiled street."

"It frequently happens that one tenement is held by several families... The demoralizing effects of this utter absence of domestic privacy must be seen before they can be thoroughly appreciated. By laying bare all the wants and actions of the sexes, it strips them of outward regard for decency - modesty is annihilated - the father and the mother, the brother and the sister, the male and female lodger, do not scruple to commit acts in front of each other which even the savage keeps hid from his fellows."

"Most of these houses have cellars beneath them, occupied - if it is possible to find a lower class - by a still lower class than those living above them."

The abuse of child labor was one of the worst features of early industrialism in England. Sometimes small children, starting at the age of six or seven, were forced to work, because wages were so low that the family would otherwise starve; and sometimes the children were orphans, taken from parish workhouses. The following extract from John Fielden's book, *The Curse of the Factory System* (1836), describes the condition of young children working in the cotton industry:

"It is well known that Arkwright's (so called at least) inventions took manufactures out of the cottages and farmhouses of England... and assembled them in the counties of Derbyshire, Nottinghamshire and more particularly, in Lancashire, where the newly-invented machinery was used in large factories built on the side of streams capable of turning the water wheel. Thousands of hands were suddenly required in these places, remote from towns."

"The small and nimble fingers of children being by far the most in request, the custom instantly sprang up of procuring 'apprentices' from the different parish workhouses of London, Birmingham and elsewhere... Overseers were appointed to see to the works, whose interest it was to work the children to the utmost, because their pay was in proportion to the quantity of work which they could exact."

"Cruelty was, of course, the consequence; and there is abundant evidence on record to show that in many of the manufacturing districts, the most heart-rending cruelties were practiced on the unoffending and friendless creatures... that they were flogged, fettered and tortured in the most exquisite refinement of cruelty, that they were, in many cases, starved to the bone while flogged to their work, and that even in some instances they were driven to commit suicide... The profits of manufacture were enormous; but this only whetted the appetite it should have satisfied."

One of the arguments which was used to justify the abuse of labor was that the alternative was starvation. The population of Europe had begun to grow rapidly for a variety of reasons: - because of the application of scientific knowledge to the prevention of disease; because the potato had been introduced into the diet of the poor; and because bubonic plague had become less frequent after the black rat had been replaced by the brown rat, accidentally imported from Asia.

It was argued that the excess population could not be supported unless workers were employed in the mills and factories to produce manufactured goods, which could be exchanged for imported food. In order for the manufactured goods to be competitive, the labor which produced them had to be cheap: hence the abuses. (At least, this is what was argued).

Overpopulation

When the facts about the abuse of industrial workers in England became known, there were various attempts to explain what had gone wrong with the optimistic expectations of the Enlightenment. Among the writers who discussed this problem was the economist David Ricardo (1772-1823). In his book, *The Principles of Political Economy and Taxation* (1817), Ricardo proposed his "iron law of wages".

According to Ricardo, labor is a commodity, and wages are determined by the law of supply and demand: When wages fall below the starvation level, the workers' children die. Labor then becomes a scarce commodity, and the wages rise. On the other hand, when wages rise above the starvation level, the working population multiplies rapidly, labor becomes a plentiful commodity, and wages fall again. Thus, according to Ricardo, there is an "iron law" which holds wages at the minimum level at which life can be supported.

Ricardo's reasoning assumes industrialists to be completely without social conscience or governmental regulation; it fails to anticipate the development of trade unionism; and it assumes that the working population will multiply without restraint as soon as their wages rise above the starvation level. This was an accurate description of what was happening in England during Ricardo's lifetime, but it obviously does not hold for all times and all places.

A more general and complete description of the situation was given by Thomas Robert Malthus (1766-1834). Malthus came from an intellectual family: His father, Daniel Malthus, was a friend of Rousseau, Hume and Goodwin. The famous book on population by the younger Malthus grew out of his conversations with his father.

Daniel Malthus was an enthusiastic believer in the optimistic philosophy of the Enlightenment. Like Goodwin, Condorcet and Voltaire, he believed that the application of scientific progress to agriculture and industry would inevitably lead humanity forward to a golden age. His son, Robert, was more pessimistic. He pointed out that the benefits of scientific progress would probably be eaten up by a growing population.

At his father's urging, Robert Malthus developed his ideas into a book, *An Essay on the Principle of Population*, which he published anonymously in 1798. In this famous book, Malthus pointed out that under optimum conditions, every biological population, including that of humans, is capable of increasing exponentially. For humans under optimum conditions, the population can double every twenty-five years, quadruple every fifty years and increase by a factor of 8 every seventy-five years. It can grow by a factor of 16 every century, and by a factor of 256 every two centuries, and so on.

Obviously, human populations cannot increase at this rate for very long, since if they did, the earth would be completely choked with people in a very few centuries. Therefore, Malthus pointed out, various forces must be operating to hold the population in check. Malthus listed first the "positive checks" to population growth - disease, famine and war - which we now call the "Malthusian forces". In addition, he listed checks of another kind - birth control (which he called "Vice"), late marriage, and "Moral Restraint". Being a clergyman, Malthus naturally favored moral restraint.

According to Malthus, a population need not outrun its food supply, provided that late marriage, birth control or moral restraint are practiced; but without these less painful checks, the population will quickly grow to the point where the grim Malthusian forces - famine, disease and war - begin to act.

Curiously, it was France, a Catholic country, which led the way in the development of birth control. Robert Owen (who was an enlightened English industrialist, and the founder of the cooperative movement), wished to advise his workers about birth control; and so he went to France to learn about the techniques practiced there. In 1825, an article (by Richard Carlile) appeared in *The Republican*. The article described the importation of birth control from France to England as follows:

"...It was suggested to Mr. Owen that, in his new establishments, the healthy state of the inhabitants would tend to breed an excess of children. The matter was illustrated and explained to him, so that he felt the force of it. He was told that on the Continent, the women used some means of preventing conception which were uniformly successful. Mr. Owen set out for Paris to discover the process. He consulted the most eminent physicians, and assured himself of what was the common practice among their women."

"...A piece of soft sponge is tied by a bobbin or penny ribbon, and inserted before sexual intercourse takes place, and is withdrawn again as soon as it has taken place... If the sponge be large enough, that is, as large as a green walnut or a small apple, it will prevent conception, without diminishing the pleasures of married life."

Carlile goes on to say:

"...When the number of working people in any trade or manufacture has for some years been too great, wages are reduced very low, and the working people become little better than slaves... By limiting the number of children, the wages of both children and grown persons will rise; and the hours of working will be no more than they ought to be."

Birth control and late marriage have (until now) kept the grim predictions of Ricardo and Malthus from being fulfilled in the developed industrial nations of the modern world. Most of these nations have gone through a process known as the "demographic transition" - the shift from an equilibrium where population growth is held in check by the Malthusian forces of disease, starvation and war, to one where it is held in check by birth control and late marriage.

The transition begins with a fall in the death rate, caused by various factors, among which the most important is the application of scientific knowledge to the prevention of disease. Cultural patterns require some time to adjust to the lowered death rate, and so the birth rate continues to be high. Families continue to have six or seven children, just as they did when most of the children died before having children of their own. Therefore, at the start of the demographic transition, the population increases sharply. After a certain amount of time, however, cultural patterns usually adjust to the lowered death rate, and a new equilibrium is established, where both the birth rate and the death rate are low.

In Europe, this period of adjustment required about two hundred years. In 1750, the death rate began to fall sharply: By 1800, it had been cut in half, from 35 deaths per thousand people in 1750 to 18 in 1800; and it continued to fall. Meanwhile, the birth rate did not fall, but even increased to 40 births per thousand per year in 1800. Thus the number of children born every year was more than twice the number needed to compensate for the deaths!

By 1800, the population was increasing by more than two percent every year. In 1750, the population of Europe was 150 million; by 1800, it was roughly 220 million; by 1950 it had exceeded 540 million, and in 1970 it was 646 million.

Meanwhile the achievements of medical science and the reduction of the effects of famine and warfare had been affecting the rest of the world: In 1750, the non-European population of the world was only 585 million. By 1850 it had reached 877 million. During the century between 1850 and 1950, the population of Asia, Africa and Latin America more than doubled, reaching 1.8 billion in 1950. In the twenty years between 1950 and 1970, the population of Asia, Africa and Latin America increased still more sharply, and in 1970, this segment of the world's population reached 2.6 billion, bringing the world total to 3.6 billion. The fastest increase was in Latin America, where population almost doubled during the twenty years between 1950 and 1970.

The latest figures show that the population explosion is leveling off in Europe, Russia, North America and Japan, where the demographic transition is almost complete. However, the population of the rest of the world is still increasing at a breakneck speed; and it cannot continue to expand at this rate for very much longer without producing widespread famine.

4.8 Colonialism

In the 18th and 19th centuries, the continually accelerating development of science and science-based industry began to affect the whole world. As the factories of Europe poured out cheap manufactured goods, a change took place in the patterns of world trade: Before the Industrial Revolution, trade routes to Asia had brought Asian spices, textiles and luxury goods to Europe. For example, cotton cloth and fine textiles, woven in India, were imported to England. With the invention of spinning and weaving machines, the trade was reversed. Cheap cotton cloth, manufactured in England, began to be sold in India, and the Indian textile industry withered.

The rapid development of technology in the west also opened an enormous gap in military strength between the industrialized nations and the rest of the world. Taking advantage of their superior weaponry, the advanced industrial nations rapidly carved the remainder of the world into colonies, which acted as sources of raw materials and food, and as markets for manufactured goods.

In North America, the native Indian population had proved vulnerable to European diseases, such as smallpox, and large numbers of them had died. The remaining Indians were driven westward by streams of immigrants arriving from Europe. In Central and South America, European diseases proved equally fatal to the Indians.

Often the industrialized nations made their will felt by means of naval bombardments: In 1854, Commodore Perry and an American fleet forced Japan to accept foreign traders by threatening to bombard Tokyo. In 1856, British warships bombarded Canton in China to punish acts of violence against Europeans living in the city. In 1864, a force of European and American warships bombarded Choshu in Japan, causing a revolution. In 1882, Alexandria was bombarded, and in 1896, Zanzibar.

Between 1800 and 1875, the percentage of the earth's surface under European rule increased from 35 percent to 67 percent. In the period between 1875 and 1914, there was a new wave of colonial expansion, and the fraction of the earth's surface under the domination of colonial powers (Europe, the United States and Japan) increased to 85 percent, if former colonies are included.

During the period between 1880 and 1914, English industrial and colonial dominance began to be challenged. Industrialism had spread from England to Belgium, Germany and the United States, and, to a lesser extent, to France, Italy, Russia and Japan. By 1914, Germany was producing twice as much steel as Britain, and the United States was producing four times as much.

New techniques in weaponry were introduced, and a naval armaments race began among the major industrial powers. The English found that their old navy was obsolete, and they had to rebuild. Thus, the period of colonial expansion between 1880 and 1914 was filled with tensions, as the industrial powers raced to arm themselves in competition with each other, and raced to seize as much as possible of the rest of the world.

Much that was beautiful and valuable was lost, as mature traditional cultures collapsed, overcome by the power and temptations of modern industrial civilization. For the Europeans and Americans of the late 19th century and early 20th century, progress was a religion, and imperialism was its crusade. The cruelties of the crusade were justified, in the eyes of the westerners, by their mission to "civilize" and Christianize the rest of the world. To a certain extent, the industrial countries were right in feeling that they had something of value to offer to the rest of the world; and among the people whom they sent out were educators and medical workers who often accepted lives of extreme discomfort and danger in order to be of service.

At the beginning of the 19th century, the world was divided into parts: China was a world in itself; India was a separate world; Africa south of the Sahara was another enclosed world; and the Islamic world was also self-contained, as was the west. By 1900, there was only one world, bound together by constantly-growing ties of trade and communication.

4.9 Trade Unions and minimum wage laws

Robert Owen and social reform

During the early phases of the Industrial Revolution in England, the workers suffered greatly. Enormous fortunes were made by mill and mine owners, while workers, including young children, were paid starvation wages for cruelly long working days. However, trade unions, child labor laws, and the gradual acceptance of birth control finally produced a more even distribution of the benefits of industrialization.

One of the most interesting pioneers of these social reforms was Robert Owen (1771-1858), who is generally considered to have been the father of the Cooperative Movement. Although in his later years not all of his projects developed as he wished, his life started as an amazing success story. Owen's life is not only fascinating in itself; it also illustrates some of the reforms that occurred between 1815 and 1850.

Robert Owen was born in Wales, the youngest son of a family of iron-mongers and saddle-makers. He was a very intelligent boy, and did well at school, but at the age of 9, he was apprenticed to a draper, at first in Wales. Later, at the age of 11, he was moved to London, where he was obliged to work eighteen hours a day, six days a week, with only short pauses for meals. Understandably, Robert Owen found this intolerable, and he moved again, this time to Manchester, where he again worked for a draper.

While in Manchester, Robert Owen became interested in the machines that were beginning to be used for spinning and weaving. He borrowed a hundred pounds from his brother, and entered (as a partner) a small business that made these machines. After two years of moderate success as a small-scale industrialist, Owen saw the newspaper advertisement of a position for manager of a large spinning mill, owned by a Mr. Drinkwater.

“I put on my hat”, Owen wrote later, “and proceeded straight to Mr. Drinkwater’s counting house. ‘How old are you?’ ‘Twenty this May’, was my reply. ‘How often do you get drunk in the week?’... ‘I was never’, I said, ‘drunk in my life.’ blushing scarlet at this unexpected question. ‘What salary do you ask?’ ‘Three hundred a year’, was my reply. ‘What?’, Mr. Drinkwater said with some surprise, repeating the words, ‘Three hundred pounds! I have had this morning I know not how many seeking the situation and I do not think that all of their askings would amount to what you require.’ ‘I cannot be governed by what others seek’, said I, ‘and I cannot take less.’

Apparently impressed by Robert Owen’s success as a small-scale industrialist, and perhaps also impressed by his courage, Mr. Drinkwater hired him. Thus, at the age of 19, Owen became the manager of a large factory. Mr. Drinkwater had no cause to regret his decision, since his new manager quickly became the boy wonder of Manchester’s textile community. Within six months, Drinkwater offered Owen a quarter interest in his business.

After several highly successful years in his new job, Robert Owen heard of several mills that were for sale in the village of New Lanark, near to Glasgow. The owner, Mr. Dale, happened to be the father of the girl with whom Robert Owen had fallen in love. Instead of directly asking Dale for permission to marry his daughter, Owen (together with some business partners) first purchased the mills, after which he won the hand of the daughter.

Ownership of the New Lanark mills gave Robert Owen the chance to put into practice the ideas of social reform that he had been developing throughout his life. Instead of driving his workers by threats of punishment, and instead of subjecting them to cruelly long working hours (such as he himself had experienced as a draper’s apprentice in London), Owen made the life of his workers at New Lanark as pleasant as he possibly could. He established a creche for the infants of working mothers, free medical care, concerts, dancing, music-making, and comprehensive education, including evening classes. Instead of the usual squalid one-room houses for workers, neat two-room houses were built. Garbage was collected regularly instead of being thrown into the street. New Lanark also featured pleasant landscaped areas.

Instead of leading to bankruptcy, as many of his friends predicted, Robert Owen’s reforms led to economic success. Owen’s belief that a better environment would lead to better work was vindicated. The village, with its model houses, schools and mills, became internationally famous as a demonstration that industrialism need not involve oppression of the workers. Crowds of visitors made the journey over narrow roads from Glasgow to learn from New Lanark and its visionary proprietor. Among the twenty thousand visitors who signed the guest-book between 1815 and 1825 were the Grand Duke Nicholas of Russia (who later became Czar Nicholas I), and Princes John and Maximilian of Austria.

Robert Owen’s ideas of social reform can be seen in the following extract from an “Address to the Inhabitants of New Lanark”, which he presented on New Year’s Day, 1616: “What ideas individuals may attach to the term ‘Millennium’ I know not; but I know that society may be formed so as to exist without crime, without poverty, with health greatly improved, with little, if any, misery. and with intelligence and happiness

Figure 4.9: **New Lanark World Heritage village in Scotland. A view of the school.**

increased a hundredfold; and no obstacle whatsoever intervenes at this moment except ignorance to prevent such a state of society from becoming universal."

Robert Owen believed that these principles could be applied not only in New Lanark but also in the wider world. He was soon given a chance to express this belief. During the years from 1816 to 1820, apart from a single year, business conditions in England were very bad, perhaps as a result of the Napoleonic Wars, which had just ended. Pauperism and social unrest were widespread, and threatened to erupt into violence. A committee to deal with the crisis was formed under the leadership of the Dukes of Kent and York.

Because of Owen's reputation, he was asked for his opinion, but the committee was hardly expecting the answer that they received from him. Robert Owen handed the two Dukes and the other committee members a detailed plan for getting rid of pauperism by making paupers productive. They were to be settled in self-governing Villages of Cooperation, each with between 800 and 1,200 inhabitants. Each family was to have a private apartment, but there were to be common sitting rooms, reading rooms and kitchens. Near to the houses, there were to be gardens tended by the children, and farther out, fields to be cultivated by the adults. Still farther from the houses, there was to be a small factory.

Owen's idea for governmentally-planned paupers' collectives was at first rejected out of hand. The early 19th century was, after all, a period of unbridled *laissez-faire* economics. Owen then bombarded the Parliament with pamphlets advocating his scheme. Finally a committee was formed to try to raise the money to establish one Village of Cooperation as an experiment; but the money was never raised.

Unwilling to accept defeat, Robert Owen sold his interest in New Lanark and sailed for America, where he believed that his social experiment would have a better chance of success. He bought the town of Harmonie and 30,000 acres of land on the banks of the Wabash River in Indiana. There he established a Village of Cooperation which he named "New Harmony". He dedicated it on the 4th of July, 1826. It remained a collective for only two years, after which individualism reasserted itself. Owen's four sons and one of his daughters made their homes in New Harmony, and it also became the home of numerous scientists, writers and artists.

Owen's son, Robert Dale Owen, became a member of the U.S. House of Representatives, where he introduced the bill establishing the Smithsonian Institution. In 1862 he wrote an eloquent letter to Abraham Lincoln urging emancipation of the slaves. Three days later, probably influenced by Owen's letter, Lincoln read the Emancipation Proclamation to his cabinet. Another son, Richard Owen, served as President of the University of Indiana, and was later elected as the first President of Purdue University.

When Robert Owen returned to England shortly after dedicating New Harmony, he found that he had become a hero of the working classes. They had read his writings avidly, and had begun to establish cooperatives, following his principles. There were both producer's cooperatives and consumer's cooperatives. In England, the producer's cooperatives failed, but in Denmark they succeeded[2].

One of the early consumer's cooperatives in England was called the Rochdale Society of Equitable Pioneers. It was founded by 28 weavers and other artisans, who were being forced into poverty by mechanization. They opened a small cooperative store selling butter, sugar, flour, oatmeal and candles. After a few months, they also included tobacco and tea. From this small beginning, the Cooperative Movement grew, finally becoming one of the main pillars of the British Labour Party.

Robert Owen's attention now turned from cooperatives to the embryonic trade union movement, which was struggling to establish itself in the face of fierce governmental opposition. He assembled the leaders of the working class movement and proposed the formation of the "Grand National Moral Union of Productive and Useful Classes". The name was soon shortened to "The Grand National Consolidated Trades Union" or simply the "Grand National".

Owen's Grand National was launched in 1833, and its membership quickly grew to half a million. It was the forerunner of modern nationwide trade unions, but it lasted only two years. Factory-owners saw the Grand National as a threat, and they persuaded the government to prosecute it under anti-union laws. Meanwhile, internal conflicts helped to destroy the Grand National. Owen was accused of atheism by the working class leaders, and he accused them of fermenting class hatred.

Robert Owen's influence helped to give raw *laissez faire* capitalism a more human face, and helped to spread the benefits of industrialization more widely. Through the work of other reformers like Owen, local trade unions succeeded, both in England and elsewhere; and in the end, successful national unions were finally established. The worst features of the

[2]The success of Danish agricultural producer's cooperatives was helped by the People's High School movement, founded by N.F.S. Grundvig (1783-1872).

Figure 4.10: **Robert Owen, (1771-1858), founder of the Cooperative Movement.**

early Industrial Revolution were moderated by the growth of the trade union movement, by child labor laws, by birth control and by minimum wage laws.

Rusting of the Iron Law

David Ricardo's Iron Law of Wages maintained that workers must necessarily live at the starvation level: Their wages are determined by the law of supply and demand, Ricardo said. If the wages should increase above the starvation level, more workers' children would survive, the supply of workers would increase, and the wages would fall again. This gloomy pronouncement was enthusiastically endorsed by members of the early 19th century Establishment, since it absolved them from responsibility for the miseries of the poor. However, the passage of time demonstrated that the Iron Law of Wages held only under the assumption of an economy totally free from governmental intervention.

Both the growth of the political power of industrial workers, and the gradual acceptance of birth control were important in eroding Ricardo's Iron Law. Birth control is especially important in countering the argument used to justify child labor under harsh conditions. The argument (still used in many parts of the world) is that child labor is necessary in order to save the children from starvation, while the harsh conditions are needed because if a business provided working conditions better than its competitors, it would go out of business. However, with a stable population and appropriate social legislation prohibiting both child labor and harsh working conditions, the Iron Law argument fails.

4.10 Rising standards of living

Since the year 1000, world population has risen 22-fold, global per capita Gross Domestic Product 13-fold, and world GDP nearly 300-fold. These data come from Angus Maddison's recent book, *World Population, GDP and Per Capita GDP, 1-2003*. More detailed data, from a report that Prof. Maddison presented to the British House of Lords, are shown in Tables 5.1 and 5.2.

During the period between 1820 and 2001, the average years of education per person employed increased from 2.00 years to 15.45 years in the United Kingdom, from 1.75 years to 20.21 years in the United States, and from 1.50 years to 16.61 years in Japan. This increased education in the highly industrialized countries was necessary because of the complexity of modern machines and modern life.

Today, most citizens of the industrialized countries have lives of greatly-increased pleasure and freedom compared with the lives of their great-grandparents. Furthermore, their lives are also remarkably easy and pleasant compared with the remainder of the world. In later chapters we will try to discuss to what extent this privileged life-style is sustainable.

Table 4.1: GDP per capita (1990 int. $). Data from Maddison.

	1900	1950	1990	2001
W. Europe	2,893	4,579	15,966	19,256
USA	4,091	9,561	23,201	27,948
Ca.,Au.,NZ	3,435	7,424	17,902	21,718
Japan	1,180	1,921	18,789	20,683
E. Europe	1,438	2,111	5,450	6,207
fUSSR	1,237	2,841	6,878	4,626
L. America	1,109	2,506	5,053	5,811
China	545	439	1,858	3,583
India	599	619	1,309	1,957
Other Asia	802	919	3,084	3,997
Africa	601	894	1,444	1,489
World	1,262	2,111	5,157	6,049

Table 4.2: Gross stock of machinery and equipment per capita (1990 $). Data from Maddison. These figures are a measure of the degree of industrialization of the countries shown. Similar increases occurred in the gross stock of non-residential structures per capita. For example, in the USA the value of these structures increased from $1,094 (1990 $) in 1820 to $36,330 in 2001. In Japan there was a dramatic increase during the 20th century, from $852 per capita in 1913 to $57,415 in 2001.

	UK	USA	Japan
1820	92	87	na
1870	334	489	94
1913	878	2,749	329
1950	2,122	6,110	1,381
1973	6,203	10,762	6,431
2001	16,082	30,600	32,929

4.11 Robber barons and philanthropists

"Hain't I got the power?"

We can experience some of the flavor of early American industrial growth by looking at the life of Cornelius Vanderbilt (1794-1877). In those days, the United States was a place where a man with luck, intelligence and energy, could start with nothing and become a multimillionaire. That is exactly what Vanderbilt did.

Vanderbilt was born into a poor New York family. He quit school at 11 to help his father, and later remarked, "If I had learned education, I wouldn't have had time to learn anything else." At 16 he started his first business, using $100 borrowed from his mother - a small ferry boat between New York and Staten Island, charging 18 cents per trip. The business succeeded because of the fair price that he charged and because of his prodigious work. Within a year, he was able to give his mother $1,000 in return for her loan.

During the War of 1812, Vanderbilt had a government contract to sail supplies to forts in the New York area. He was by then operating a small fleet of sailing schooners, and as a consequence he received the nickname, "Commodore".

Cornelius Vanderbilt then became interested in steamships, but Robert Fulton and Robert Livingston had been granted a 30-year monopoly on the steamboat trade. This did not stop Vanderbilt. He started a competing steam line, and his boat evaded capture. Finally a Supreme Court decision broke the Fulton-Livingston monopoly. By the 1840's, Vanderbilt was operating about 100 steamships, and his business had the most employees of any in the United States.

Turning his attention to railways, Vanderbilt bought several lines, including the New York and Harlem Railroad, the Hudson River Railroad, and the New York Central Railroad. He extended his lines as far as Chicago, and attempted to acquire the Erie Railroad. This brought him into conflict with the unscrupulous financier Jim Fisk. Vanderbilt's methods were equally rough, so it was a fight with no holds barred. (Cornelius Vanderbilt once remarked, "What do I care about the law? Hain't I got the power?")

At the time of his death, Cornelius Vanderbilt was one of the richest men in the United States, with a fortune of over $100,000,000. He left most of this amount to his son William [3], but gave one million to Central University, which then became Vanderbilt University.

Carnegie's philanthropies

We can contrast Vanderbilt's relatively small interest in philanthropy with Andrew Carnegie's large-scale efforts for public improvement. Like Vanderbilt, Andrew Carnegie (1835-1919) was a self-made multimillionaire, but after making a fortune in oil wells, steel, iron ore and railways, he gave almost all of his money away. Early in his career, he wrote:

"I propose to take an income no greater than $50,000 per annum! Beyond this I need never earn, make no effort to increase my fortune, but spend the surplus each year for benevolent purposes! Let us cast aside business forever, except for others. Let us settle in

[3] William Vanderbilt is best remembered for his remark, "The public be damned!"

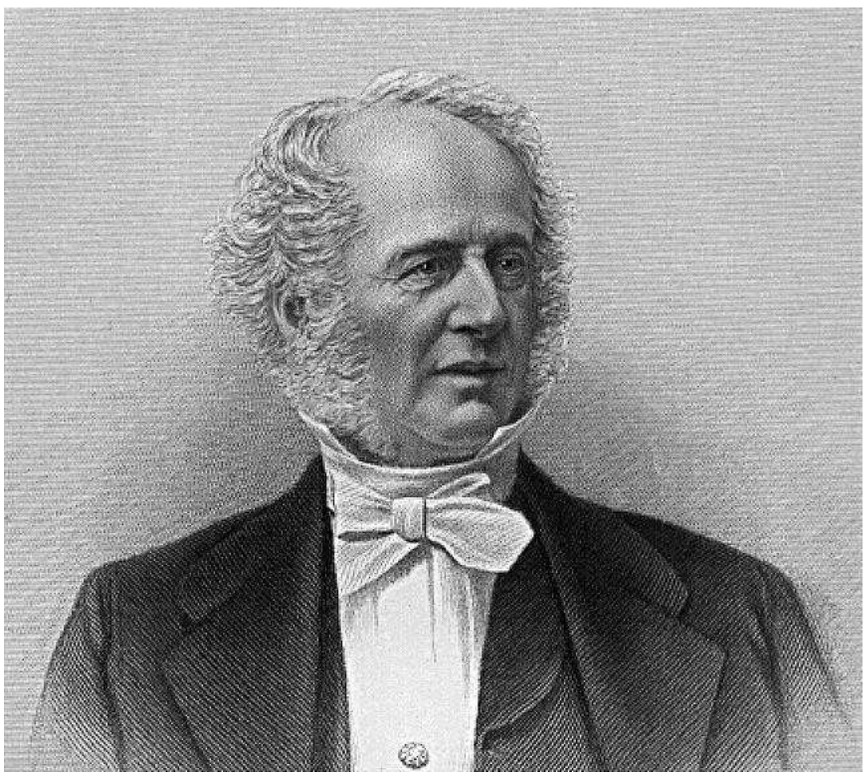

Figure 4.11: **Cornelius "Commodore" Vanderbilt.**

Figure 4.12: **Andrew Carnegie circa 1878.**

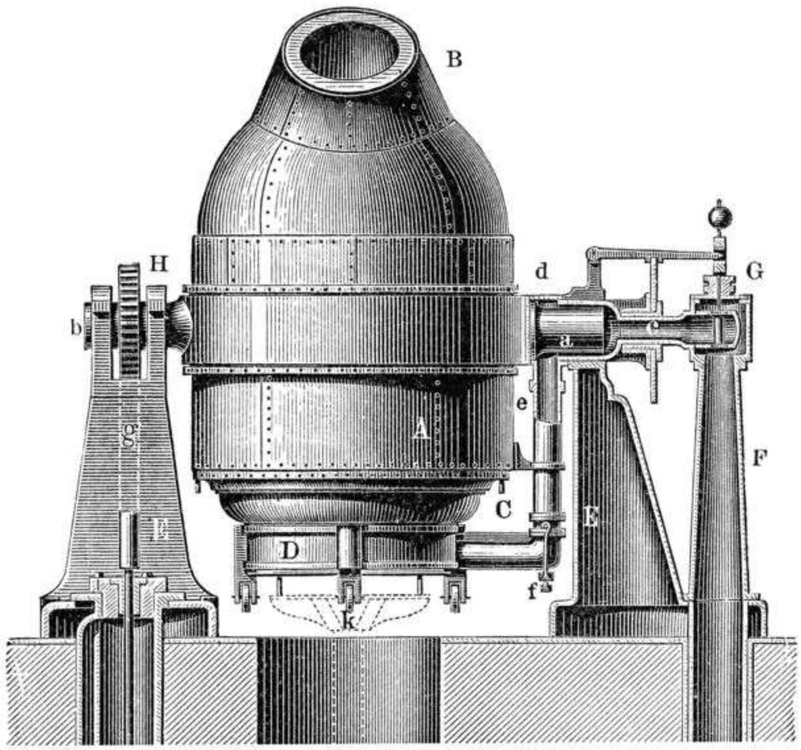

Figure 4.13: **A Bessemer converter, used in making steel.**

Oxford, and I shall get a thorough education, making the acquaintance of literary men... To continue much longer overwhelmed by business cares and with most of my thoughts wholly upon the way to make more money in the shortest time, must degrade me beyond hope of permanent recovery."

When he sold his share of the United States Steel Corporation in 1901, Andrew Carnegie became one of the wealthiest men in the world. He devoted the remainder of his life to educational projects and to philanthropy. He established a large number of public libraries, not only in the United Kingdom and in the United States, but also in Canada, Ireland, Australia, New Zealand, the West Indies and Fiji. In all, Carnegie established 3,000 libraries. In addition, he founded the Carnegie Institution in Washington D.C. and the Carnegie Institute of Technology in Pittsburgh, which later became the Carnegie Mellon University.

In Scotland, his birthplace, where he lived for part of each year, Andrew Carnegie established a trust to assist in university education. In recognition of this generous gift (and perhaps also in recognition of his authorship of a number of books and articles), Andrew Carnegie was elected Lord Rector of the University of St. Andrews. Carnegie also gave a large amount of money to Booker T. Washington's Tuskegee Institute. He established generous pension funds for his former employees, and also for American university professors. As if all this were not enough, he paid for the construction of 7,000 church organs, contributed to the erection of the Peace Palace at the Hague, and established the Carnegie Foundation, which continues to perform good works, especially in the field of education.

In the lives of Cornelius Vanderbilt and Andrew Carnegie we see exemplified some of the features of the age in which they lived, when ruthless business behavior was often balanced by splendid acts of public generosity.

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Chapter 5

CANALS, RAILROADS, BRIDGES AND TUNNELS

5.1 Canals

Two of the world's most famous canals are the Suez Canal and the Panama Canal. The Suez Canal has a very long history. In his book, *Meteorology*, Aristotle wrote of the Egyptian pharaohs: "One of their kings tried to make a canal to it (for it would have been of no little advantage to them for the whole region to have become navigable; Sesostris is said to have been the first of the ancient kings to try), but he found that the sea was higher than the land. So he first, and Darius afterwards, stopped making the canal, lest the sea should mix with the river water and spoil it."

Also, according to Pliny the Elder, " Next comes the Tyro tribe and, the harbour of the Daneoi, from which Sesostris, king of Egypt, intended to carry a ship-canal to where the Nile flows into what is known as the Delta; this is a distance of over 60 miles. Later the Persian king Darius had the same idea, and yet again Ptolemy II, who made a trench 100 feet wide, 30 feet deep and about 35 miles long, as far as the Bitter Lakes." Remnants of an ancient east-west canal were discovered by Napoleon's engineers in 1799.

Ferdinand de Lesseps and the Suez Canal

A company to dig a canal joining the Mediterranean and the Red Sea was formed by the French diplomat, Viscoumte Ferdinand de Lesseps, in 1858. He was able to obtain permission from the Egyptian authorities because his diplomatic activities in Egypt had led to especially friendly relationships. The excavations took 10 years, and some sources say that at any given time about 30,000 people were working on the project, The canal was successfully completed and was opened in 1869.

Figure 5.1: **Walter Reed (1851-1902). He demonstrated conclusively that yellow fever is spread by mosquitos. A campaign to eradicate mosquitos made the Panama Canal possible.**

The Panama Canal

Ferdinand de Lesseps tried to repeat his Suez success in Panama, but was defeated by the high mortality rate among workers resulting from malaria and yellow fever. Another factor in the defeat of the French effort was their attempt to dig the canal entirely at sea level, an idea that proved to be impractical.

A later United States effort to construct a Panama Canal joining the Atlantic and Pacific oceans was successful because an anti-mosquito campaign solved the medical problems, and because the canal was built with a system of locks. It made use of pre-existing lakes, and therefore the excavation effort, although colossal, was minimized. The Panama Canal was opened in 1916.

Figure 5.2: **The Suez Canal, viewed from space.**

Figure 5.3: **A schematic of the Panama Canal, illustrating the sequence of locks and passages.**

Figure 5.4: **Panorama of Pacific entrance of the canal. Left: Pacific Ocean and Puente de las Americas (Bridge of Pan-American Highway); far right: Miraflores locks.**

Figure 5.5: **Gatun locks on the Panama Canal, showing the "mule" locomotives at work.**

Figure 5.6: **Small boat canals such as the Basingstoke Canal provided transportation for the early industrial revolution in much of Europe and the United States.**

Figure 5.7: **Bridge on the Naviglio Grande, in the town of Cassinetta di Lugagnano, in Italy.**

Figure 5.8: **Canal in Broek in Waterland, Netherlands.**

Figure 5.9: **A canal in Venice.**

5.2 Isambard Kingdon Brunel

One of the greatest engineers in history

Isambard Kingdom Brunel (1806-1859) is considered to be "...one of the most ingenious and prolific figures in engineering history". He "...changed the face of the English landscape with his groundbreaking designs and ingenious constructions". In a 2002 BBC Poll to determine the 100 Greatest Britons, Brunel was placed second.

Brunel's education

Brunel was born in Portsmouth, England, to the French engineer, Sir Marc Isambard Brunel (1769-1849), and an English mother, Sophia Kingdom (1775-1855). During Brunel's early years, his father acted as his tutor, and by the time he was eight, he had learned Euclidean geometry. He also learned fluent French from his father, as well as basic engineering principles. As a young boy, Brunel was encouraged to draw interesting buildings, and to notice any faults in their construction.

When he was eight years old, Brunel was sent to Dr Morrell's boarding school in Hove, where he studied the classics. i.e. Greek and Roman language, history and literature. At the age of 14, Brunel was sent to France and enrolled, first in the University of Caen Normandy, later at Lycée Henri-IV in Paris. When he completed his studies at Lycée Henri-IV in 1822, Brunel's father wanted him to enroll in the famous engineering school, École Polytechnique, b ut as a foreigner, he was ineligible. Instead he studied under the famous horologist and clockmaker, Abraham-Louis Breguet, who praised the younger Brunel's great abilities in letters to Sir Marc.

Brunel's engineering achievements

Together with his father he designed and built the first tunnel under a navigable river, the Thames. He designed and built the Great Western Railway, with its London terminus, Paddington Station. He also revolutionized steamship design. Wishing to extend transportation westward to the United States from Bristol, the end station of the Great Western Railway, Brunel designed and built the first propeller-driven transatlantic steamship. He realized that the amount of coal and cargo that a ship can carry increases as the cube of its linear dimension, while water friction increases only as the square. Therefore a transatlantic steamship had to be enormously large. His huge ships, the Great Western (1838), and the Great Briton (1843), and the the Great Eastern (1859), held records for size at the time that they were built. They helped to lay the transatlantic cable, and to transport immigrants to Australia.

Besides being a great engineer, Brunel was an artist. His bridges, and railway stations are valued today for their great beauty, as well as for their innovative design.

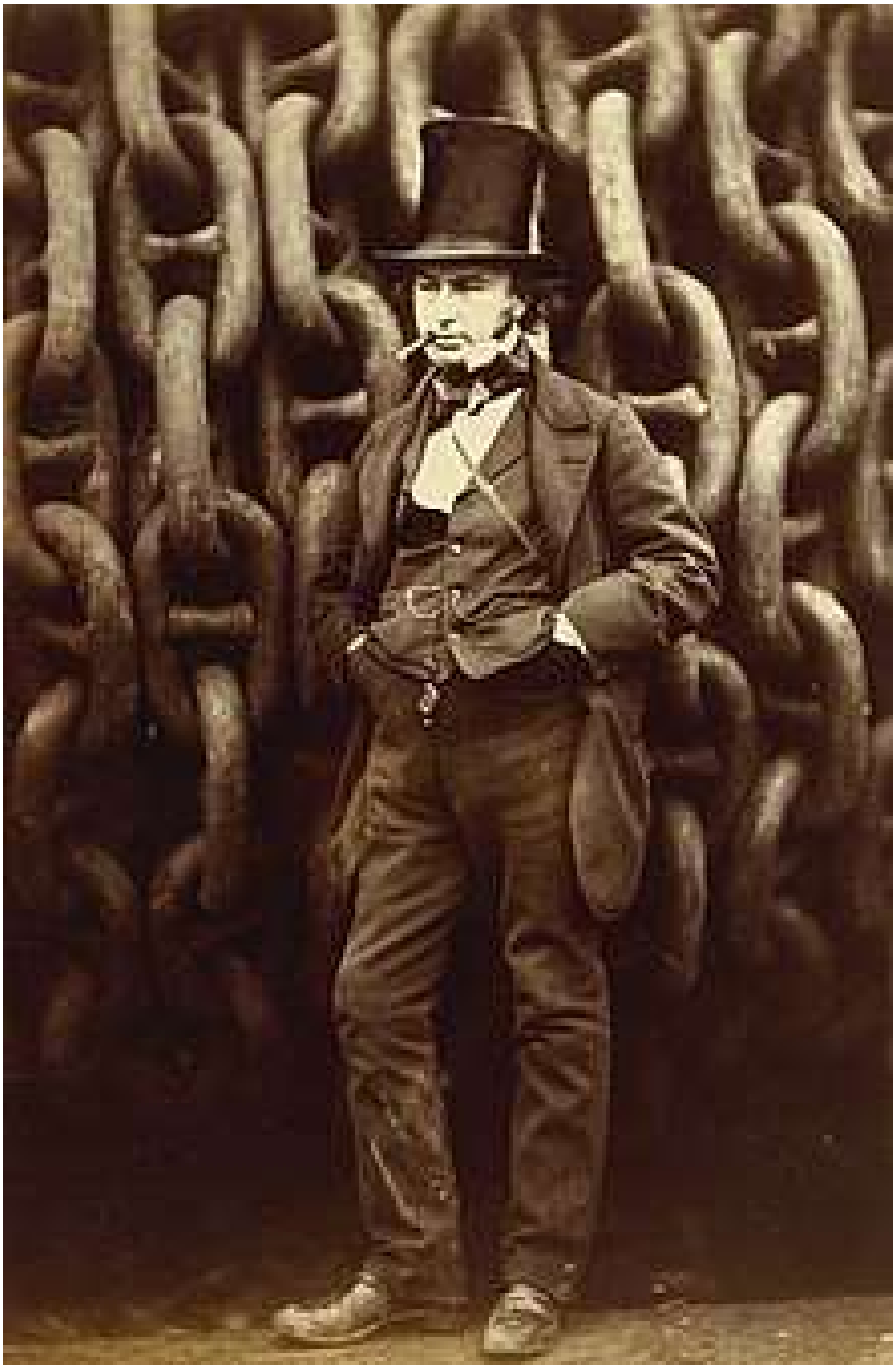

Figure 5.10: **The great 19th century engineer, Isambard Kingdom Brunel (1806-1959), beside the launching chain of the Great Eastern.**

Figure 5.11: **Brunel's Clifton Suspension Bridge spans Avon Gorge, linking Clifton in Bristol to Leigh Woods in North Somerset. It was completed in 1862.**

Figure 5.12: **Paddington station, still a mainline station, was the London terminus of the Great Western Railway. Both the station and the railway were designed by Brunel.**

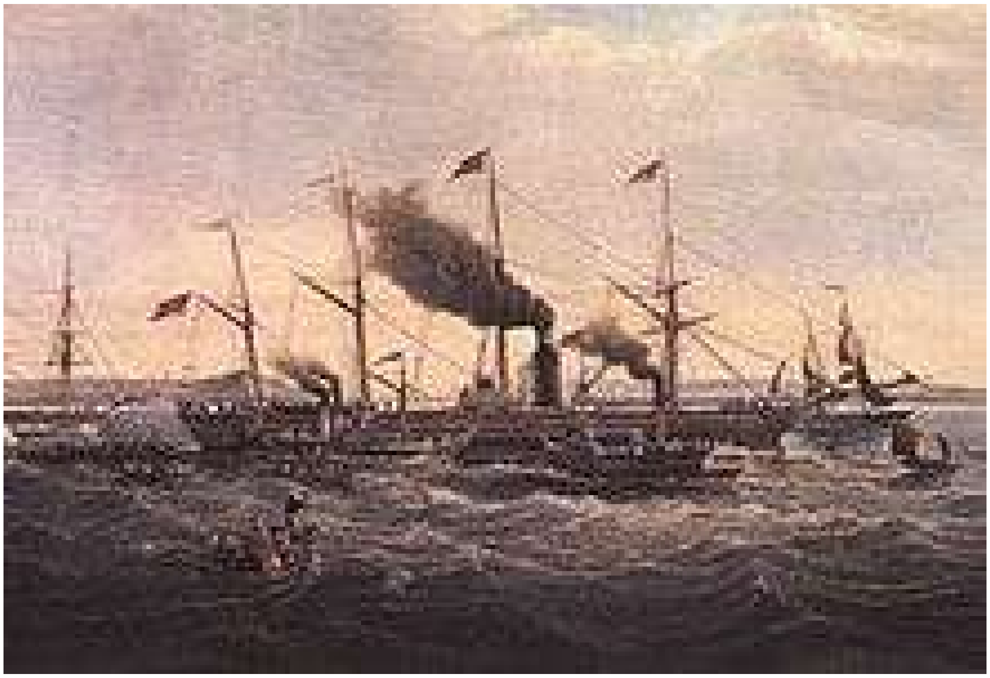

Figure 5.13: **Maiden voyage of the Great Western in April 1838.**

Figure 5.14: **Launch of the Great Britain in 1843.**

5.3 Some famous bridges

Ponte Vecchio

The bridge is famous for still having shops built along it, as was common in the days of the Medici. This midevil bridge is the only bridge in Florence to survive World War II.

Millau Bridge

Spanning the valley of the river Tarn near Millau in southern France, this bridge is the tallest vehicular bridge in the world. The highest pylon's summit is 343 meters (1,125 ft) tall - slightly taller than the Eiffel Tower.

Charles Bridge

This bridge crosses the Vltava river in Prague. Its construction was started in 1357 under the auspices of King Charles IV, and finished in the early part of the 15th century. Today it is a famous tourist attraction.

Rialto Bridge

This is the oldest bridge across the Grand Canal in Venice, Italy. It was completed in 1591 and was used to replace a wooden bridge that collapsed in 1524. Today it is one of the most famous attractions of Venice.

Akashi-Kaikyo Bridge

Also known as the Pearl Bridge, is the longest suspension bridge in the world at 1,991 meters (6,532 feet). It spans the Akashi Strait in Japan connecting Kobe on the mainland and Iwaya on Awayi Island.

Chapel Bridge

Chapel Bridge, in Lucerne, Switzerland, is the oldest wooden covered bridge in Europe, and one of Switzerland's main tourist attractions. It was constructed in 1333. Inside the bridge are a series of paintings from the 17th century, depicting events from Luzerne's history.

Great Belt Bridge (Storbæltsbroen)

The Great Belt bridge is actually two bridges - an Eastern and a Western section, split by the small island of Sprogoe. The East Bridge's two pylons are the highest points in Denmark.

Figure 5.15: **Si-o-se Pol (The Bridge of 33 Arches) is a famous bridge in the Iranian city of Isfahan. It is highly ranked as being one of the most famous examples of Safavid bridge design. Commissioned in 1602 by Shah Abbas I, the bridge is build of bricks and stones. It is 295 meters long and 13.75 meters wide. It is said that the bridge originally comprised 40 arches however this number gradually reduced to 33.**

Figure 5.16: **Tower Bridge is a combined bascule and suspension bridge in London, over the River Thames. It is close to the Tower of London, which gives it its name and has become an iconic symbol of London. Construction started in 1886 and took eight years to build. The bridge consists of two towers which are tied together at the upper level by means of two horizontal walkways which are designed to withstand the forces of the suspended sections of the bridge.**

Figure 5.17: **Completed in 1883, Brooklyn Bridge connects Manhattan and Brooklyn by spanning the East River. At the time it opened, and for several years, it was the longest suspension bridge in the world and it has become a famous and iconic landmark of New York. The bridge has a wide pedestrian walkway open to walkers and cyclists. This walkway takes on a special importance in times of difficulty when usual means of crossing the East River have become unavailable as happened during several blackouts and most famously after the September 11, 2001, attacks.**

Figure 5.18: **Sydney Harbour Bridge is one of Australia's most well known and photographed landmarks. It is the world's largest (but not the longest) steel arch bridge with the top of the bridge standing 134 meters (440 feet) above Sydney Harbour. It took eight years to build and opened in March 1932. Because the steel expands or contracts depending on whether it is hot or cold the bridge is not completely stationary and can rise or fall up to 18 cm (7.1 inch).**

Figure 5.19: **The Golden Gate Bridge is a suspension bridge spanning the Golden Gate, the strait between San Francisco and Marin County to the north. The masterwork of architect Joseph B. Strauss, whose statue graces the southern observation deck, the bridge took seven years to build, and was completed in 1937. The Golden Gate Bridge was the longest suspension bridge span in the world when it was completed, and has become one of the most popular tourist attractions in San Francisco and California. Since its completion, the span length has been surpassed by eight other bridges. The famous red-orange color of the bridge was specifically chosen to make the bridge more visible in the thick fog that frequently surrounds it.**

5.4 The US Transcontinental Railway

According to Wikipedia,

In February 1860, Iowa Representative Samuel Curtis introduced a bill to fund the railroad. It passed the House but died when it could not be reconciled with the Senate version due to opposition from southern states who wanted a southern route near the 42nd parallel. Curtis tried and failed again in 1861. After the southern states seceded from the Union, the House of Representatives approved the bill on May 6, 1862, and the Senate on June 20. Lincoln signed the Pacific Railroad Act of 1862 into law on July 1. It authorized creation of two companies, the Central Pacific in the west and the Union Pacific in the mid-west, to build the railroad. The legislation called for building and operating a new railroad from the Missouri River at Council Bluffs, Iowa, west to Sacramento, California, and on to San Francisco Bay. Another act to supplement the first was passed in 1864. The Pacific Railroad Act of 1863 established the standard gauge to be used in these federally financed railways...

Many of the civil engineers and surveyors who were hired by the Union Pacific had been employed during the American Civil War to repair and operate the over 2,000 miles (3,200 km) of railroad line the U.S. Military Railroad controlled by the end of the war. The Union Pacific also utilized their experience repairing and building truss bridges during the war. Most of the semi-skilled workers on the Union Pacific were recruited from the many soldiers discharged from the Union and Confederate armies along with emigrant Irishmen...

The railroad experimented by hiring local emigrant Chinese as manual laborers, many of whom were escaping the poverty and terrors of the Taiping Rebellion in the Guangdong province in China.[citation needed] When they proved themselves as workers, the CPRR from that point forward preferred to hire Chinese, and even set up recruiting efforts in Canton. Despite their small stature[46] and lack of experience, the Chinese laborers were responsible for most of the heavy manual labor since only a very limited amount of that work could be done by animals, simple machines, or black powder. The railroad also hired some black people escaping the aftermath of the American Civil War. Most of the black and white workers were paid $30 per month and given food and lodging. Most Chinese were initially paid $31 per month and provided lodging, but they preferred to cook their own meals...

It was at Promontory Summit on May 10, 1869, that Leland Stanford drove The Last Spike (or golden spike) that joined the rails of the transcontinental railroad. The spike is now on display at the Cantor Arts Center at Stanford University, while a second "Last" Golden Spike is also on display at the California State Railroad Museum in Sacramento... Travel from coast to coast was reduced from six months or more to just one week.

Figure 5.20: **The ceremony for the driving of the "Last Spike" at Promontory Summit, Utah, May 10, 1869.**

Figure 5.21: **Transcontinental Railroad 75th Anniversary Issue stamp of 1944.**

5.5 The Trans-Siberian railway

The Trans-Siberian Railway, which runs from Moscow to Vladivostok, is the longest railway in the world, with a length of 9,289 kilometers (5,772 miles). It was constructed between 1891 and 1916, under the supervision of ministers especially appointed by Czar Alexander III and his son, who later became Czar Nicholas II. The Trans-Siberian Railway has branch lines, which link it with Mongolia, China and North Korea.

Wikipedia states that:

The Trans-Siberian Railway brought with it millions of peasant-migrants from the Western regions of Russia and Ukraine. Between 1906 and 1914, the peak migration years, about 4 million peasants arrived in Siberia. Despite the low speed and low possible weights of trains, the railway fulfilled its promised role as a transit route between Europe and East Asia.

The railway also produced an enormous development in the agricultural output of Siberia. Grain exports to Central Russia became so large that tarrifs had to be imposed to protect the livelihoods of Central Russian farmers. From 1896 until 1913 Siberia exported on average 501,932 tonnes of grain and flour annually.

Today, travelers on the Trans-Siberian Railway can enjoy a unique 8-day experience in which they enjoy a journey through the unspoiled landscape of Siberia while drinking tea. Travelers bring with them their own tea sets, but hot water is provided by the railway.

Figure 5.22: **Clearing on the right-of-way of the Eastern Siberian Railway, 1895.**

Figure 5.23: **Construction work being performed by convicts on the Eastern Siberian Railway near Khabarovsk, 1895.**

Figure 5.24: **Siberian peasants watching a train at a station, 1902.**

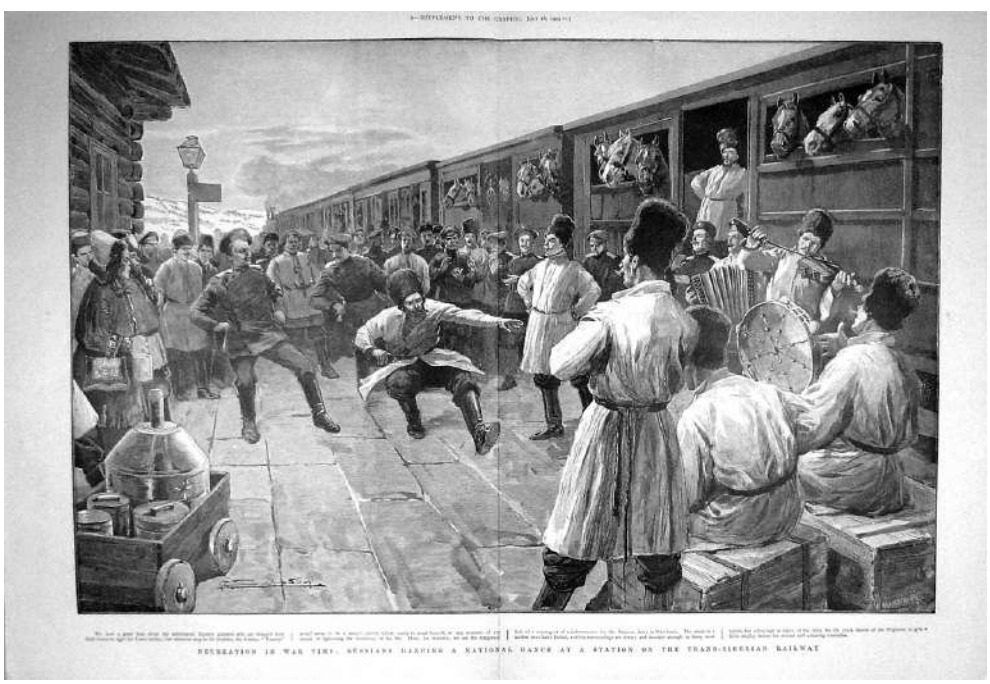

Figure 5.25: **A dance to celebrate the railway.**

Figure 5.26: **Trans-Siberian Railroad map. Red: Route of the Trans-Siberian Railway since 1930.**

5.6 The Channel Tunnel

Early proposals

Proposals for a channel tunnel linking England and France began in 1802, when the French mining engineer Albert Mathieu-Favier proposed a tunnel with illumination from oil lamps, horse-drawn coaches, and an artificial island positioned mid-Channel for changing horses.

Later proposals had the enthusiastic support of such important figures as Sir John Hawkshaw, Sir Edward Watkin, David Lloyd George and Winston Churchill. In an essay entitled *Should Strategists Veto The Tunnel?*, published in 1924, Churchill argued against the idea that a channel tunnel would pose a threat to British security. Churchill also expressed his enthusiasm in a 1936 article published in The Daily Mail: *Why Not A Channel Tunnel?*. However, worries that the tunnel might be used by an invading military force, and worries about the cost of the project prevented progress until the late 1980's, when construction of a privately financed tunnel was approved by the governments of both England and France.

The Channel Tunnel is finally constructed

Wikipedia states that

Tunnelling commenced in 1988, and the tunnel began operating in 1994. In 1985 prices, the total construction cost was 4.65 billion pounds (equivalent to 13 billion pounds in 2015), an 80% cost overrun. At the peak of construction 15,000 people were employed with daily expenditure over 3 million pounds. Ten workers, eight of them British, were killed during construction between 1987 and 1993, most in the first few months of boring...

On 1 December 1990, Englishman Graham Fagg and Frenchman Phillippe Cozette broke through the service tunnel with the media watching. Eurotunnel completed the tunnel on time. (A BBC TV television commentator called Graham Fagg "the first man to cross the Channel by land for 8000 years".)

The tunnel was officially opened, one year later than originally planned, by Queen Elizabeth II and the French president, Francois Mitterrand, in a ceremony held in Calais on 6 May 1994. The Queen travelled through the tunnel to Calais on a Eurostar train, which stopped nose to nose with the train that carried President Mitterrand from Paris. Following the ceremony President Mitterrand and the Queen travelled on Le Shuttle to a similar ceremony in Folkestone.

In 2018, the Channel Tunnel carried 11,000,000 passengers and 1,301,460 tons of freight.

Figure 5.27: **A map showing the tunnel crossing the Strait of Dover and connecting England with France.**

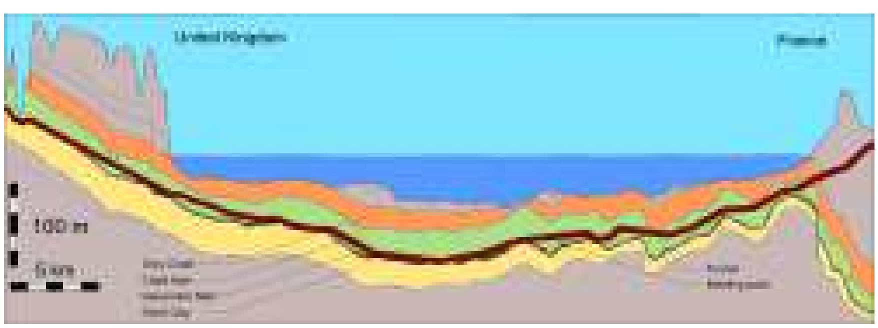

Figure 5.28: **Geological profile along the tunnel as constructed. For most of its length the tunnel bores through a chalk marl stratum.**

Figure 5.29: **An English tunnel team with their boring machine.**

Figure 5.30: **Interior of the Eurotunnel Shuttle, used to carry motor vehicles through the Channel Tunnel (cars are unable to be driven through it) between its two termini. This shuttle is the largest railway wagon in the world.**

Figure 5.31: **An average of 60,000 passengers pass through the tunnel each day.**

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Chapter 6

TELEGRAPH, RADIO AND TELEPHONE

6.1 A revolution in communication

The modern communication revolution began with the prediction of electromagnetic waves by James Clerk Maxwell, their discovery by Heinrich Hertz, Marconi's wireless telegraph messages across the Atlantic, and the invention of the telephone by Alexander Graham Bell. Radio and television programs were quick to follow. Today cell phones and Skype allow us to talk across vast distances with little effort and almost no expense. The Internet makes knowledge universally and instantly available.

Galvani and Volta

While Dalton's atomic theory was slowly gaining ground in chemistry, the world of science was electrified (in more ways than one) by the discoveries of Franklin, Galvani, Volta, Ørsted, Ampère, Coulomb and Faraday.

A vogue for electrical experiments had been created by the dramatic experiments of Benjamin Franklin (1706-1790), who drew electricity from a thundercloud, and thus showed that lightning is electrical in nature. Towards the end of the 18th century, almost every scientific laboratory in Europe contained some sort of machine for generating static electricity. Usually these static electricity generators consisted of a sphere of insulating material which could be turned with a crank and rubbed, and a device for drawing off the accumulated static charge. Even the laboratory of the Italian anatomist, Luigi Galvani (1737-1798), contained such a machine; and this was lucky, since it led indirectly to the invention of the electric battery.

In 1771, Galvani noticed that some dissected frog's legs on his work table twitched violently whenever they were touched with a metal scalpel while his electrostatic machine was running. Since Franklin had shown lightning to be electrical, it occurred to Galvani to hang the frog's legs outside his window during a thunderstorm. As he expected, the frog's

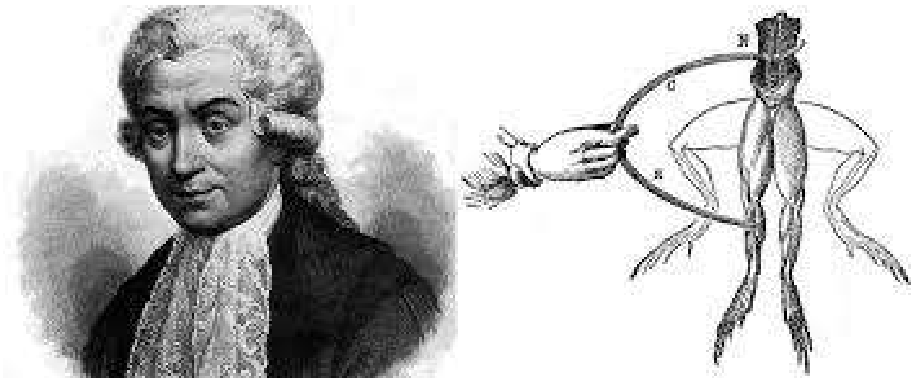

Figure 6.1: **Luigi Galvani (1737-1798)**

Figure 6.2: **Alessandro Volta (1745-1827).**

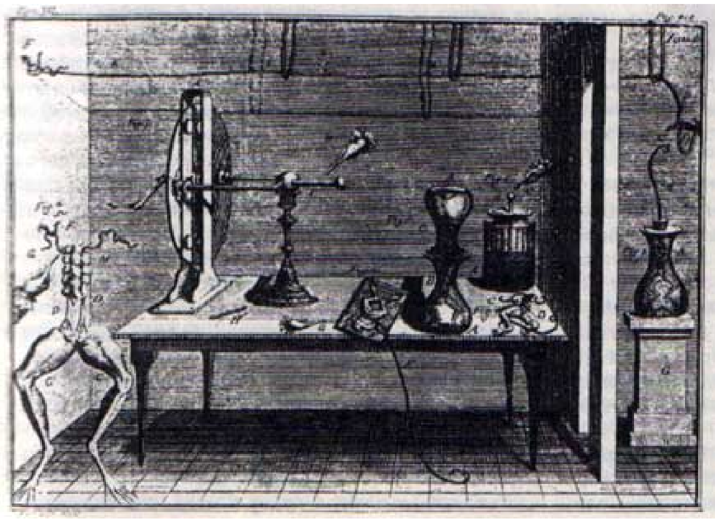

Figure 6.3: **Apparatus used by Galvani.**

legs twitched violently during the thunderstorm, but to Galvani's surprise, they continued to move even after the storm was over. By further experimentation, he found that what made the frog's legs twitch was a closed electrical circuit, involving the brass hook from which they were hanging, and the iron lattice of the window.

Galvani mentioned these experiments to his friend, the physicist Alessandro Volta (1745-1827). Volta was very much interested, but he could not agree with Galvani about the source of the electrical current which was making the frog's legs move. Galvani thought that the current was "animal electricity", coming from the frog's legs themselves, while Volta thought that it was the two different metals in the circuit which produced the current.

The argument over this question became bitter, and finally destroyed the friendship between the two men. Meanwhile, to prove his point, Volta constructed the first electrical battery. This consisted of a series of dishes containing salt solution, connected with each other by bridges of metal. One end of each bridge was made of copper, while the other end was made of zinc. Thus, as one followed the circuit, the sequence was: copper, zinc, salt solution, copper, zinc, salt solution, and so on.

Volta found that when a closed circuit was formed by such an arrangement, a steady electrical current flowed through it. The more units connected in series in the battery, the stronger was the current. He next constructed a more compact arrangement, which came to be known as the "Voltaic pile". Volta's pile consisted of a disc of copper, a disc of zinc, a disc of cardboard soaked in salt solution, another disc of copper, another disc of zinc, another disc of cardboard soaked in salt solution, and so on. The more elements there were in the pile, the greater was the electrical potential and current which it produced.

The invention of the electric battery lifted Volta to a peak of fame where he remained for the rest of his life. He was showered with honors and decorations, and invited to demonstrate his experiments to Napoleon, who made him a count and a senator of the

Kingdom of Lombardy. When Napoleon fell from power, Volta adroitly shifted sides, and he continued to receive honors as long as he lived.

News of the Voltaic pile spread like wildfire throughout Europe and started a series of revolutionary experiments both in physics and in chemistry. On March 20, 1800, Sir Joseph Banks, the President of the Royal Society, received a letter from Volta explaining the method of constructing batteries. On May 2 of the same year, the English chemist, William Nicholson (1755-1815), (to whom Banks had shown the letter), used a Voltaic pile to separate water into hydrogen and oxygen.

Shortly afterwards, the brilliant young English chemist, Sir Humphrey Davy (1778-1829), constructed a Voltaic pile with more than two hundred and fifty metal plates. On October 6, 1807, he used this pile to pass a current through molten potash, liberating a previously unknown metal, which he called potassium. During the year 1808, he isolated barium, strontium, calcium, magnesium and boron, all by means of Voltaic currents.

6.2 Ørsted, Ampère and Faraday

In 1819, the Danish physicist, Hans Christian Ørsted (1777-1851), was demonstrating to his students the electrical current produced by a Voltaic pile. Suspecting some connection between electricity and magnetism, he brought a compass needle near to the wire carrying the current. To his astonishment, the needle turned from north, and pointed in a direction perpendicular to the wire. When he reversed the direction of the current, the needle pointed in the opposite direction.

Ørsted's revolutionary discovery of a connection between electricity and magnetism was extended in France by André Marie Ampère (1775-1836). Ampère showed that two parallel wires, both carrying current, repel each other if the currents are in the same direction, but they attract each other if the currents are opposite. He also showed that a helical coil of wire carrying a current produces a large magnetic field inside the coil; and the more turns in the coil, the larger the field.

The electrochemical experiments of Davy, and the electromagnetic discoveries of Ørsted and Ampère, were further developed by the great experimental physicist and chemist, Michael Faraday (1791-1867). He was one of ten children of a blacksmith, and as a boy, he had little education. At the age of 14, he was sent out to work, apprenticed to a London bookbinder. Luckily, the bookbinder sympathized with his apprentice's desire for an education, and encouraged him to read the books in the shop (outside of working hours). Faraday's favorites were Lavoisier's textbook on chemistry, and the electrical articles in the Encyclopedia Britannica.

In 1812, when Michael Faraday was 21 years old, a customer in the bookshop gave him tickets to attend a series of lectures at the Royal Institution, which were to be given by the famous chemist Humphrey Davy. At that time, fashionable London socialites (particularly ladies) were flocking to the Royal Institution to hear Davy. Besides being brilliant, he was also extremely handsome, and his lectures, with their dramatic chemical demonstrations, were polished to the last syllable.

Michael Faraday was, of course, thrilled to be present in the glittering audience, and he took careful notes during the series of lectures. These notes, to which he added beautiful colored diagrams, came to 386 pages. He bound the notes in leather and sent them to Sir Joseph Banks, the President of the Royal Society, hoping to get a job related to science. He received no reply from Banks, but, not discouraged, he produced another version of his notes, which he sent to Humphrey Davy.

Faraday accompanied his notes with a letter saying that he wished to work in science because of "the detachment from petty motives and the unselfishness of natural philosophers". Davy told him to reserve judgement on that point until he had met a few natural philosophers, but he gave Faraday a job as an assistant at the Royal Institution.

In 1818, Humphrey Davy was knighted because of his invention of the miner's safety lamp. He married a wealthy and fashionable young widow, resigned from his post as Director of the Royal Institution, and set off on a two-year excursion of Europe, taking Michael Faraday with him. Lady Davy regarded Faraday as a servant; but in spite of the humiliations which she heaped on him, he enjoyed the tour of Europe and learned much from it. He met, and talked with, Europe's most famous scientists; and in a sense, Europe was his university.

Returning to England, the modest and devoted Faraday finally rose to outshine Sir Humphrey Davy, and he became Davy's successor as Director of the Royal Institution. Faraday showed enormous skill, intuition and persistence in continuing the electrical and chemical experiments begun by Davy.

In 1821, a year after H.C. Ørsted's discovery of the magnetic field surrounding a current-carrying wire, Michael Faraday made the first electric motor. His motor was simply a current-carrying wire, arranged so that it could rotate around the pole of a magnet; but out of this simple device, all modern electrical motors have developed. When asked what use his motor was, Faraday replied: "What use is a baby?"

Ørsted had shown that electricity could produce magnetism; and Faraday, with his strong intuitive grasp of the symmetry of natural laws, believed that the relationship could be reversed. He believed that magnetism could be made to produce electricity. In 1822, he wrote in his notebook: "Convert magnetism to electricity". For almost ten years, he tried intermittently to produce electrical currents with strong magnetic fields, but without success. Finally, in 1831, he discovered that a *changing* magnetic field would produce a current.

Faraday had wrapped two coils of wire around a soft iron ring; and he discovered that at precisely the instant when he started a current flowing in one of the coils, a momentary current was induced in the other coil. When he stopped the current in the first coil, so that the magnetic field collapsed, a momentary current in the opposite direction was induced in the second coil.

Next, Faraday tried pushing a permanent magnet in and out of a coil of wire; and he found that during the time when the magnet was in motion, so that the magnetic field in the coil was changing, a current was induced in the coil. Finally, Faraday made the first dynamo in history by placing a rotating copper disc between the poles of a magnet. He demonstrated that when the disc rotated, an electrical current flowed through a circuit

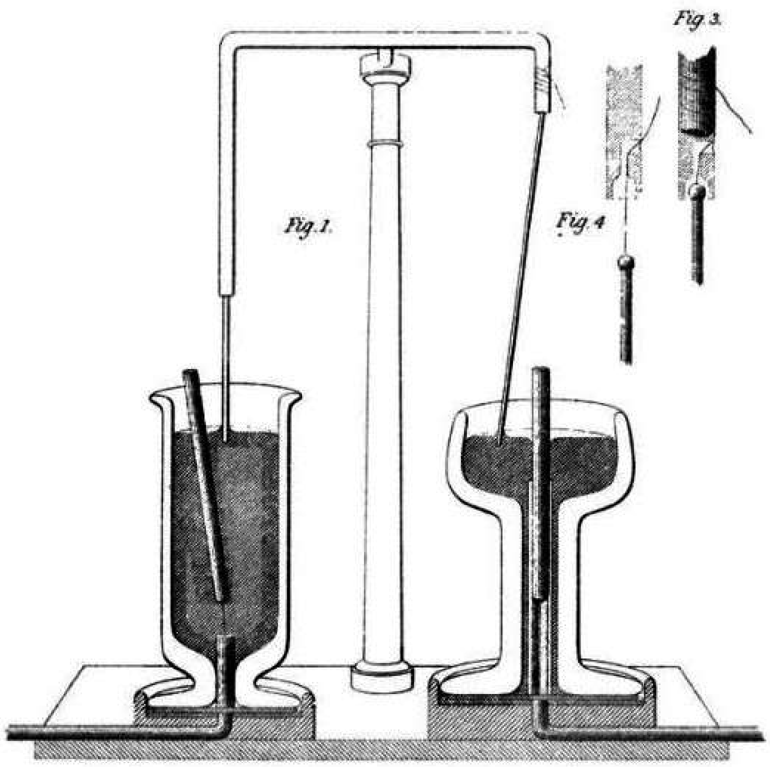

Figure 6.4: **Faraday's experiment showing that an electric current could produce mechanical rotation in a magnetic field. This was the first electric motor! On the right side of the figure, a current-carrying rod rotates about a fixed magnet in a pool of mercury. On the left, the rod is fixed and the magnet rotates.**

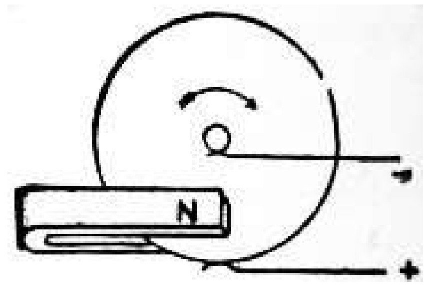

Figure 6.5: **Faraday also showed that a copper disc, rotating between the poles of a magnet could produce an electric current.**

connecting the center with the edge. He also experimented with static electricity, and showed that insulating materials become polarized when they are placed in an electric field.

Faraday continued the experiments on electrolysis begun by Sir Humphrey Davy. He showed that when an electrical current is passed through a solution, the quantities of the chemical elements liberated at the anode and cathode are directly proportional to the total electrical charge passed through the cell, and inversely proportional to the valence of the elements. He realized that these laws of electrolysis supported Dalton's atomic hypothesis, and that they also pointed to the existence of an indivisible unit of electrical charge.

Faraday believed (correctly) that light is an electromagnetic wave; and to prove the connection of light with the phenomena of electricity and magnetism, he tried for many years to change light by means of electric and magnetic fields. Finally, towards the end of his career, he succeeded in rotating the plane of polarization of a beam of light passing through a piece of heavy glass by placing the glass in a strong magnetic field. This phenomenon is now known as the "Faraday effect".

Because of his many contributions both to physics and to chemistry (including the discovery of benzene and the first liquefaction of gases), and especially because of his contributions to electromagnetism and electrochemistry, Faraday is considered to be one of the greatest masters of the experimental method in the history of science. He was also a splendid lecturer. Fashionable Londoners flocked to hear his discourses at the Royal Institution, just as they had flocked to hear Sir Humphrey Davy. Prince Albert, Queen Victoria's husband, was in the habit of attending Faraday's lectures, bringing with him Crown Prince Edward (later Edward VII).

As Faraday grew older, his memory began to fail, probably because of mercury poisoning. Finally, his unreliable memory forced him to retire from scientific work. He refused both an offer of knighthood and the Presidency of the Royal Society, remaining to the last the simple, modest and devoted worker who had first gone to assist Davy at the Royal Institution.

Figure 6.6: **Michael Faraday (1791-1867) is considered to be one of the greatest experimental physicists in history. His family was too poor to give him an ordinary education and as a boy he was apprenticed to a bookbinder. In the evenings, after work, he educated himself by reading scientific books. After hearing lectures by Sir Humphrey Davy at the Royal Institution, Faraday wrote and bound a beautiful set of notes for the lectures. Impressed by the notes, Davy accepted Faraday as an assistant. In the end, through his brilliant discoveries in electromagnetism and electrochemistry, Faraday rose in fame and became Davy's successor as Director of the Royal Institution.**

6.3 Electromagnetic waves: Maxwell and Hertz

The experimental discoveries of Galvani, Volta, Ørsted and Faraday, demonstrated that electricity and magnetism were two faces of a larger phenomenon: electromagnetism.

During the nine years from 1864 to 1873, the great Scottish mathematician James Clerk Maxwell worked on the problem of putting Faraday's laws of electricity and magnetism into mathematical form. In 1873, he published *A Treatise on Electricity and Magnetism*, one of the truly great scientific classics. Maxwell achieved a magnificent synthesis by expressing in a few simple equations the laws governing electricity and magnetism in all its forms. His electromagnetic equations have withstood the test of time; and now, a century later, they are considered to be among the most fundamental laws of physics.

Maxwell's equations not only showed that visible light is indeed and electromagnetic wave, as Faraday had suspected, but they also predicted the existence of many kinds of invisible electromagnetic waves, both higher and lower in frequency than visible light. We now know that the spectrum of electromagnetic radiation includes (starting at the low-frequency end) radio waves, microwaves, infra-red radiation, visible light, ultraviolet rays, X-rays and gamma rays. All these types of radiation are fundamentally the same, except that their frequencies and wave lengths cover a vast range. They all are oscillations of the electromagnetic field; they all travel with the speed of light; and they all are described by Maxwell's equations.

Maxwell's book opened the way for a whole new category of inventions, which have had a tremendous impact on society. However, when it was published, very few scientists could understand it. Part of the problem was that the scientists of the 19th century would have liked a mechanical explanation of electromagnetism.

The German physicist Hermann von Helmholtz (1821-1894), tried hard to understand Maxwell's theory in mechanical terms, and ended by accepting Maxwell's equations without ever feeling that he really understood them. In 1883, the struggles of von Helmholtz to understand Maxwell's theory produced a dramatic proof of its correctness: Helmholtz had a brilliant student named Heinrich Hertz (1857-1894), whom he regarded almost as a son. In 1883, the Berlin Academy of Science offered a prize for work in the field of electromagnetism; and von Helmholtz suggested to Hertz that he should try to win the prize by testing some of the predictions of Maxwell's theory.

Hertz set up a circuit in which a very rapidly oscillating electrical current passed across a spark gap. He discovered that electromagnetic waves were indeed produced by this rapidly-oscillating current, as predicted by Maxwell! The waves could be detected with a small ring of wire in which there was a gap. As Hertz moved about the darkened room with his detector ring, he could see a spark flashing across the gap, showing the presence of electromagnetic waves, and showing them to behave exactly as predicted by Maxwell.

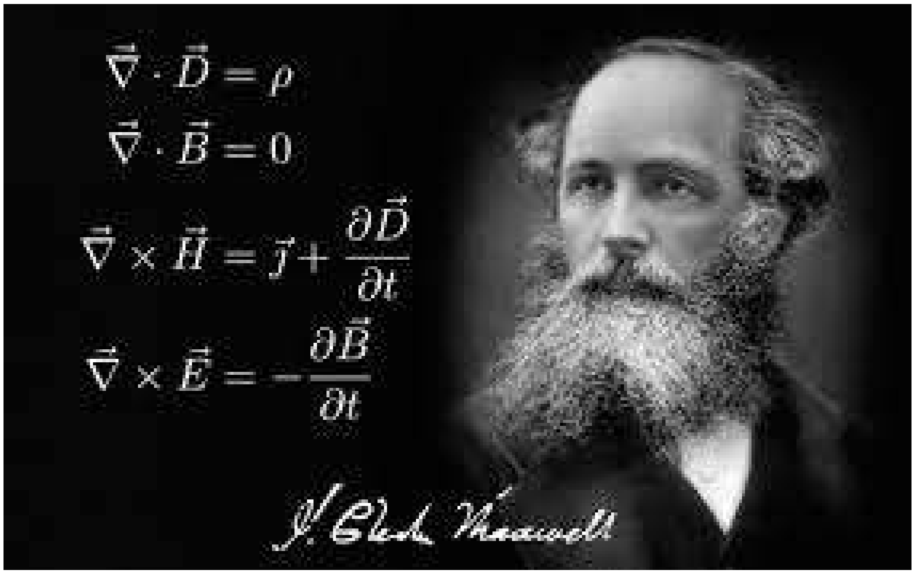

Figure 6.7: **James Clerk Maxwell (1831-1879).**

Figure 6.8: **Heinrich Hertz (1857-1894).**

6.4 The discovery of electrons

In the late 1880's and early a 1890's, a feeling of satisfaction, perhaps even smugness, prevailed in the international community of physicists. It seemed to many that Maxwell's electromagnetic equations, together with Newton's equations of motion and gravitation, were the fundamental equations which could explain all the phenomena of nature. Nothing remained for physicists to do (it was thought) except to apply these equations to particular problems and to deduce the consequences. The inductive side of physics was thought to be complete.

However, in the late 1890's, a series of revolutionary discoveries shocked the physicists out of their feeling of complacency and showed them how little they really knew. The first of these shocks was the discovery of a subatomic particle, the electron. In Germany, Julius Plücker (1801-1868), and his friend, Heinrich Geisler (1814-1879), had discovered that an electric current could be passed through the gas remaining in an almost completely evacuated glass tube, if the pressure were low enough and the voltage high enough. When this happened, the gas glowed, and sometimes the glass sides of the tube near the cathode (the negative terminal) also glowed. Plücker found that the position of the glowing spots on the glass near the cathode could be changed by applying a magnetic field.

In England, Sir William Crookes (1832-1919) repeated and improved the experiments of Plücker and Geisler: He showed that the glow on the glass was produced by rays of some kind, streaming from the cathode; and he demonstrated that these "cathode rays" could cast shadows, that they could turn a small wheel placed in their path, and that they heated the glass where they struck it.

Sir William Crookes believed that the cathode rays were electrically charged particles of a new kind - perhaps even a "fourth state of matter". His contemporaries laughed at these speculations; but a few years later a brilliant young physicist named J.J.Thomson (1856-1940), working at Cambridge University, entirely confirmed Crookes' belief that the cathode rays were charged particles of a new kind.

Thomson, an extraordinarily talented young scientist, had been appointed full professor and head of the Cavendish Laboratory at Cambridge at the age of 27. His predecessors in this position had been James Clerk Maxwell and the distinguished physicist, Lord Rayleigh, so the post was quite an honor for a man as young as Thomson. However, his brilliant performance fully justified the expectations of the committee which elected him. Under Thomson's direction, and later under the direction of his student, Ernest Rutherford, the Cavendish Laboratory became the world's greatest center for atomic and subatomic research; and it maintained this position during the first part of the twentieth century.

J.J. Thomson's first achievement was to demonstrate conclusively that the "cathode rays" observed by Plücker, Geisler and Crookes were negatively charged particles. He and his students also measured their ratio of charge to mass. If the charge was the same as that on an ordinary negative ion, then the mass of the particles was astonishingly small - almost two thousand times smaller than the mass of a hydrogen atom! Since the hydrogen atom is the lightest of all atoms, this indicated that the cathode rays were *subatomic* particles.

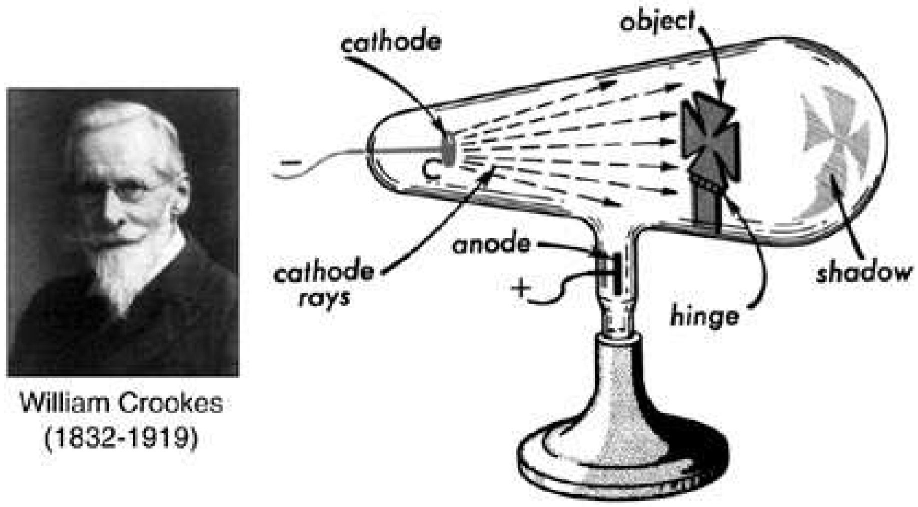

Figure 6.9: **Sir William Crookes showed that cathode rays could cast shadows.**

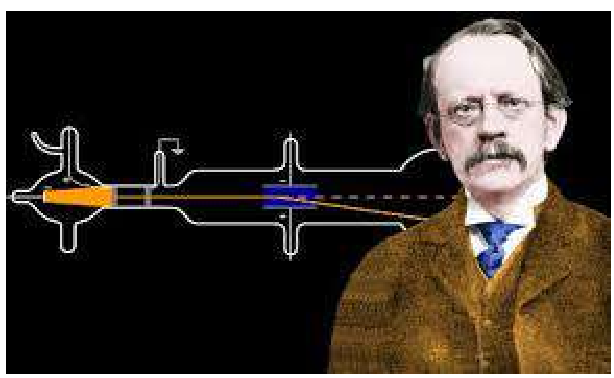

Figure 6.10: **Sir Joseph John Thomson (1856-1940).**

The charge which the cathode rays particles carried was recognized to be the fundamental unit of electrical charge, and they were given the name "electrons". All charges observed in nature were found to be integral multiples of the charge on an electron. The discovery of the electron was the first clue that the atom, thought for so long to be eternal and indivisible, could actually be torn to pieces.

6.5 History of the electrical telegraph

Many people contributed to the development of the telegraph. Here is a timeline showing some important events:

Figure 6.11: **An early telegraph key**

1774	Georges-Louis Le Sage (26 separate wires)
1800	Alessandro Volta invents the electric pile
1809	Samuel Thomas von Sömmering (up to 35 wires for letters and numerals)
1816	Francis Ronalds demonstrates an electrostatic telegraph at Hammersmith
1820	H.C. Ørsted discovers that an electric current produces a magnetic field
1821	André Marie Ampere suggests telegraph using a galvanometer
1828	Joseph Henry invents an improved electromagnet
1830	Joseph Henry demonstrates magnetic telegraph to Albany Academy
1832	Baron Schilling von Canstatt's 16-key transmitting device (binary system)
1833	C.F. Gauss and W. Weber install 1200-meter-long telegraph in Göttingen
1835	C.F. Gauss installs a telegraph along a German railway line
1835	Joseph Henry and Edward Davy invent electrical relay
1836	David Alter's telegraph system in America
1837	Edward Davy demonstrates his telegraph system in Regents Park
1837	Samuel Morse develops and patents recording telegraph
1837	W.F. Cooke and C. Wheatstone patent the first commercial telegraph
1838	Morse and his assistant Alfred Vale develop Morse code
1840	Charles Wheatstone's ABC system could be used by an unskilled operator
1846	Royal Earl House develops and patents letter printing telegraph
1855	David Edward Hughes invents a printing telegraph using a spinning type wheel
1861	Overland telegraph connects east and west coasts of the United States

Figure 6.12: **Professor Samuel F.B. Morse (1791-1872). For many years, most telegraph systems throughout the world made use of Morse code, which allowed messages to be sent over a single wire.**

6.6 The transatlantic cable

The first durable translantic cable was laid in 1866 by Isambard Kingdom Brunel's unprecedentedly large ship, the Great Eastern. Brunel had pioneered many engineering innovations, including the Great Western Railway, the first tunnel under a navigable river, and the first propeller-driven ocean-going iron steamship, the SS Great Britain. launched in 1843. He had realized that in order to carry enough coal for a transatlantic crossing, a ship had to be very large, since water resistance to be overcome is proportional to surface area, while the amount of coal (and cargo) that can be carried is proportional to volume. As a ship becomes larger, the ratio of volume to surface increases.

At first, transatlantic telegraphic transmissions were extremely slow, because the designers of the cable had not realizer that for efficient signal transmission the ratio of the cable's inductance to capacitance had to be correctly adjusted.

The first message sent was "Directors of Atlantic Telegraph Company, Great Britain, to Directors in America: Europe and America are united by telegraph. Glory to God in the highest; on earth peace, good will towards men." The second message was from Queen Victoria to President Buchanan of the United States, expressing the hope that the cable link would prove to be "an additional link between the nations whose friendship is founded on their common interest and reciprocal esteem." Buchanan replied that "it is a triumph more glorious, because far more useful to mankind, than was ever won by conqueror on the field of battle. May the Atlantic telegraph, under the blessing of Heaven, prove to be a bond of perpetual peace and friendship between the kindred nations, and an instrument destined by Divine Providence to diffuse religion, civilization, liberty, and law throughout the world."

Public enthusiasm for the transatlantic cable was enormous. In New York, 100 guns were fired, the streets were decorated with flags, and church bells were rung.

Figure 6.13: **Landing of the Atlantic Cable of 1866, Heart's Content, Newfoundland, a painting by by Robert Charles Dudley.**

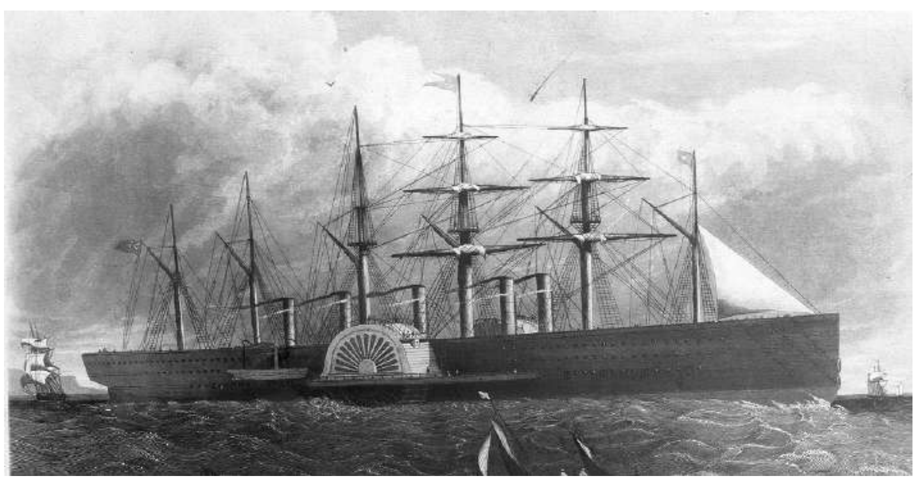

Figure 6.14: **Under Sir James Anderson, the Great Eastern laid 4,200 kilometers (2,600 mi) of the 1865 transatlantic telegraph cable. Under Captains Anderson and then Robert Halpin, from 1866 to 1878 the ship laid over 48,000 kilometers (30,000 mi) of submarine telegraph cable including from Brest, France to Saint Pierre and Miquelon in 1869, and from Aden to Bombay in 1869 and 1870.**

6.7 Marconi

The waves detected by Hertz were, in fact, radio waves; and it was not long before the Italian engineer, Guglielmo Marconi (1874-1937), turned the discovery into a practical means of communication. In 1898, Marconi used radio signals to report the results of the boat races at the Kingston Regatta, and on December 12, 1901, using balloons to lift the antennae as high as possible, he sent a signal across the Atlantic Ocean from England to Newfoundland.

In 1904, a demonstration of a voice-carrying radio apparatus developed by Fessenden was the sensation of the St. Louis World's Fair; and in 1909, Marconi received the Nobel Prize in physics for his development of radio communications. In America, the inventive genius of Alexander Graham Bell (1847-1922) and Thomas Alva Edison (1847-1931) turned the discoveries of Faraday and Maxwell into the telephone, the electric light, the cinema and the phonograph.

Figure 6.15: **Marconi's wireless telegraph**

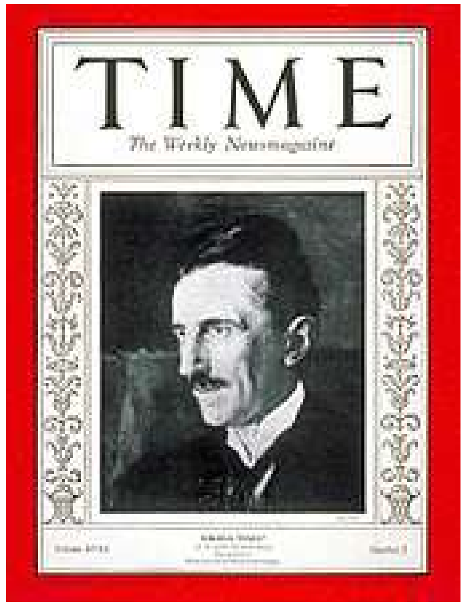

Figure 6.16: **The Serbian-American inventer Nikola Tesla (1856-1943) on a 1931 issue of Time Magazine celebrating his 75th birthday.**

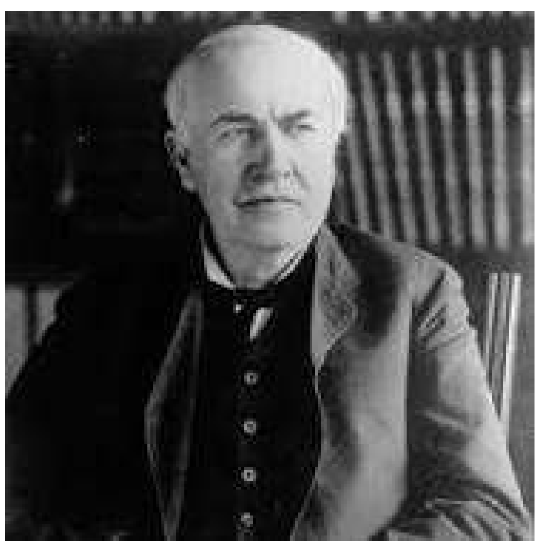

Figure 6.17: **Thomas Edison (1847-1931) lost the battle with Tesla over whether the world's electrical systems should be AC or DC, but his name is immortal because of his many other inventions.**

6.8 Alexander Graham Bell

Alexander Graham Bell (1847-1922) is credited with inventing the first workable telephone, but in addition, his inventions and scientific work reached many other fields. Bell was born in Edinburgh, Scotland, where his father. Professor Alexander Melville Bell, worked in phonetics, a branch of linguistics that studies the sounds of human speech and their physical properties. Alexander Graham Bell's grandfather and his two brothers also worked in this field.

At the age of 12, Alexander Graham Bell invented a dehusking machine that was used for many years to prepare grain to be milled into flour. As a reward, the local mill owner and gave young Bell the materials and workshop that he needed to work on other inventions.

Motivated not only by the fact that so many of his family members worked in phonetics but also by his mother's gradually increasing deafness, Bell began experiments on the mechanical reproduction of sound. When he was 19, a report on Bell's work in this field was sent to Alexander Ellis[1]. Ellis informed Bell that very similar work had been done in Germany by Hermann von Helmholtz. Unable to read German, Bell studied a French translation of the work of von Helmholtz. He later said:

"Without knowing much about the subject, it seemed to me that if vowel sounds could be produced by electrical means, so could consonants, so could articulate speech. I thought that Helmholtz had done it ... and that my failure was due only to my ignorance of electricity. It was a valuable blunder ... If I had been able to read German in those days, I might never have commenced my experiments!"

When Bell was 23, he and his family moved to Canada because several family members were threatened with tuberculosis[2]. They hoped that Canada's climate would help their struggles with the disease. Two years later Bell moved to Boston, Massachusetts, where he opened his School of Vocal Physiology and Mechanics of Speech. Among his numerous students was Helen Keller.

Because the late nights and overwork resulting from combining electrical voice transmission experimentation with teaching was affecting his health, Bell decided to keep only two students, 6 year old Georgie Sanders and 15 year old Mable Hubbard. Georgie Sanders' wealthy father provided Bell with free lodging and a laboratory. Mable was a bright and attractive girl, ten years younger than Bell, and she later became his wife.

At that time, in 1874, the telegraph was becoming more and more commercially important, and William Orton, the President of the Western Union telegraph company had hired Thomas Edison and Elisha Gray to invent a method for sending multiple messages over the same wire. When Bell confided to the wealthy fathers of his two pupils that he was working on a method to send multiple voice messages over the same wire, the two fathers supported Bell's race with Edison and Gray to be first with a practical method and a patent.

[1]later portrayed as Henry Higgins in Shaw's play *Pygmalion*

[2]Both of Bell's brothers eventually died of tuberculosis.

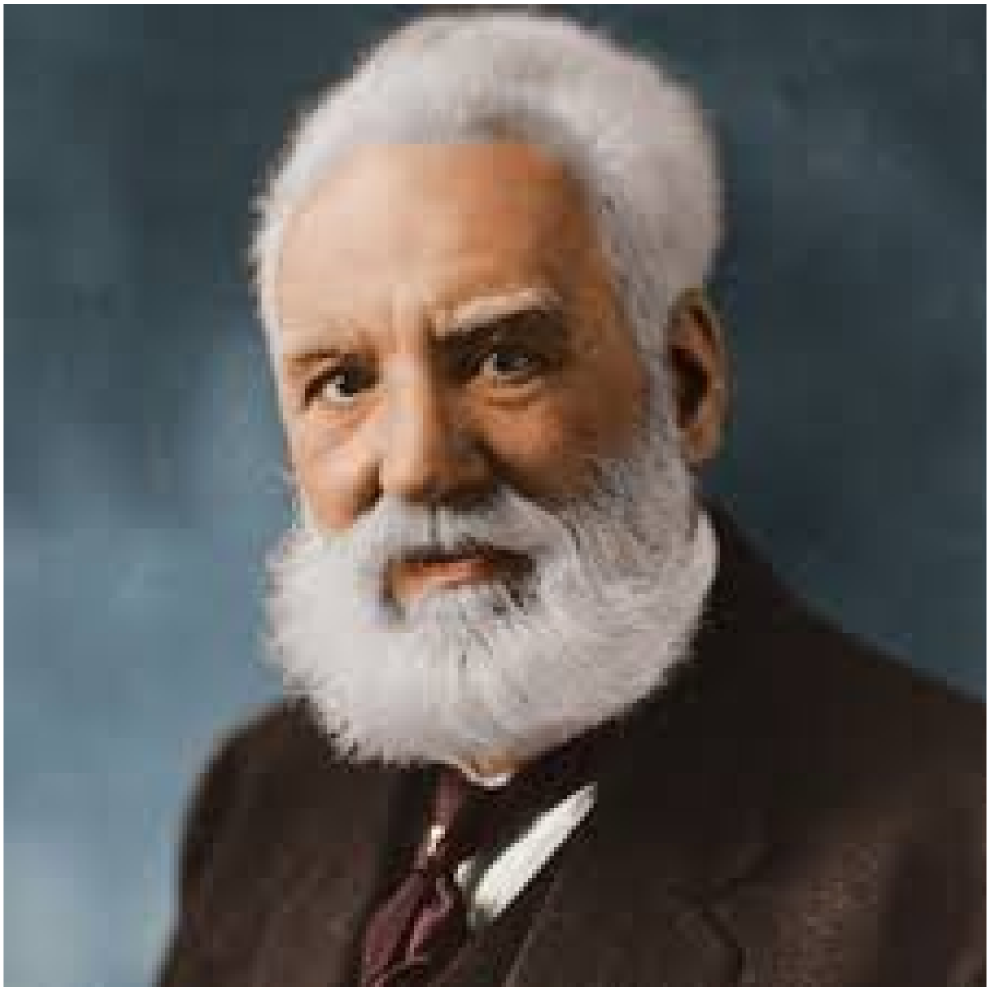

Figure 6.18: **Alexander Graham Bell (1847-1922).**

In the same year, Bell happened to meet Thomas A. Watson, an experienced designer of electrical machines. With the financial help of Sanders and Hubbard, Bell hired Watson as his assistant. In 1876, Bell spoke the first intelligible words over his newly invented telephone: "Mr. Watson, come here. I need you." That same year U.S. and U.K patents were granted to Bell, but a somewhat similar patent application from Elisha Gray had arrived almost simultaneously, initiating a controversy over priority.

Bell and his supporters offered to sell another patent which covered their method for sending multiple messages over the same telegraph wire to Western Union for $100,000, but the offer was refused. Two years later the President of Western Union said that if he could obtain the patent for $25,000,000, he would consider it a bargain, but by that time, the Bell Telephone Company no longer wished to sell.

Although Bell is best known for the telephone, his interests were very wide According to Wikipedia,

Bell's work ranged "unfettered across the scientific landscape" and he often went to *bed voraciously reading the Encyclopedia Britannica, scouring it for new areas of interest. The range of Bell's inventive genius is represented only in part by the 18 patents granted in his name alone and the 12 he shared with his collaborators. These included 14 for the telephone and telegraph, four for the photophone, one for the phonograph, five for aerial vehicles, four for "hydroairplanes", and two for selenium cells. Bell's inventions spanned a wide range of interests and included a metal jacket to assist in breathing, the audiometer to detect minor hearing problems, a device to locate icebergs, investigations on how to separate salt from seawater, and work on finding alternative fuels.*

Bell worked extensively in medical research and invented techniques for teaching speech to the deaf. During his Volta Laboratory period, Bell and his associates considered impressing a magnetic field on a record as a means of reproducing sound. Although the trio briefly experimented with the concept, they could not develop a workable prototype. They abandoned the idea, never realizing they had glimpsed a basic principle which would one day find its application in the tape recorder, the hard disc and floppy disc drive, and other magnetic media.

Bell's own home used a primitive form of air conditioning, in which fans blew currents of air across great blocks of ice. He also anticipated modern concerns with fuel shortages and industrial pollution. Methane gas, he reasoned, could be produced from the waste of farms and factories. At his Canadian estate in Nova Scotia, he experimented with composting toilets and devices to capture water from the atmosphere. In a magazine interview published shortly before his death, he reflected on the possibility of using solar panels to heat houses.

As of today, the Bell Laboratories, funded by the Bell Telephone Company, has produced 13 Nobel Prize winners. Most notably, the 1956 Nobel Prize in Physics was shared by Bell Laboratory scientists John Bardeen, Walter Brattain, and William Shockley for the invention of the transistor, a device that has made the astonishing modern stages of the information explosion possible.

Suggestions for further reading

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Chapter 7

THE INTERNAL COMBUSTION ENGINE

7.1 The history of internal combustion engines

Wikipedia's timeine

- **202 BCE-220 CE: The earliest hand-operated cranks appeared in China during the Han Dynasty.**
- **3rd century CE: Evidence of a crank and connecting rod mechanism dates to the Hierapolis sawmill in Byzantine Asia Minor , then part of the Roman Empire.**
- **6th century: Several sawmills use a crank and connecting rod mechanism in Asia Minor and Syria, then part of the Byzantine Empire.**
- **9th century: The crank appears in the mid-9th century in several of the hydraulic devices described by the Banu Musa brothers in their Book of Ingenious Devices.**
- **1206: Al-Jazari invented an early crankshaft, which he incorporated with a crank-connecting rod mechanism in his twin-cylinder pump. Like the modern crankshaft, Al-Jazari's mechanism consisted of a wheel setting several crank pins into motion, with the wheel's motion being circular and the pins moving back-and-forth in a straight line. The crankshaft described by al-Jazari transforms continuous rotary motion into a linear reciprocating motion.**
- **17th century: Samuel Morland experiments with using gunpowder to drive water pumps.**
- **17th century: Christiaan Huygens designs gunpowder to drive water pumps, to supply 3000 cubic meters of water/day for the Versailles palace gardens, essentially creating the first idea of a rudimentary internal combustion piston engine.**

- **1780s: Alessandro Volta built a toy electric pistol in which an electric spark exploded a mixture of air and hydrogen, firing a cork from the end of the gun.**
- **1791: John Barber receives British patent No. 1833 for A Method for Rising Inflammable Air for the Purposes of Producing Motion and Facilitating Metallurgical Operations. In it he describes a turbine.**
- **1794: Robert Street built a compressionless engine. He was also the first to use liquid fuel in an internal combustion engine.**
- **1794: Thomas Mead patents a gas engine.**
- **1798: John Stevens builds the first double-acting, crankshaft-using internal combustion engine.**
- **1801: Philippe LeBon D'Humberstein comes up with the use of compression in a two-stroke engine.**
- **1807: Nicéphore Niépce installed his "moss, coal-dust and resin" fueled Pyréolophore internal combustion engine in a boat and powered up the river Saone in France. A patent was subsequently granted by Emperor Napoleon Bonaparte on 20 July 1807.**
- **1807: Swiss engineer Francois Isaac de Rivaz built an internal combustion engine powered by a hydrogen and oxygen mixture, and ignited by electric spark. (See 1780s: Alessandro Volta above.)**
- **1823: Samuel Brown patented the first internal combustion engine to be applied industrially, the gas vacuum engine. The design used atmospheric pressure, and was demonstrated in a carriage and a boat, and in 1830 commercially to pump water to the upper level of the Croydon Canal.**
- **1824: French physicist Sadi Carnot established the thermodynamic theory of idealized heat engines.**
- **1826 April 1: American Samuel Morey received a patent for a compressionless "Gas or Vapor Engine." This is also the first recorded example of a carburetor.**
- **1833: Lemuel Wellman Wright, UK patent no. 6525, table-type gas engine. Double-acting gas engine, first record of water-jacketed cylinder.**
- **1838: A patent was granted to William Barnett, UK patent no. 7615 April 1838. According to Dugald Clerk, this was the first recorded use of in-cylinder compression.**
- **1853-1857: Eugenio Barsanti and Felice Matteucci invented and patented the internal combustion engine using the free-piston principle in an atmospheric two cycle engine.**
- **1856: in Florence at Fonderia del Pignone (now Nuovo Pignone, later a subsidiary of General Electric), Pietro Benini realized a working prototype of the Italian engine supplying 5 HP. In subsequent years he developed more powerful engines - with one or two pistons - which served as steady power sources, replacing steam engines.**

- **1857: Eugenio Barsanti and Felice Matteucci describe the principles of the free piston engine where the vacuum after the explosion allows atmospheric pressure to deliver the power stroke (British patent no. 1625).**
- **1860: Belgian Jean Joseph Etienne Lenoir (1822-1900) produced a gas-fired internal combustion engine similar in appearance to a horizontal double-acting steam engine, with cylinders, pistons, connecting rods, and flywheel in which the gas essentially took the place of the steam. This was the first internal combustion engine to be produced in numbers.**
- **1861: Nikolaus Otto builds a copy of the Lenoir engine.**
- **1862: Nikolaus Otto attempts the construction of the compressed charge four cycle engine, and fails.**
- **1862: The earliest confirmed patent of the 4-cycle engine, by Alphonse Beau de Rochas. This was principle only, there was NO engine built to prove the concept.**
- **1862: The German Nikolaus Otto begins to manufacture a no compression gas Lenoir engine with a free piston.**
- **1864: Nikolaus Otto, patented in England and other countries his first atmospheric gas engine. Otto was the first to build and sell this type of compressionless engine designed with an indirect-acting free-piston, whose great efficiency won the support of Eugen Langen and then most of the market, which at that time was mainly for small stationary engines fueled by lighting gas. Eugen Langen collaborated with Otto in the design and they began to manufacture it in 1864.**
- **1865: Pierre Hugon started production of the Hugon engine, similar to the Lenoir engine, but with better economy, and more reliable flame ignition.**
- **1867: Otto and Langen exhibited their free piston engine at the Paris Exhibition in 1867, and they won the greatest award. It had less than half the gas consumption of the Lenoir or Hugon engines.**
- **1870: In Vienna, Siegfried Marcus put the first mobile gasoline and the first modern internal combustion engine on a handcart.**
- **1872: In America George Brayton invented Brayton's Ready Motor and went into commercial production, this used constant pressure combustion, and was the first commercial liquid fuelled internal combustion engine.**
- **1876: Nikolaus Otto, working with Gottlieb Daimler and Wilhelm Maybach, patented the compressed charge, four-stroke engine. The German courts, however, did not hold his patent to cover all in-cylinder compression engines or even the four-stroke cycle, and after this decision, in-cylinder compression became universal.**
- **1878: Dugald Clerk designed the first two-stroke engine with in-cylinder compression. He patented it in England in 1881.**
- **1879: Karl Benz, working independently, was granted a patent for his reliable two-stroke, internal combustion engine, gas engine.**

- **1882: James Atkinson invented the Atkinson cycle engine. Atkinson's engine had one power phase per revolution together with different intake and expansion volumes, potentially making it more efficient than the Otto cycle, but certainly avoiding Otto's patent.**
- **1884: British engineer Edward Butler constructed the first petrol (gasoline) internal combustion engine. Butler invented the spark plug, ignition magneto, coil ignition and spray jet carburetor, and was the first to use the word petrol.**
- **1885: German engineer Gottlieb Daimler received a German patent for a supercharger**
- **1885/1886 Karl Benz designed and built his own four-stroke engine that was used in his automobile, which was developed in 1885, patented in 1886, and became the first automobile in series production.**
- **1887: Gustaf de Laval introduces the de Laval nozzle**
- **1889: Félix Millet begins development of the first vehicle to be powered by a rotary engine in transportation history.**
- **1891: Herbert Akroyd Stuart built his oil engine, leasing rights to Hornsby of England to build them. They built the first cold-start compression-ignition engines. In 1892, they installed the first ones in a water pumping station. In the same year, an experimental higher-pressure version produced self-sustaining ignition through compression alone.**
- **1892: Rudolf Diesel developed the first compressed charge, compression ignition engine .**
- **1893 February 23: Rudolf Diesel received a patent for his compression ignition (diesel) engine.**
- **1896: Karl Benz invented the boxer engine, also known as the horizontally opposed engine, or the flat engine, in which the corresponding pistons reach top dead center at the same time, thus balancing each other in momentum.**
- **1897: Robert Bosch was the first to adapt a magneto ignition to a vehicle engine.**
- **1898: Fay Oliver Farwell designs the prototype of the line of Adams-Farwell automobiles, all to be powered with three or five cylinder rotary internal combustion engines.**
- **1900: Rudolf Diesel demonstrated the diesel engine in the 1900 Exposition Universelle (World's Fair) using peanut oil fuel (see biodiesel).**
- **1900: Wilhelm Maybach designed an engine built at Daimler Motoren Gesellschaft - following the specifications of Emil Jellinek - who required the engine to be named Daimler-Mercedes after his daughter. In 1902 automobiles with that engine were put into production by DMG.**
- **1903: Konstantin Tsiolkovsky begins a series of theoretical papers discussing the use of rocketry to reach outer space. A major point in his work is liquid fueled rockets.**

- **1903: Ægidius Elling builds a gas turbine using a centrifugal compressor which runs under its own power. By most definitions, this is the first working gas turbine.**
- **1905: Alfred Buchi patents the turbocharger and starts producing the first examples.**
- **1903-1906: The team of Armengaud and Lemale in France build a complete gas turbine engine. It uses three separate compressors driven by a single turbine. Limits on the turbine temperatures allow for only a 3:1 compression ratio, and the turbine is not based on a Parsons-like "fan", but a Pelton wheel-like arrangement. The engine is so inefficient, at about 3% thermal efficiency, that the work is abandoned.**
- **1908: New Zealand inventor Ernest Godward started a motorcycle business in Invercargill and fitted the imported bikes with his own invention - a petrol economiser. His economisers worked as well in cars as they did in motorcycles.**
- **1908: Hans Holzwarth starts work on extensive research on an "explosive cycle" gas turbine, based on the Otto cycle. This design burns fuel at a constant volume and is somewhat more efficient. By 1927, when the work ended, he has reached about 13% thermal efficiency.**
- **1908: René Lorin patents a design for the ramjet engine.**
- **1916: Auguste Rateau suggests using exhaust-powered compressors to improve high-altitude performance, the first example of the turbocharger.**
- **1920: William Joseph Stern reports to the Royal Air Force that there is no future for the turbine engine in aircraft. He bases his argument on the extremely low efficiency of existing compressor designs. Due to Stern's eminence, his paper is so convincing there is little official interest in gas turbine engines anywhere, although this does not last long.**
- **1921: Maxime Guillaume patents the axial-flow gas turbine engine. It uses multiple stages in both the compressor and turbine, combined with a single very large combustion chamber.**
- **1923: Edgar Buckingham at the United States National Bureau of Standards publishes a report on jets, coming to the same conclusion as W.J. Stern, that the turbine engine is not efficient enough. In particular he notes that a jet would use five times as much fuel as a piston engine.**
- **1925: The Hesselman engine is introduced by Swedish engineer Jonas Hesselman represented the first use of direct gasoline injection on a spark-ignition engine.**
- **1925: Wilhelm Pape patents a constant-volume engine design.**
- **1926: Alan Arnold Griffith publishes his groundbreaking paper Aerodynamic Theory of Turbine Design, changing the low confidence in jet engines. In it he demonstrates that existing compressors are "flying stalled", and that major improvements can be made by redesigning the blades from a flat profile into an airfoil, going on to mathematically demonstrate that**

a practical engine is definitely possible and showing how to build a turboprop.

- **1926: Robert Goddard launches the first liquid-fueled rocket**
- **1927: Aurel Stodola publishes his "Steam and Gas Turbines" - basic reference for jet propulsion engineers in the US.**
- **1927: A testbed single-shaft turbo-compressor based on Griffith's blade design is tested at the Royal Aircraft Establishment.**
- **1929: Frank Whittle's thesis on jet engines is published**
- **1930: Schmidt patents a pulse-jet engine in Germany.**
- **1935: Hans von Ohain creates plans for a turbojet engine and convinces Ernst Heinkel to develop a working model. Along with a single mechanic von Ohain develops the world's first turbojet on a test stand.**
- **1936: French engineer René Leduc, having independently rediscovered René Lorin's design, successfully demonstrates the world's first operating ramjet.**
- **1937: The first successful run of Sir Frank Whittle's gas turbine for jet propulsion.**
- **March, 1937: The Heinkel HeS 1 experimental hydrogen fueled centrifugal jet engine is tested at Hirth.**
- **27 August 1939: Flight of the world's first turbojet power aircraft. Hans von Ohain's Heinkel He 178 V1 pioneer turbojet aircraft prototype makes its first flight, powered by an He S 3 von Ohain engine.**
- **15 May 1941: The Gloster E.28/39 becomes the first British jet-engined aircraft to fly, using a Power Jets W.1 turbojet designed by Frank Whittle and others.**
- **1942: Max Bentele discovers in Germany that turbine blades can break if vibrations are in its resonance range, a phenomenon already known in the US from the steam turbine experience.**
- **18 July 1942: The Messerschmitt Me 262 first jet engine flight**
- **1946: Samuel Baylin develops the Baylin Engine a three cycle internal combustion engine with rotary pistons. A crude but complex example of the future Wankel engine.**
- **1951: Engineers for The Texas Company - i.e. now Chevron - developed a four stroke engine with a fuel injector that employed what was called the Texaco Combustion Process, which unlike normal four stroke gasoline engines which used a separate valve for the intake of the air-gasoline mixture, with the T.C.P. engine the intake valve with a built in special shroud delivers the air to the cylinder in a tornado type fashion and then the fuel is injected and ignited by a spark plug. The inventors claimed their engine could burn on almost any petroleum based fuel of any octane and even some alcohol based fuels - e.g. kerosene, benzine, motor oil, tractor oil, etc. - without the pre-combustion knock and the complete burning of the**

fuel injected into the cylinder. While development was well advanced by 1950, there are no records of the T.C.P. engine being used commercially.

- **1950s: Development begins by US firms of the Free-piston engine concept which is a crankless internal combustion engine.**
- **1954: Felix Wankel's first working prototype DKM 54 of the Wankel engine.**
- **1986: Benz Gmbh files for patent protection for a form of Scotch yoke engine and begins development of same. Development subsequently abandoned.**
- **1996: Ford Motor Company files patent for compact turbine engine.**
- **2004: Hyper-X first scramjet to maintain altitude**
- **2004: Toyota Motor Corp files for patent protection for new form of Scotch yoke engine.**

7.2 The automobile culture

Automobile worship - a false religion

We are in love with our automobiles, but it is not certain that they make our lives happier. We love our cars so much that we are willing to die (and kill) for them: Wikipedia states that "It is estimated that motor vehicle collisions caused the death of around 60 million people during the 20th century, around the same number of World War II casualties. Just in 2010 alone, 1.23 million people were killed due to traffic collisions."

Besides being dangerous, automobiles make our cities unpleasant. A pleasant city center is, almost by definition, a car-free one. Today, both tourists and Danish citizens enjoy Copenhagen's bicycle culture and car-free city center[1], and throughout the world, the pleasantness of cities is inversely proportional to the number of automobiles.

Some people visualize the transition from internal combustion engines to electric vehicles as the only change needed to make transportation environmentally friendly; but this ignores the enormous amount of energy, water (148,000 liters), and other resources needed to manufacture private automobiles. A truly sustainable future requites a transition, wherever possible, from private to public transport.

The government of Luxomberg recently announced that it intends to make all public transportation entirely free[2], thus saving on the collection of fares, and eliminating the massive traffic jams that have plagued the country's capital.Luxembourg City, the capital of the small Grand Duchy, suffers from some of the worst traffic congestion in the world. It is home to about 110,000 people, but a further 400,000 commute into the city to work.

[1]https://www.theguardian.com/cities/2016/may/05/story-cities-copenhagen-denmark-modernist-utopia

[2]https://www.theguardian.com/world/2018/dec/05/luxembourg-to-become-first-country-to-make-all-public-transport-free

Figure 7.1: **Henry Ford (1863-1947). He is credited with "Fordism" - the mass production of inexpensive goods, coupled with high wages for workers. Ford converted the automobile from an expensive curiosity into a practical conveyance that would profoundly impact the landscape of the 20th century.**

It will be interesting to follow the progress of this enlightened decision, due to take effect in 2020. Hopefully other countries will follow Luxomberg's example. Luxembourg has increasingly shown a progressive attitude to transport. This summer, the government brought in free transport for every child and young person under the age of 20. Secondary school students can use free shuttles between their institution and their home.

Top Gear is long-running BBC program celebrating the delights of car ownership and motor sport. It is an example of the fact that our mass media actively encourage harmful and unsustainable human behavior. The program appeals to car enthusiasts - people who are passionate about automobiles. How much better it would be if they were passionate about saving human civilization and the biosphere from irreversible feedback loops leading in the long run to catastrophic climate change, mass extinctions, and the collapse of human civilization!

According to a recent article in AutoNation [3], the top five reasons why we love our cars are the following:

1. **Meditation** You've heard it from friends and you've most likely done the same - you recall vivid details about setting out in your trusty automobile and arriving at your destination. But the details in between are a bit foggy. This is the cathartic, driving-induced trance that we sometimes slip into under just the right conditions and coordinates. Think about it. This is an outstanding entryway into mediation. Where else can such profound introspection occur? The fact that you weren't even trying to meditate makes it all the more special. The same results apply for those who work on their cars, or who travel long distances in their favorite vehicles.

2. **Sunday Drives** The pointlessness of the Sunday Drive is - the point. You love your car when it gets you swiftly and reliably to work. But what fun - windows down, tunes blasting, twisty roads and big empty spaces - no pressure to be anywhere or answer to anyone. Bliss.

3. **Freedom** From the moment you get that driver's license, you'll never be the same again. You can go places. You break the bonds of being a dependent to actually being able to just bounce, on a whim, whenever you like. You are free to move about the country at your own pace. Getting the keys for the first time is your official rite of passage into adulthood.

4. **Personality/Status** The wheels you choose are a direct extension of how you view yourself as a person. You should have a car that reflects traits of your personality. For the bold and adventurous, maybe you define yourself with a Subaru Outback. For those concerned about the environment, perhaps a Toyota Prius shows the world who you are.

[3]http://autonationdrive.com/5-reasons-why-we-love-cars/

Figure 7.2: **Motor traffic in Manila.**

5. **Bonding** Cars are one of the greatest environments for bonding with family and friends. If you're forming a new relationship, there are dozens of features and details about your car that can be used as conversation fodder. Long trips in a car with a new friend can also be the perfect tool to get to know someone fast and there are endless opportunities to get glimpses into the genuine personality of your new special friend.

In another article [4], Tim Dugan explains why he loves his car:

"This car is bought and paid for by my own hand, it is the first major purchase I ever made as an adult. I worked off the loan and it wholly belongs to me. There is a sense of pride in this. Seeing the fruits of your labor and your saving and scrounging.

"This car is a tribute to my mother, who has passed away a few years ago. I grew up in a 1981 Camaro, she loved her car like I love mine.

"This car goes FAST. I don't care much for racing but I do love driving fast and boy does her 700rwhp provide that!!

[4] https://www.quora.com/Why-are-people-so-in-love-with-their-cars

Figure 7.3: **We love our cars.**

"I have personally seen her at her worst and best. I've had my hands covered in Camaro guts, elbow deep. I've felt the pain of seeing your brand new car with a blown motor out of it sitting in your garage with a hole where the engine is supposed to be and knowing your warranty ain't gonna cover that. These experiences made this vehicle mine through blood, sweat, tears, and vulgar language.

"This car is an extension of my personality. I am loud and noisy when I need to be but I prefer to stay subdued. This machine doesn't need to prove anything. She exudes confidence in herself and her ability to perform at 110% at a moments' notice - but she don't need to prove it, you can look at it, you can hear it and you'll know what's up. Just like her owner. I have nothing to prove - I've made my mark, I believe in myself and let the world make its decision.

"Lastly, this car changed my life. It gave me confidence and pride in myself. It helped me to get in touch with the man I would later grow up to become. It pushed me into a direction in life of working with my hands and being proud of doing well for myself without being stuck in a cubicle. It introduced and brought me into a huge group of amazing people I wouldn't have otherwise known. It gave my future wife a sense of my personality before she even met me. She knew I was a confident self sufficient red blooded American Male without me even saying a word - my Camaro did all the talking for me. She turns heads, she makes kids jump up and down screaming, 'THERE'S THE BAT-MOBILE!' She is a fantastic money sink, a pleasure to drive, and a fine automobile. Never will this vehicle leave my possession and never will it find decay in a junk heap while I walk this earth. It is my friend and compatriot, through thick and thin we have been together, even on the worst days I can hop in this thing and go for a spin and find solace, enjoyment, and testosterone producing speed."

7.3 The end of the fossil fuel era

According to a recent United Nations report, extreme weather events displaced 2 million people during 2018. While no single event can be unambiguously attributed to anthropogenic climate change, scientists believe the the increasing frequency of extreme weather events is definitely linked to global warming. The same is true of their increasing severity.

The report states that during 2018, extreme weather events impacted roughly 62 million people, of whom 2 million were displaced from their homes. In the words of the WMO report, "The physical signs and socio-economic impacts of climate change are accelerating, as record greenhouse gas concentrations drive global temperatures towards increasingly dangerous levels."

UN Secretary General Antonio Guterres, speaking at the launching of the WMO report, used the occasion to remind global leaders of the urgency of the climate emergency. Guterres has convened a climate summit meeting scheduled for September 23, 2019, and referring to the meeting, he said: "Don't come with a speech, come with a plan. This is what science says is needed. It is what young people around the globe are rightfully demanding." Two weeks previously, on March 15, one and a half million students from more that 130 countries had skipped school to participate in the largest climate demonstration in history, demanding action to save the future from the threat of catastrophic climate change.

The world's leading scientists met at the Forty-Eighth Session of the IPCC and First Joint Session of Working Groups I, II, and III, 1-5 October 2018 in Inchon, Republic of Korea and openly declared that civilization is on track for collapse because of reckless use of fossil fuels, unless immediate action is taken to drastically cut the extraction and use of fossil fuels.

The report finds that limiting global warming to 1.5^{o}C would require "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities. Global net human-caused emissions of carbon dioxide would need to fall by about 45 percent from 2010 levels by 2030, reaching 'net zero' around 2050.

"It's a line in the sand and what it says to our species is that this is the moment and we must act now," said Debra Roberts, a co-chair of the working group on impacts. "This is the largest clarion bell from the science community and I hope it mobilizes people and dents the mood of complacency."

"We have presented governments with pretty hard choices. We have pointed out the enormous benefits of keeping to 1.5C, and also the unprecedented shift in energy systems and transport that would be needed to achieve that," said Jim Skea, a co-chair of the working group on mitigation. "We show it can be done within laws of physics and chemistry. Then the final tick box is political will. We cannot answer that. Only our audience can - and that is the governments that receive it."

Bob Ward, of the Grantham Research Institute on Climate Change, said the final document was "incredibly conservative" because it did not mention the likely rise in climate-driven refugees or the danger of tipping points that could push the world on to an irreversible path of extreme warming.

Investment in electric vehicles

On July 5, 2017, the Volvo Car Group made the following announcement: [5]

"Volvo Cars, the premium car maker, has announced that every Volvo it launches from 2019 will have an electric motor, marking the historic end of cars that only have an internal combustion engine (ICE) and placing electrification at the core of its future business.

"The announcement represents one of the most significant moves by any car maker to embrace electrification and highlights how over a century after the invention of the internal combustion engine electrification is paving the way for a new chapter in automotive history.

"'This is about the customer,' said Håkan Samuelsson, president and chief executive. 'People increasingly demand electrified cars and we want to respond to our customers' current and future needs. You can now pick and choose whichever electrified Volvo you wish.'

"Volvo Cars will introduce a portfolio of electrified cars across its model range, embracing fully electric cars, plug in hybrid cars and mild hybrid cars.

"It will launch five fully electric cars between 2019 and 2021, three of which will be Volvo models and two of which will be high performance electrified cars from Polestar, Volvo Cars' performance car arm. Full details of these models will be announced at a later date."

The electric vehicle investment opportunity was also illustrated by the 2017 vote of Germany's Bundesrat to ban the manufacture of internal combustion engines after 2030 [6].

The article announcing the vote adds that "It's a strong statement in a nation where the auto industry is one of the largest sectors of the economy; Germany produces more automobiles than any other country in Europe and is the third largest in the world. The resolution passed by the Bundesrat calls on the European Commission (the executive arm of the European Union) to 'evaluate the recent tax and contribution practices of Member States on their effectiveness in promoting zero-emission mobility,' which many are taking to mean an end to the lower levels of tax currently levied on diesel fuel across Europe."

France plans to end the sale of vehicles powered by gasoline and diesel by 2040, environment minister Nicolas Hulot announced recently.

Hulot made the announcement on Thursday, June 13, 2017, in Paris as he launched the country's new Climate Plan to accelerate the transition to clean energy and to meet its targets under the Paris climate agreement.

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[5] https://www.media.volvocars.com/global/en-gb/media/pressreleases/210058/volvo-cars-to-go-all-electric

[6] https://arstechnica.com/cars/2016/10/germanys-bundesrat-votes-to-ban-the-internal-combustion-engine-by-2030/

To ease the transition, Hulot said the French government will offer tax incentives to replace fossil-fuel burning cars with clean alternatives.

Furthermore, the government of India has recently announced its intention to only nave electric vehicles by 2030[7]. This hugely ambitious plan was announced during the 2017 Confederation of Indian Industry Annual Session. Besides the avoidance of climate change, which might make many regions of India uninhabitable, the motive for replacing 28 million combustion engine vehicles by electric ones was the severe air pollution from which India suffers. Severe air pollution also motivates efforts by the government of China to promote the transition to electric vehicles.

The governments of Norway and the Netherlands have taken steps towards banning the internal combustion engine[8]. Both the upper and lower houses of the Netherlands' government voted to ban cars driven by internal combustion engines by 2025, the same year in which Norway plans to sell nothing but zero-emission vehicles.

In a report commissioned by the investment bankers Cowan & Co, managing director and senior research analyst Jeffrey Osborne, predicted that electric vehicles will cost less than gasoline-powered cars by the early- to mid-2020s due to falling battery prices as well as the costs that traditional carmakers will incur as they comply to new fuel-efficiency standards. Osbourne pointed out that a number of major car brands are hopping onto the electric bandwagon to compete in a space carved out by industry disrupter, Tesla.

"We see the competitive tides shifting in 2019 and beyond as European [car makers] roiled by the diesel scandal and loss of share to Tesla in the high margin luxury segment step on the gas and accelerate the pace of EV introductions", he wrote.

Bloomberg New Energy Finance reported similar predictions: "Falling battery costs will mean electric vehicles will also be cheaper to buy in the U.S. and Europe as soon as 2025," the report said. "Batteries currently account for about half the cost of EVs, and their prices will fall by about 77 percent between 2016 and 2030."

In October, 2017, General Motors unveiled plans to roll out 20 new entirely electric car models by 2023, with two of the new EVs coming out in the next 18 months. Meanwhile, Ford announced the creation of "Team Edison," intended to accelerate the company's EV development and partnership work. The name, is "seemingly in direct response to Elon Musk's Tesla, which recently surpassed Ford's market capitalization."

Tesla's Chairman, highly successful inventor and entrepreneur Elon Musk, has made massive investments in factories manufacturing electric vehicles, improved lithium ion storage cells, and photovoltaic panels, as will be discussed in Chapter 2.

Elon Musk and renewable energy technology

Elon Reve Musk was born in 1971 in South Africa. At the age of 10, he developed an interest in computer programming, and by 12 he had invented a computer game which he

[7]https://www.greentechmedia.com/articles/read/what-country-will-become-the-first-to-ban-internal-combustion-cars

[8]http://www.prnewswire.com/news-releases/the-dutch-revolution-in-smart-charging-of-electric-vehicles-597268791.html

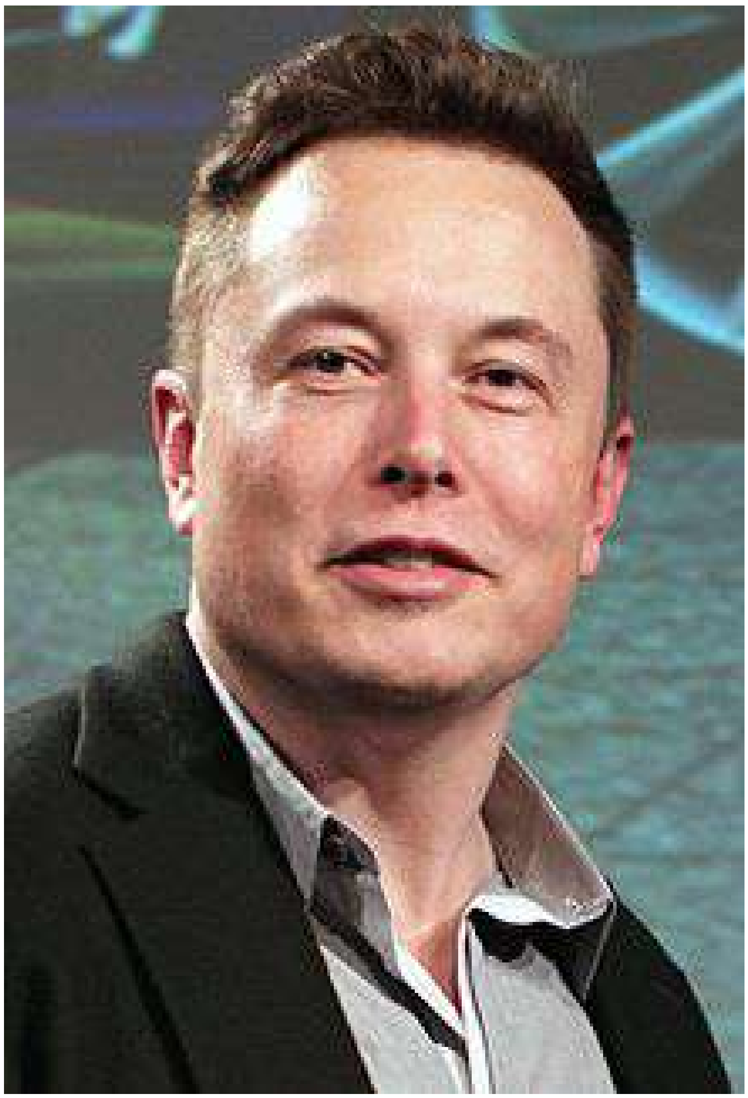

Figure 7.4: **Elon Musk in 2015 (Wikipedia)**

Figure 7.5: **Tesla's Gigafactory 1 in Nevada produces improved lithium ion batteries. Energy for the factory is supplied by solar panels on the roof.**

sold for $500. Just before his 18th birthday, Musk moved to Canada, obtaining citizenship through his Canadian-born mother. After studying for two years at Queens University in Kingston Ontario, Musk moved to the University of Pennsylvania, where where he obtained degrees in both science and economics.

At the age of 24, Elon Musk started Ph.D. studies in applied physics and material science at Stanford University, but he left the program (after 2 days!) to pursue his interests in the Internet-based businesses, renewable energy and outer space. He became a US citizen in 2002. In the meantime, Musk's business ventures and his inventions have made him the 80th wealthiest person in the world. In 2016 he was ranked as 21st on the Forbes list of the world's most powerful people. He has been called the new Thomas Edison.

Luckily, the transition to 100% renewable energy holds a high place in Musk's priorities, and he has applied his genius both as an inventor and as a businessman to achieving this goal. Two of the corporations led by Musk, Tesla and Solar City, are devoted to solving the problem of intermittency through improved storage batteries, replacing petroleum-driven automobiles by attractive and affordable electric cars, and harnessing solar energy.

SolarCity leases rooftop solar to customers who pay no upfront costs. In exchange, customers pay for 20 years for power generated by those panels.

Wikipedia states that "In June 2014, SolarCity announced plans to build a new manufacturing facility in Buffalo, New York, in coordination with the SUNY Polytechnic Institute after acquiring Silevo, a maker of high-efficiency solar modules. The initial manufacturing complex will be a 1.2-million-square-foot (110,000 m2) facility that will cost $900 million and employ 1,500 workers in Buffalo and 5,000 statewide."

Figure 7.6: **Gigafactory 2. SolarCity's factory in Buffalo New York produces high-efficiency solar modules. Elon Musk estimates that only 100 gigafactories would be enough to achieve a worldwide transition to 100% renewable energy.**

Figure 7.7: **Tesla was the world's best selling plug-in passenger car manufacturer in 2018.**

Figure 7.8: **Tesla Model 3 production model.**

Figure 7.9: **An electric car currently being produced by General Motors.**

Speaking at the University of Paris during the recent climate talks, Elon Musk said "The important thing to appreciate is if let's say the only thing we had was solar energy, that that was the only power source, if you just took a small section of Spain, you could power all of Europe. It's a very small amount of area that's actually needed to generate the electricity we need to power civilization, or in the case of the US, a little corner of Nevada or Utah, power the entire United States."

Musk has also predicted that by 2031, solar energy will be the world's largest energy source.

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Chapter 8

THE FIRST COMPUTERS

8.1 Pascal and Leibniz

If civilization survives, historians in the distant future will undoubtedly regard the invention of computers as one of the most important steps in human cultural evolution - as important as the invention of writing or the invention of printing. The possibilities of artificial intelligence have barely begun to be explored, but already the impact of computers on society is enormous.

The first programmable universal computers were completed in the mid-1940's; but they had their roots in the much earlier ideas of Blaise Pascal (1623-1662), Gottfried Wilhelm Leibniz (1646-1716), Joseph Marie Jacquard (1752-1834) and Charles Babbage (1791-1871).

In 1642, the distinguished French mathematician and philosopher Blaise Pascal completed a working model of a machine for adding and subtracting. According to tradition, the idea for his "calculating box" came to Pascal when, as a young man of 17, he sat thinking of ways to help his father (who was a tax collector). In describing his machine, Pascal wrote: "I submit to the public a small machine of my own invention, by means of which you alone may, without any effort, perform all the operations of arithmetic, and may be relieved of the work which has often times fatigued your spirit when you have worked with the counters or with the pen."

Pascal's machine worked by means of toothed wheels. It was much improved by Leibniz, who constructed a mechanical calculator which, besides adding and subtracting, could also multiply and divide. His first machine was completed in 1671; and Leibniz' description of it, written in Latin, is preserved in the Royal Library at Hanover: "There are two parts of the machine, one designed for addition (and subtraction), and the other designed for multiplication (and division); and they should fit together. The adding (and subtracting) machine coincides completely with the calculating box of Pascal. Something, however, must be added for the sake of multiplication..."

"The wheels which represent the multiplicand are all of the same size, equal to that of the wheels of addition, and are also provided with ten teeth which, however, are movable

Figure 8.1: **Blaise Pascal (1623-1662) was a French mathematician, physicist, writer, inventor and theologian. Pascal, a child prodigy, was educated by his father, who was a tax-collector. He invented his calculating box to make his father's work less tedious.**

Figure 8.2: **The German mathematician, philosopher and universal genius Gottfried Wilhelm von Leibniz (1646-1716) was a contemporary of Isaac Newton. He invented differential and integral calculus independently, just as Newton had done many years earlier. However, Newton had not published his work on calculus, and thus a bitter controversy over priority was precipitated. When his patron, the Elector of Hanover moved to England to become George I, Leibniz was left behind because the Elector feared that the controversy would alienate the English. Leibniz extended Pascal's calculating box so that it could perform multiplication and division. Calculators of his design were still being used in the 1960's.**

so that at one time there should protrude 5, at another 6 teeth, etc., according to whether the multiplicand is to be represented five times or six times, etc."

"For example, the multiplicand 365 consists of three digits, 3, 6, and 5. Hence the same number of wheels is to be used. On these wheels, the multiplicand will be set if from the right wheel there protrude 5 teeth, from the middle wheel 6, and from the left wheel 3."

8.2 Jacquard and Babbage

By 1810, calculating machines based on Leibniz' design were being manufactured commercially; and mechanical calculators of a similar (if much improved) design could be found in laboratories and offices until the 1960's. The idea of a programmable universal computer is due to the English mathematician, Charles Babbage, who was the Lucasian Professor of Mathematics at Cambridge University. (In the 17th century, Isaac Newton held this post, and in the 20th century, P.A.M. Dirac and Stephen Hawking also held it.)

In 1812, Babbage conceived the idea of constructing a machine which could automat-

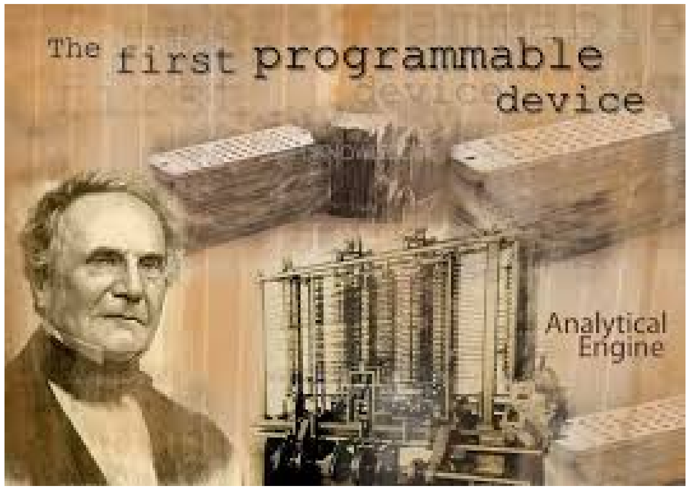

Figure 8.3: **Charles Babbage (1791-1871) and his analytical engine.**

ically produce tables of functions, provided that the functions could be approximated by polynomials. He constructed a small machine, which was able to calculate tables of quadratic functions to eight decimal places, and in 1832 he demonstrated this machine to the Royal Society and to representatives of the British government.

The demonstration was so successful that Babbage secured financial support for the construction of a large machine which would tabulate sixth-order polynomials to twenty decimal places. The large machine was never completed, and twenty years later, after having spent seventeen thousand pounds on the project, the British government withdrew its support. The reason why Babbage's large machine was never finished can be understood from the following account by Lord Moulton of a visit to the mathematician's laboratory:

"One of the sad memories of my life is a visit to the celebrated mathematician and inventor, Mr. Babbage. He was far advanced in age, but his mind was still as vigorous as ever. He took me through his workrooms."

"In the first room I saw the parts of the original Calculating Machine, which had been shown in an incomplete state many years before, and had even been put to some use. I asked him about its present form. 'I have not finished it, because in working at it, I came on the idea of my Analytical Machine, which would do all that it was capable of doing, and much more. Indeed, the idea was so much simpler that it would have taken more work to complete the Calculating Machine than to design and construct the other in its entirety; so I turned my attention to the Analytical Machine.'"

"After a few minutes talk, we went into the next workroom, where he showed me the working of the elements of the Analytical Machine. I asked if I could see it. 'I have never completed it,' he said, 'because I hit upon the idea of doing the same thing by a different and far more effective method, and this rendered it useless to proceed on the old lines.'"

"Then we went into a third room. There lay scattered bits of mechanism, but I saw no trace of any working machine. Very cautiously I approached the subject, and received the dreaded answer: 'It is not constructed yet, but I am working at it, and will take less time

Figure 8.4: **Joseph Marie Jacquard (1752-1834) invented a loom which could be programed to produce any design by means of punched cards. News of his invention inspired Babbage to invent a universal programmable computing machine.**

to construct it altogether than it would have taken to complete the Analytical Machine from the stage in which I left it.' I took leave of the old man with a heavy heart."

Babbage's first calculating machine was a special-purpose mechanical computer, designed to tabulate polynomial functions; and he abandoned this design because he had hit on the idea of a universal programmable computer. Several years earlier, the French inventor Joseph Marie Jacquard had constructed an automatic loom in which large wooden "punched cards" were used to control the warp threads. Inspired by Jacquard's invention, Babbage planned to use punched cards to program his universal computer. (Jacquard's looms could be programmed to weave extremely complex patterns: A portrait of the inventor, woven on one of his looms in Lyon, hung in Babbage's drawing room.)

One of Babbage's frequent visitors was Augusta Ada[1], Countess of Lovelace (1815-1852), the daughter of Lord and Lady Byron. She was a mathematician of considerable ability, and it is through her lucid descriptions that we know how Babbage's never-completed Analytical Machine was to have worked.

[1] The programming language ADA is named after her.

Figure 8.5: **Jacquard's loom.**

Figure 8.6: **Lord Byron's daughter, Augusta Ada, Countess of Lovelace (1815-1852) was an accomplished mathematician and a frequent visitor to Babbage's workshop. It is through her lucid description of his ideas that we know how Babbage's universal calculating machine was to have worked. The programming language ADA is named after her.**

8.3 Harvard's sequence-controlled calculator

The next step towards modern computers was taken by Herman Hollerith, a statistician working for the United States Bureau of the Census. He invented electromechanical machines for reading and sorting data punched onto cards. Hollerith's machines were used to analyze the data from the 1890 United States Census. Because the Census Bureau was a very limited market, Hollerith branched out and began to manufacture similar machines for use in business and administration. His company was later bought out by Thomas J. Watson, who changed its name to International Business Machines.

In 1937, Howard Aiken, of Harvard University, became interested in combining Babbage's ideas with some of the techniques which had developed from Hollerith's punched card machines. He approached the International Business Machine Corporation, the largest manufacturer of punched card equipment, with a proposal for the construction of a large, automatic, programmable calculating machine.

Aiken's machine, the Automatic Sequence Controlled Calculator (ASCC), was completed in 1944 and presented to Harvard University. Based on geared wheels, in the Pascal-Leibniz-Babbage tradition, ASCC had more than three quarters of a million parts and used 500 miles of wire. ASCC was unbelievably slow by modern standards - it took three-tenths of a second to perform an addition - but it was one of the first programmable general-purpose digital computers ever completed. It remained in continuous use, day and night, for fifteen years.

Figure 8.7: **The Automatic Sequence-Controlled Calculator ASCC can still be seen by visitors at Harvard's science building and cafeteria.**

8.4 The first electronic computers

In the ASCC, binary numbers were represented by relays, which could be either on or off. The on position represented 1, while the off position represented 0, these being the only two digits required to represent numbers in the binary (base 2) system. Electromechanical calculators similar to ASCC were developed independently by Konrad Zuse in Germany and by George R. Stibitz at the Bell Telephone Laboratory.

Electronic digital computers

In 1937, the English mathematician A.M. Turing published an important article in the Proceedings of the London Mathematical Society in which envisioned a type of calculating machine consisting of a long row of cells (the "tape"), a reading and writing head, and a set of instructions specifying the way in which the head should move the tape and modify the state and "color" of the cells on the tape. According to a hypothesis which came to be known as the "Church-Turing hypothesis", the type of computer proposed by Turing was capable of performing every possible type of calculation. In other words, the Turing machine could function as a universal computer.

In 1943, a group of English engineers, inspired by the ideas of Alan Turing and those of the mathematician M.H.A. Newman, completed the electronic digital computer Colossus. Colossus was the first large-scale electronic computer. It was used to break the German Enigma code; and it thus affected the course of World War II.

In 1946, ENIAC (Electronic Numerical Integrator and Calculator) became operational. This general-purpose computer, designed by J.P. Eckert and J.W. Mauchley of the University of Pennsylvania, contained 18,000 vacuum tubes, one or another of which was often out of order. However, during the periods when all its vacuum tubes were working, an electronic computer like Colossus or ENIAC could shoot ahead of an electromechanical machine (such as ASCC) like a hare outdistancing a tortoise.

During the summer of 1946, a course on "The Theory and Techniques of Electronic Digital Computers" was given at the University of Pennsylvania. The ideas put forward in this course had been worked out by a group of mathematicians and engineers headed by J.P. Eckert, J.W. Mauchley and John von Neumann, and these ideas very much influenced all subsequent computer design.

Cybernetics

The word "Cybernetics", was coined by the American mathematician Norbert Wiener (1894-1964) and his colleagues, who defined it as "the entire field of control and communication theory, whether in the machine or in the animal". Wiener derived the word from the Greek term for "steersman".

Norbert Wiener began life as a child prodigy: He entered Tufts University at the age of 11 and received his Ph.D. from Harvard at 19. He later became a professor of mathematics at the Massachusetts Institute of Technology. In 1940, with war on the horizon,

Figure 8.8: **Alan Turing (1912-1954). He is considered to be the father of theoretical computer science. During World War II, Turing's work allowed the allies to crack the German's code. This appreciably shortened the length of the war in Europe, and saved many lives.**

Figure 8.9: **John von Neumann (1903-1957, right) with J. Robert Oppenheimer. In the background is an electronic digital computer.**

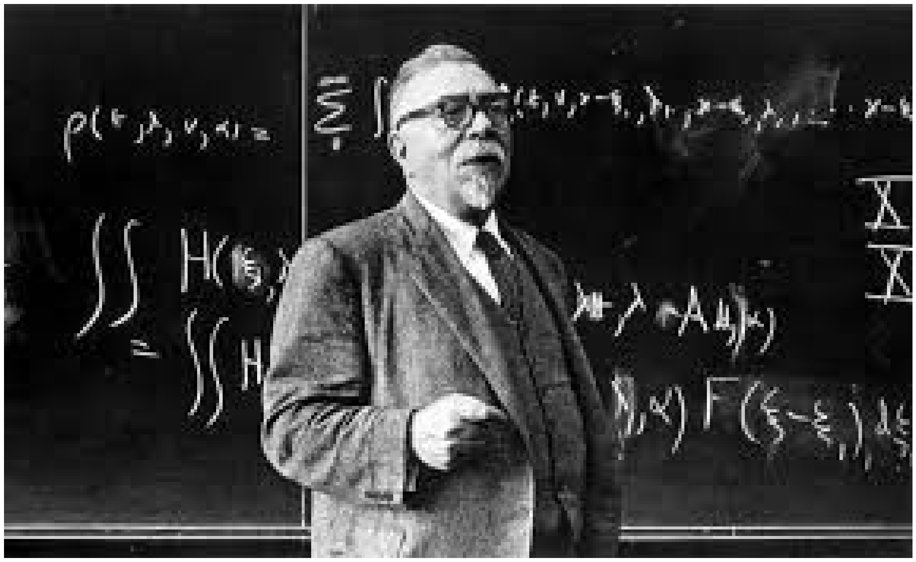

Figure 8.10: **MIT's Norbert Wiener (1894-1964) coined the word "Cybernetics", derived from a Greek word meaning "steersman". Wiener was one of the principle organizers of the Macy Conferences.**

Wiener sent a memorandum to Vannevar Bush, another MIT professor who had done pioneering work with analogue computers, and had afterwards become the chairman of the U.S. National Defense Research Committee. Wiener's memorandum urged the American government to support the design and construction of electronic digital computers, which would make use of binary numbers, vacuum tubes, and rapid memories. In such machines, the memorandum emphasized, no human intervention should be required except when data was to be read into or out of the machine.

Like Leo Szilard, John von Neumann, Claude Shannon and Erwin Schrödinger, Norbert Wiener was aware of the relation between information and entropy. In his 1948 book Cybernetics he wrote: "...we had to develop a statistical theory of the amount of information, in which the unit amount of information was that transmitted by a single decision between equally probable alternatives. This idea occurred at about the same time to several writers, among them the statistician R.A. Fisher, Dr. Shannon of Bell Telephone Laboratories, and the author. Fisher's motive in studying this subject is to be found in classical statistical theory; that of Shannon in the problem of coding information; and that of the author in the problem of noise and message in electrical filters... The notion of the amount of information attaches itself very naturally to a classical notion in statistical mechanics: that of entropy. Just as the amount of information in a system is a measure of its degree of organization, so the entropy of a system is a measure of its degree of disorganization; and the one is simply the negative of the other."

During World War II, Norbert Wiener developed automatic systems for control of anti-aircraft guns. His systems made use of feedback loops closely analogous to those with which animals coordinate their movements. In the early 1940's, he was invited to attend a

Figure 8.11: **Margaret Mead (1901-1978) and Gregory Bateson (1904-1980). They used the feedback loops studied by Wiener to explain many aspects of human behavior. Bateson is considered to be one of the main founders of the discipline Biosemiotics, which considers information to be the central feature of living organisms.**

series of monthly dinner parties organized by Arturo Rosenbluth, a professor of physiology at Harvard University. The purpose of these dinners was to promote discussions and collaborations between scientists belonging to different disciplines. The discussions which took place at these dinners made both Wiener and Rosenbluth aware of the relatedness of a set of problems that included homeostasis and feedback in biology, communication and control mechanisms in neurophysiology, social communication among animals (or humans), and control and communication involving machines.

Wiener and Rosenbluth therefore tried to bring together workers in the relevant fields to try to develop common terminology and methods. Among the many people whom they contacted were the anthropologists Gregory Bateson and Margaret Mead, Howard Aiken (the designer of the Automatic Sequence Controlled Calculator), and the mathematician John von Neumann. The Josiah Macy Jr. Foundation sponsored a series of ten yearly meetings, which continued until 1949 and which established cybernetics as a new research discipline. It united areas of mathematics, engineering, biology, and sociology which had previously been considered unrelated. Among the most important participants (in addition to Wiener, Rosenbluth, Bateson, Mead, and von Neumann) were Heinz von Foerster, Kurt Lewin, Warren McCulloch and Walter Pitts. The Macy conferences were small and informal, with an emphasis on discussion as opposed to the presentation of formal papers. A stenographic record of the last five conferences has been published, edited by von Foerster. Transcripts of the discussions give a vivid picture of the enthusiastic and creative atmosphere of the meetings. The participants at the Macy Conferences perceived Cybernetics as a much-needed bridge between the natural sciences and the humanities. Hence their enthusiasm. Weiner's feedback loops and von Neumann's theory of games were used by anthropologists Mead and Bateson to explain many aspects of human behavior.

8.5 Biosemiotics

The Oxford Dictionary of Biochemistry and Molecular Biology (Oxford University Press, 1997) defines Biosemiotics as "the study of signs, of communication, and of information in living organisms". The biologists Claus Emmeche and K. Kull offer another definition of Biosemiotics: "biology that interprets living systems as sign systems".

The American philosopher Charles Sanders Peirce (1839-1914) is considered to be one of the founders of Semiotics (and hence also of Biosemiotics). Peirce studied philosophy and chemistry at Harvard, where his father was a professor of mathematics and astronomy. He wrote extensively on philosophical subjects, and developed a theory of signs and meaning which anticipated many of the principles of modern Semiotics. Peirce built his theory on a triad: (1) the sign, which represents (2) something to (3) somebody. For example, the sign might be a broken stick, which represents a trail to a hunter, it might be the arched back of a cat, which represents an aggressive attitude to another cat, it might be the waggle-dance of a honey bee, which represents the coordinates of a source of food to her hive-mates, or it might be a molecule of trans-10-cis-hexadecadienol, which represents irresistible sexual temptation to a male moth of the species Bombyx mori. The sign might be a sequence of nucleotide bases which represents an amino acid to the ribosome-transfer-RNA system, or it might be a cell-surface antigen which represents self or non-self to the immune system. In information technology, the sign might be the presence or absence of a pulse of voltage, which represents a binary digit to a computer. Semiotics draws our attention to the sign and to its function, and places much less emphasis on the physical object which forms the sign. This characteristic of the semiotic viewpoint has been expressed by the Danish biologist Jesper Hoffmeyer in the following words: "The sign, rather than the molecule, is the basic unit for studying life."

A second important founder of Biosemiotics was Jakob von Uexküll (1864-1944). He was born in Estonia, and studied zoology at the University of Tartu. After graduation, he worked at the Institute of Physiology at the University of Heidelberg, and later at the Zoological Station in Naples. In 1907, he was given an honorary doctorate by Heidelberg

Figure 8.12: **Charles Sanders Pearce (1839-1914).**

Figure 8.13: **Jakob Johann Baron von Uexküll (1964-1944). Together with Pearce and Bateson, he is one of the principle founders of Biosemiotics.**

for his studies of the physiology of muscles. Among his discoveries in this field was the first recognized instance of negative feedback in an organism. Von Uexküll's later work was concerned with the way in which animals experience the world around them. To describe the animal's subjective perception of its environment he introduced the word Umwelt; and in 1926 he founded the Institut fur Umweltforschung at the University of Heidelberg. Von Uexküll visualized an animal - for example a mouse - as being surrounded by a world of its own - the world conveyed by its own special senses organs, and processed by its own interpretative systems. Obviously, the Umwelt will differ greatly depending on the organism. For example, bees are able to see polarized light and ultraviolet light; electric eels are able to sense their environment through their electric organs; many insects are extraordinarily sensitive to pheromones; and a dog's Umwelt far richer in smells than that of most other animals. The Umwelt of a jellyfish is very simple, but nevertheless it exists.[2] Von Uexküll's Umwelt concept can even extend to one-celled organisms, which receive chemical and tactile signals from their environment, and which are often sensitive to light. The ideas and research of Jakob von Uexküll inspired the later work of the Nobel Laureate ethologist Konrad Lorenz, and thus von Uexküll can be thought of as one of the founders of ethology as well as of Biosemiotics. Indeed, ethology and Biosemiotics are closely related.

Biosemiotics also values the ideas of the American anthropologist Gregory Bateson (1904-1980), who was mentioned in Chapter 7 in connection with cybernetics and with the Macy Conferences. He was married to another celebrated anthropologist, Margaret Mead, and together they applied Norbert Wiener's insights concerning feedback mechanisms to sociology, psychology and anthropology. Bateson was the originator of a famous epigrammatic definition of information: "..a difference which makes a difference" . This definition occurs in Chapter 3 of Bateson's book, Mind and Nature: A Necessary Unity, Bantam, (1980), and its context is as follows: "To produce news of a difference, i.e. information", Bateson wrote, "there must be two entities... such that news of their difference can be represented as a difference inside some information-processing entity, such as a brain or, perhaps, a computer. There is a profound and unanswerable question about the nature of these two entities that between them generate the difference which becomes information by making a difference. Clearly each alone is - for the mind and perception - a non-entity, a non-being... the sound of one hand clapping. The stuff of sensation, then, is a pair of values of some variable, presented over time to a sense organ, whose response depends on the ratio between the members of the pair."

8.6 Some personal memories of early computers

I hope that readers will forgive me if I tell them of my own personal memories of early computers:

When I arrived at Imperial College (then part of the University of London) in 1962,

[2] It is interesting to ask to what extent the concept of Umwelt can be equated to that of consciousness. To the extent that these two concepts can be equated, von Uexküll's Umweltforschung offers us the opportunity to explore the phylogenetic evolution of the phenomenon of consciousness.

I worked with a crystallographic group that using the Mercury computer at University College to do the calculations needed to arrive at molecular structures. This gave me the chance to use Mercury to do quantum chemical calculations. I used to go over to University College with the crystallographers at night, because time on the computer was so expensive that we could only afford to use it at night. I would make a bed for myself out of three chairs in a row and would try to sleep. At 3 AM or 4 AM they would wake me up and would say "Now it's your turn".

Mercury was as big as a house, but could do far less than a modern laptop. It had 50,000 or so vacuum tubes which required cooling. The cooling system sometimes broke down, and one or another of the vacuum tubes sometimes failed, so one had to be grateful for the periods when Mercury was working. Our programs were written on punched tape in a language called CHLF3. (The letters stood for Cambridge, London, Harwell and Farnsborough, the four places that had Mercurys). After we had read the paper tape into the computer, the program was converted into a magnetic form on a rapidly rotating drum, and then checked against the original input. If it did not check, we had a so-called "drum parity", which meant that we had to stop the computer and restart it by hand, using a bewildering array of manual controls.

After finishing the work on Mercury at 6 AM or so, I would walk home, passing through the almost-deserted streets of Soho, and seeing pale-faced teenagers who had been up all night, high on amphetamines. They were sitting on the pavement near an underground station, waiting for it to open.

After we had used Mercury for two years or so, IBM gave Imperial College one of their early computers. Using this was much better. Programs for the IBM machine were written on punched cards. We just went over to the machine with our punched cards and stood in line to have them read into the computer. Then a few minutes later we were handed a printout of the output.

The IBM was much better than the machines that were available in eastern Europe, and for this reason I was contacted by Janos Ladik and his group at the Hungarian Academy of Science, who proposed a collaboration. We worked together for several years, calculating the electronic structure of a number of polypeptides and polynucleotides.

In 1965, Janos Ladik invited me to attend a meeting of quantum theorists and computer scientists from both East and West, held at a town on the Hungarian Puszta, the great Hungarian plain east of Budapest. At the meeting, Enrico Clementi spoke about computer programs that he had developed for performing *ab-initio*[3] calculation of the electronic structure of molecules. Clementi was an important IBM scientist, and he had his own laboratory with a large computer which he could use as he liked. The programs that he described to us took hundreds of hours to complete an electronic structure calculation on a single molecule.

In the question period after Clementi's lecture, someone from the audience said: "It's all right for you, Clementi. You can use hundreds of hours on a single calculation if you

[3] *ab-initio* is a Latin expression meaning "from the beginning". Such programs are completely free of input parameters based on experiments.

Figure 8.14: **Enrico Clementi (born 1931) explained to us that microminiaturization would soon make computers hundreds of times faster, smaller and less expensive. He was completely right.**

want to, because you are sitting at IBM with your own dedicated computer. But what about the rest of us? What good are these programs to us?"

Clementi answered: "In a few years, computers will be hundreds of times faster, and they will also be cheaper." The audience asked: "And how will this happen?". Clementi answered: "Through microminiaturization." He was completely right. That was exactly what happened.

8.7 The invention of transistors

Microelectronics

The problem of unreliable vacuum tubes was solved in 1948 by John Bardeen, William Shockley and Walter Brattain of the Bell Telephone Laboratories. Application of quantum theory to solids had lead to an understanding of the electrical properties of crystals. Like atoms, crystals were found to have allowed and forbidden energy levels.

The allowed energy levels for an electron in a crystal were known to form bands, i.e., some energy ranges with many allowed states (allowed bands), and other energy ranges with none (forbidden bands). The lowest allowed bands were occupied by electrons, while higher bands were empty. The highest filled band was called the "valance band", and the lowest empty band was called the "conduction band".

According to quantum theory, whenever the valance band of a crystal is only partly filled, the crystal is a conductor of electricity; but if the valance band is completely filled with electrons, the crystal is an electrical insulator. (A completely filled band is analogous to a room so packed with people that none of them can move.)

In addition to conductors and insulators, quantum theory predicted the existence of "semiconductors" - crystals where the valence band is completely filled with electrons, but where the energy gap between the conduction band and the valence band is very small. For example, crystals of the elements silicon and germanium are semiconductors. For such a crystal, thermal energy is sometimes enough to lift an electron from the valence band to the conduction band.

Bardeen, Shockley and Brattain found ways to control the conductivity of germanium crystals by injecting electrons into the conduction band, or alternatively by removing electrons from the valence band. They could do this by "doping" the crystals with appropriate impurities, or by injecting electrons with a special electrode. The semiconducting crystals whose conductivity was controlled in this way could be used as electronic valves, in place of vacuum tubes.

By the 1960's, replacement of vacuum tubes by transistors in electronic computers had led not only to an enormous increase in reliability and a great reduction in cost, but also to an enormous increase in speed. It was found that the limiting factor in computer speed was the time needed for an electrical signal to propagate from one part of the central processing unit to another. Since electrical impulses propagate with the speed of light, this time is extremely small; but nevertheless, it is the limiting factor in the speed of electronic computers.

8.8 The Traitorous Eight

According to the Wikipedia article on Shockley,

"In 1956 Shockley moved from New Jersey to Mountain View, California to start Shockley Semiconductor Laboratory to live closer to his ailing mother in Palo Alto, California. The company, a division of Beckman Instruments, Inc., was the first establishment working on silicon semiconductor devices in what came to be known as Silicon Valley.

"His way [of leading the group] could generally be summed up as domineering and increasingly paranoid. In one well-known incident, he claimed that a secretary's cut thumb was the result of a malicious act and he demanded lie detector tests to find the culprit, when in reality, the secretary had simply grabbed at a door handle that happened to have an exposed tack on it for the purpose of hanging paper notes on. After he received the Nobel Prize in 1956 his demeanor changed, as evidenced in his increasingly autocratic, erratic and hard-to-please management style. In late 1957, eight of Shockley's researchers, who would come to be known as the 'traitorous eight, resigned after Shockley decided not to continue research into silicon-based semiconductors. They went on to form Fairchild Semiconductor, a loss from which Shockley Semiconductor never recovered. Over the course of the next 20 years, more than 65 new enterprises would end up having employee connections back to Fairchild."

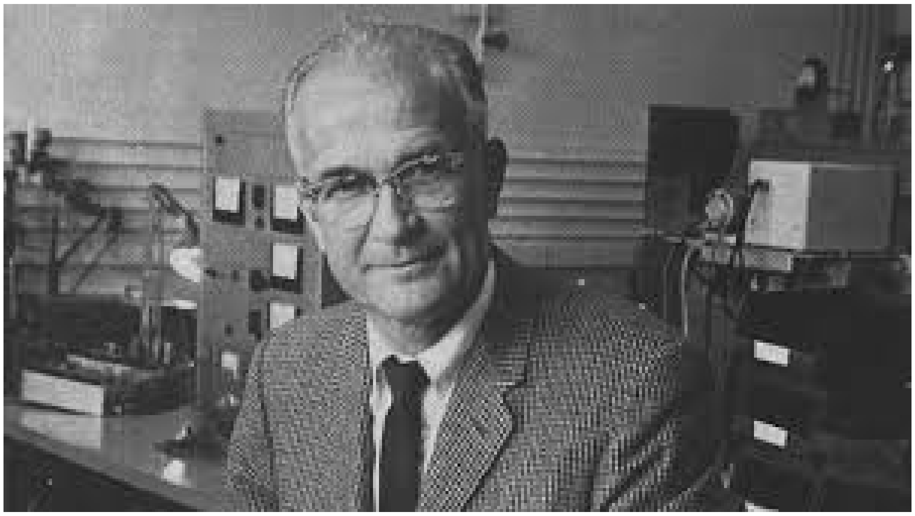

Figure 8.15: **William Shockley (1910-1989) shared the 1956 Nobel Prize in Physics with John Bardeen and Walter Brattain.**

Figure 8.16: **The Traitorous Eight: From left to right, Gordon Moore, C. Sheldon Roberts, Eugene Kleiner, Robert Noyce, Victor Grinich, Julius Blank, Jean Hoerni and Jay Last.**

8.9 Integrated circuits

In order to reduce the propagation time, computer designers tried to make the central processing units very small; and the result was the development of integrated circuits and microelectronics. (Another motive for miniaturization of electronics came from the requirements of space exploration.)

Integrated circuits were developed in which single circuit elements were not manufactured separately. Instead, the whole circuit was made at one time. An integrated circuit is a sandwich-like structure, with conducting, resisting and insulating layers interspersed with layers of germanium or silicon, "doped " with appropriate impurities. At the start of the manufacturing process, an engineer makes a large drawing of each layer. For example, the drawing of a conducting layer would contain pathways which fill the role played by wires in a conventional circuit, while the remainder of the layer would consist of areas destined to be etched away by acid.

The next step is to reduce the size of the drawing and to multiply it photographically. The pattern of the layer is thus repeated many times, like the design on a piece of wallpaper. The multiplied and reduced drawing is then focused through a reversed microscope onto the surface to be etched.

Successive layers are built up by evaporating or depositing thin films of the appropriate substances onto the surface of a silicon or germanium wafer. If the layer being made is to be conducting, the surface would consist of an extremely thin layer of copper, covered with a photosensitive layer called a "photoresist". On those portions of the surface receiving light from the pattern, the photoresist becomes insoluble, while on those areas not receiving light, the photoresist can be washed away.

The surface is then etched with acid, which removes the copper from those areas not protected by photoresist. Each successive layer of a wafer is made in this way, and finally the wafer is cut into tiny "chips", each of which corresponds to one unit of the wallpaper-like pattern.

Although the area of a chip may be much smaller than a square centimeter, the chip can contain an extremely complex circuit. A typical programmable minicomputer or "microprocessor", manufactured during the 1970's, could have 30,000 circuit elements, all of which were contained on a single chip. By 1986, more than a million transistors were being placed on a single chip.

As a result of miniaturization, the speed of computers rose steadily. In 1960, the fastest computers could perform a hundred thousand elementary operations in a second. By 1970, the fastest computers took less than a second to perform a million such operations. In 1987, a computer called GF11 was designed to perform 11 billion floating-point operations (flops) per second.

GF11 (Gigaflop 11) is a scientific parallel-processing machine constructed by IBM. Approximately ten floating-point operations are needed for each machine instruction. Thus GF11 runs at the rate of approximately a thousand million instructions per second (1,100 MIPS). The high speed achieved by parallel-processing machines results from dividing a job into many sub-jobs on which a large number of processing units can work simultaneously.

Computer memories have also undergone a remarkable development. In 1987, the magnetic disc memories being produced could store 20 million bits of information per square inch; and even higher densities could be achieved by optical storage devices. (A "bit" is the unit of information. For example, the number 25, written in the binary system, is 11001. To specify this 5-digit binary number requires 5 bits of information. To specify an n-digit binary number requires n bits of information. Eight bits make a "byte".)

In the 1970's and 1980's, computer networks were set up linking machines in various parts of the world. It became possible (for example) for a scientist in Europe to perform a calculation interactively on a computer in the United States just as though the distant machine were in the same room; and two or more computers could be linked for performing large calculations. It also became possible to exchange programs, data, letters and manuscripts very rapidly through the computer networks.

8.10 Moore's law

In 1965, only four years after the first integrated circuits had been produced, Dr. Gordon E. Moore, one of the founders of Intel, made a famous prediction which has come to be known as "Moore's Law". He predicted that the number of transistors per integrated circuit would double every two years, and that this trend would continue through 1975. In fact, the general trend predicted by Moore has continued for a much longer time. Although the number of transistors per unit area has not continued to double every two years, the logic density (bits per unit area) has done so, and thus a modified version of Moore's law still holds today. How much longer the trend can continue remains to be seen. Physical limits to miniaturization of transistors of the present type will soon be reached; but there is hope that further miniaturization can be achieved through "quantum dot" technology, molecular switches, and autoassembly.

A typical programmable minicomputer or "microprocessor", manufactured in the 1970's, could have 30,000 circuit elements, all of which were contained on a single chip. By 1989, more than a million transistors were being placed on a single chip; and by 2000, the number reached 42,000,000.

As a result of miniaturization and parallelization, the speed of computers rose exponentially. In 1960, the fastest computers could perform a hundred thousand elementary operations in a second. By 1970, the fastest computers took less than a second to perform a million such operations. In 1987, a massively parallel computer, with 566 parallel processors, called GFll was designed to perform 11 billion floating-point operations per second (flops). By 2002 the fastest computer performed 40 at teraflops, making use of 5120 parallel CPU's.

Computer disk storage has also undergone a remarkable development. In 1987, the magnetic disk storage being produced could store 20 million bits of information per square inch; and even higher densities could be achieved by optical storage devices. Storage density has until followed a law similar to Moore's law.

In the 1970's and 1980's, computer networks were set up linking machines in various

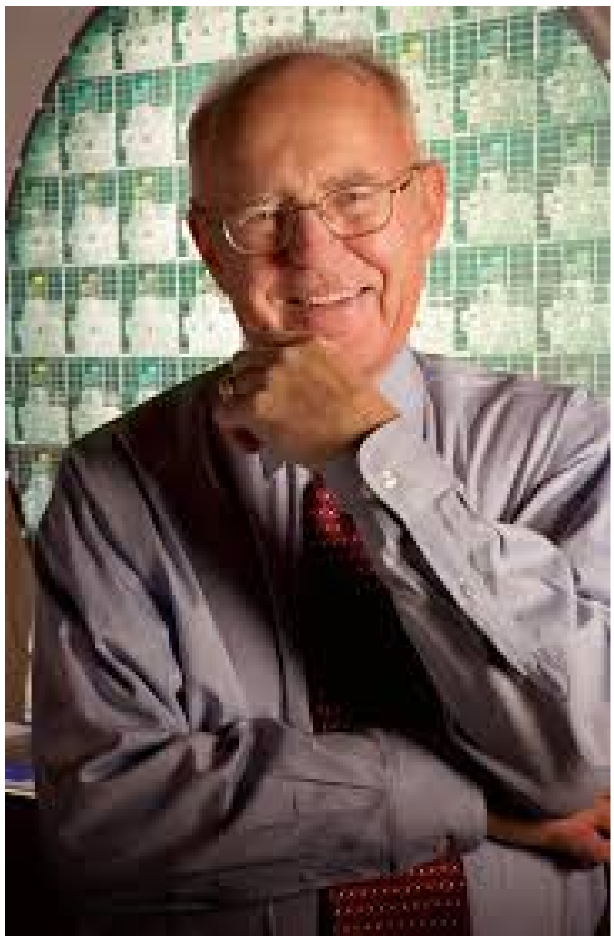

Figure 8.17: **Gordon E. Moore (born 1929), a founder of Intel and the author of Moore's Law. In 1965 he predicted that the number of components in integrated circuits would double every year for the next 10 years". In 1975 he predicted the this doubling would continue, but revised the doubling rate to "every two years. Astonishingly, Moore's Law has held much longer than he, or anyone else, anticipated.**

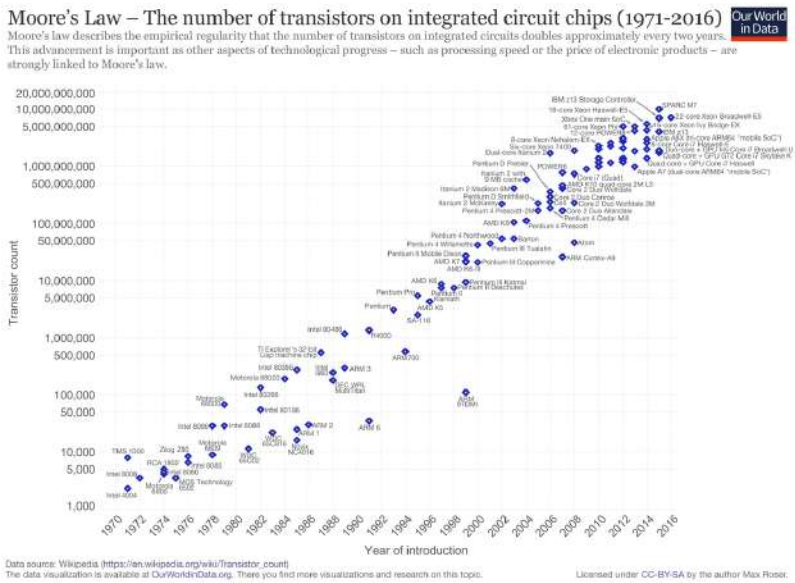

Figure 8.18: **Amazingly, Moore's Law has held much longer than he, or anyone else, anticipated. Perhaps quantum dot technologies can extend its validity even longer.**

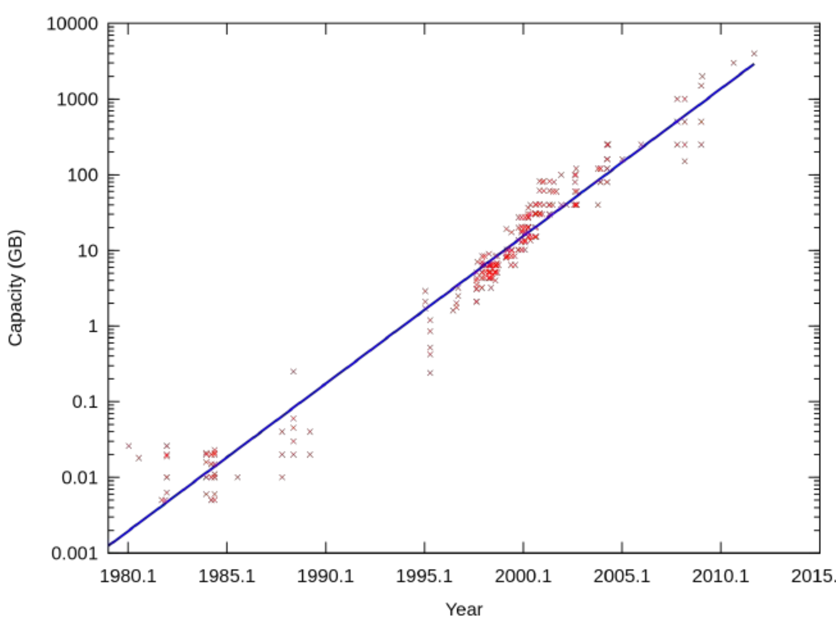

Figure 8.19: **A logarithmic plot of the increase in PC hard-drive capacity in gigabytes. An extrapolation of the rate of increase predicts that the individual capacity of a commercially available PC will reach 10,000 gigabytes by 2015, i.e. 10,000,000,000,000 bytes. (After Hankwang and Rentar, Wikimedia Commons)**

parts of the world. It became possible (for example) for a scientist in Europe to perform a calculation interactively on a computer in the United States just as though the distant machine were in the same room; and two or more computers could be linked for performing large calculations. It also became possible to exchange programs, data, letters and manuscripts very rapidly through the computer networks.

The exchange of large quantities of information through computer networks was made easier by the introduction of fiber optics cables. By 1986, 250,000 miles of such cables had been installed in the United States. If a ray of light, propagating in a medium with a large refractive index, strikes the surface of the medium at a grazing angle, then the ray undergoes total internal reflection. This phenomenon is utilized in fiber optics: A light signal can propagate through a long, hairlike glass fiber, following the bends of the fiber without losing intensity because of total internal reflection. However, before fiber optics could be used for information transmission over long distances, a technological breakthrough in glass manufacture was needed, since the clearest glass available in 1940 was opaque in lengths more than 10 m. Through studies of the microscopic properties of glasses, the problem of absorption was overcome. By 1987, devices were being manufactured commercially that were capable of transmitting information through fiber-optic cables at the rate of 1.7 billion bits per second.

8.11 Self-reinforcing information accumulation

Humans have been living on the earth for roughly two million years (more or less, depending on where one draws the line between our human and prehuman ancestors, Table 6.1). During almost all of this,time, our ancestors lived by hunting and food-gathering. They were not at all numerous, and did not stand out conspicuously from other animals. Then, suddenly, during the brief space of ten thousand years, our species exploded in numbers from a few million to seven billion, populating all parts of the earth, and even setting foot on the moon. This population explosion, which is still going on, has been the result of dramatic cultural changes. Genetically we are almost identical with our hunter-gatherer ancestors, who lived ten thousand years ago, but cultural evolution has changed our way of life beyond recognition.

Beginning with the development of speech, human cultural evolution began to accelerate. It started to move faster with the agricultural revolution, and faster still with the invention of writing and printing. Finally, modern science has accelerated the rate of social and cultural change to a completely unprecedented speed.

The growth of modern science is accelerating because knowledge feeds on itself. A new idea or a new development may lead to several other innovations, which can in turn start an avalanche of change. For example, the quantum theory of atomic structure led to the invention of transistors, which made high-speed digital computers possible. Computers have not only produced further developments in quantum theory; they have also revolutionized many other fields.

The self-reinforcing accumulation of knowledge - the information explosion - which characterizes modern human society is reflected not only in an explosively-growing global population, but also in the number of scientific articles published, which doubles roughly every ten years. Another example is Moore's law - the doubling of the information density of integrated circuits every two years. Yet another example is the explosive growth of Internet traffic shown in Table 17.1.

The Internet itself is the culmination of a trend towards increasing societal information exchange - the formation of a collective human consciousness. This collective consciousness preserves the observations of millions of eyes, the experiments of millions of hands, the thoughts of millions of brains; and it does not die when the individual dies.

8.12 Automation

During the last three decades, the cost of computing has decreased exponentially by between twenty and thirty percent per year. Meanwhile, the computer industry has grown exponentially by twenty percent per year (faster than any other industry). The astonishing speed of this development has been matched by the speed with which computers have become part of the fabric of science, engineering, industry, commerce, communications, transport, publishing, education and daily life in the industrialized parts of the world.

The speed, power and accuracy of computers has revolutionized many branches of science. For example, before the era of computers, the determination of a simple molecular structure by the analysis of X-ray diffraction data often took years of laborious calculation; and complicated structures were completely out of reach. In 1949, however, Dorothy Crowfoot Hodgkin used an electronic computer to work out the structure of penicillin from X-ray data. This was the first application of a computer to a biochemical problem; and it was followed by the analysis of progressively larger and more complex structures.

Proteins, DNA, and finally even the detailed structures of viruses were studied through the application of computers in crystallography. The enormous amount of data needed for such studies was gathered automatically by computer-controlled diffractometers; and the final results were stored in magnetic-tape data banks, available to users through computer networks.

The application of quantum theory to chemical problems is another field of science which owes its development to computers. When Erwin Schrödinger wrote down his wave equation in 1926, it became possible, in principle, to calculate most of the physical and chemical properties of matter. However, the solutions to the Schrödinger equation for many-particle systems can only be found approximately; and before the advent of computers, even approximate solutions could not be found, except for the simplest systems.

When high-speed electronic digital computers became widely available in the 1960's, it suddenly became possible to obtain solutions to the Schrödinger equation for systems of chemical and even biochemical interest. Quantum chemistry (pioneered by such men as J.C. Slater, R.S. Mullikin, D.R. Hartree, V. Fock, J.H. Van Vleck, L. Pauling, E.B. Wilson, P.O. Löwdin, E. Clementi, C.J. Ballhausen and others) developed into a rapidly-growing field, as did solid state physics. Through the use of computers, it became possible to design new materials with desired chemical, mechanical, electrical or magnetic properties. Applying computers to the analysis of reactive scattering experiments, D. Herschbach, J. Polanyi and Y. Lee were able to achieve an understanding of the dynamics of chemical reactions.

The successes of quantum chemistry led Albert Szent-Györgyi, A. and B. Pullman, H. Scheraga and others to pioneer the fields of quantum biochemistry and molecular dynamics. Computer programs for drug design were developed, as well as molecular-dynamics programs which allowed the conformations of proteins to be calculated from a knowledge of their amino acid sequences. Studies in quantum biochemistry have yielded insights into the mechanisms of enzyme action, photosynthesis, active transport of ions across membranes, and other biochemical processes.

In medicine, computers began to be used for monitoring the vital signs of critically ill patients, for organizing the information flow within hospitals, for storing patients' records, for literature searches, and even for differential diagnosis of diseases.

The University of Pennsylvania has developed a diagnostic program called INTERNIST-1, with a knowledge of 577 diseases and their interrelations, as well as 4,100 signs, symptoms and patient characteristics. This program was shown to perform almost as well as an academic physician in diagnosing difficult cases. QMR (Quick Medical Reference), a microcomputer adaptation of INTERNIST-1, incorporates the diagnostic functions of the earlier program, and also offers an electronic textbook mode.

Beginning in the 1960's, computers played an increasingly important role in engineering and industry. For example, in the 1960's, Rolls Royce Ltd. began to use computers not only to design the optimal shape of turbine blades for aircraft engines, but also to control the precision milling machines which made the blades. In this type of computer-assisted design and manufacture, no drawings were required. Furthermore, it became possible for an industry requiring a part from a subcontractor to send the machine-control instructions for its fabrication through the computer network to the subcontractor, instead of sending drawings of the part.

In addition to computer-controlled machine tools, robots were also introduced. They were often used for hazardous or monotonous jobs, such as spray-painting automobiles; and they could be programmed by going through the job once manually in the programming mode. By 1987, the population of robots in the United States was between 5,000 and 7,000, while in Japan, the Industrial Robot Association reported a robot population of 80,000.

Chemical industries began to use sophisticated computer programs to control and to optimize the operations of their plants. In such control systems, sensors reported current temperatures, pressures, flow rates, etc. to the computer, which then employed a mathematical model of the plant to calculate the adjustments needed to achieve optimum operating conditions.

Not only industry, but also commerce, felt the effects of computerization during the postwar period. Commerce is an information-intensive activity; and in fact some of the crucial steps in the development of information-handling technology developed because of the demands of commerce: The first writing evolved from records of commercial transactions kept on clay tablets in the Middle East; and automatic business machines, using punched cards, paved the way for the development of the first programmable computers.

Computerization has affected wholesaling, warehousing, retailing, banking, stockmarket transactions, transportation of goods - in fact, all aspects of commerce. In wholesaling, electronic data is exchanged between companies by means of computer networks, allowing order-processing to be handled automatically; and similarly, electronic data on prices is transmitted to buyers.

The key to automatic order-processing in wholesaling was standardization. In the United States, the Food Marketing Institute, the Grocery Manufacturers of America, and several other trade organizations, established the Uniform Communications System (UCS) for the grocery industry. This system specifies a standard format for data on products, prices and orders.

Automatic warehouse systems were designed as early as 1958. In such systems, the goods to be stored are placed on pallets (portable platforms), which are stacked automatically in aisles of storage cubicles. A computer records the position of each item for later automatic retrieval.

In retailing, just as in wholesaling, standardization proved to be the key requirement for automation. Items sold in supermarkets in most industrialized countries are now labeled with a standard system of machine-readable thick and thin bars known as the Universal Product Code (UPC). The left-hand digits of the code specify the manufacturer or packer of the item, while the right-hand set of digits specify the nature of the item. A final digit is included as a check, to make sure that the others were read correctly. This last digit (called a modulo check digit) is the smallest number which yields a multiple of ten when added to the sum of the previous digits.

When a customer goes through a check-out line, the clerk passes the purchased items over a laser beam and photocell, thus reading the UPC code into a small embedded computer or microprocessor at the checkout counter, which adds the items to the customer's bill. The microprocessor also sends the information to a central computer and inventory data base. When stocks of an item become low, the central computer generates a replacement order. The financial book-keeping for the retailing operation is also carried out automatically by the central computer.

In many places, a customer passing through the checkout counter of a supermarket is able to pay for his or her purchases by means of a plastic card with a magnetic, machine-readable identification number. The amount of the purchase is then transmitted through a computer network and deducted automatically from the customer's bank account. If the customer pays by check, the supermarket clerk may use a special terminal to determine whether a check written by the customer has ever "bounced".

Most checks are identified by a set of numbers written in the Magnetic-Ink Character Recognition (MICR) system. In 1958, standards for the MICR system were established, and by 1963, 85 percent of all checks written in the United States were identified by MICR numbers. By 1968, almost all banks had adopted this system; and thus the administration of checking accounts was automated, as well as the complicated process by which a check, deposited anywhere in the world, returns to the payers bank.

Container ships were introduced in the late 1950's, and since that time, container systems have increased cargo-handling speeds in ports by at least an order of magnitude. Computer networks contributed greatly to the growth of the container system of transportation by keeping track of the position, ownership and contents of the containers.

In transportation, just as in wholesaling and retailing, standardization proved to be a necessary requirement for automation. Containers of a standard size and shape could be loaded and unloaded at ports by specialized tractors and cranes which required only a very small staff of operators. Standard formats for computerized manifests, control documents, and documents for billing and payment, were instituted by the Transportation Data Coordinating Committee, a non-profit organization supported by dues from shipping firms.

In the industrialized parts of the world, almost every type of work has been made more efficient by computerization and automation. Even artists, musicians, architects and authors find themselves making increasing use of computers: Advanced computing systems, using specialized graphics chips, speed the work of architects and film animators. The author's traditional typewriter has been replaced by a word-processor, the composer's piano by a music synthesizer.

In the Industrial Revolution of the 18th and 19th centuries, muscles were replaced by machines. Computerization represents a Second Industrial Revolution: Machines have begun to perform not only tasks which once required human muscles, but also tasks which formerly required human intelligence.

In industrial societies, the mechanization of agriculture has very much reduced the fraction of the population living on farms. For example, in the United States, between 1820 and 1980, the fraction of workers engaged in agriculture fell from 72 percent to 3.1 percent. There are signs that computerization and automation will similarly reduce the number of workers needed in industry and commerce.

Computerization is so recent that, at present, we can only see the beginnings of its impact; but when the Second Industrial Revolution is complete, how will it affect society? When our children finish their education, will they face technological unemployment?

The initial stages of the First Industrial Revolution produced much suffering, because labor was regarded as a commodity to be bought and sold according to the laws of supply and demand, with almost no consideration for the needs of the workers. Will we repeat this mistake? Or will society learn from its earlier experience, and use the technology of automation to achieve widely-shared human happiness?

The Nobel-laureate economist, Wassily W. Leontief, has made the following comment on the problem of technological unemployment:

"Adam and Eve enjoyed, before they were expelled from Paradise, a high standard of living without working. After their expulsion, they and their successors were condemned to eke out a miserable existence, working from dawn to dusk. The history of technological progress over the last 200 years is essentially the story of the human species working its way slowly and steadily back into Paradise. What would happen, however, if we suddenly found ourselves in it? With all goods and services provided without work, no one would be gainfully employed. Being unemployed means receiving no wages. As a result, until appropriate new income policies were formulated to fit the changed technological conditions, everyone would starve in Paradise."

To say the same thing in a slightly different way: consider what will happen when a factory which now employs a thousand workers introduces microprocessor-controlled industrial robots and reduces its work force to only fifty. What will the nine hundred and fifty redundant workers do? They will not be able to find jobs elsewhere in industry, commerce or agriculture, because all over the economic landscape, the scene will be the same.

There will still be much socially useful work to be done - for example, taking care of elderly people, beautifying the cities, starting youth centers, planting forests, cleaning up pollution, building schools in developing countries, and so on. These socially beneficial goals are not commercially "profitable". They are rather the sort of projects which governments sometimes support if they have the funds for it. However, the money needed to usefully employ the nine hundred and fifty workers will not be in the hands of the government. It will be in the hands of the factory owner who has just automated his production line.

In order to make the economic system function again, either the factory owner will have to be persuaded to support socially beneficial but commercially unprofitable projects, or else an appreciable fraction of his profits will have to be transferred to the government, which will then be able to constructively re-employ the redundant workers.

The future problems of automation and technological unemployment may force us to rethink some of our economic ideas. It is possible that helping young people to make a smooth transition from education to secure jobs will become one of the important responsibilities of governments, even in countries whose economies are based on free enterprise. If such a change does take place in the future, while at the same time socialistic countries are adopting a few of the better features of free enterprise, then one can hope that the world will become less sharply divided by contrasting economic systems.

8.13 Neural networks

Physiologists have begun to make use of insights derived from computer design in their efforts to understand the mechanism of the brain; and computer designers are beginning to construct computers modeled after neural networks. We may soon see the development of computers capable of learning complex ideas, generalization, value judgements, artistic creativity, and much else that was once thought to be uniquely characteristic of the human mind. Efforts to design such computers will undoubtedly give us a better understanding of the way in which the brain performs its astonishing functions.

Much of our understanding of the nervous systems of higher animals is due to the Spanish microscopist, Ramón y Cajal, and to the English physiologists, Alan Hodgkin and Andrew Huxley. Cajal's work, which has been confirmed and elaborated by modern electron microscopy, showed that the central nervous system is a network of nerve cells (neurons) and threadlike fibers growing from them. Each neuron has many input fibers (dendrites), and one output fiber (the axon), which may have several branches.

S It is possible the computers of the future will have pattern-recognition and learning abilities derived from architecture inspired by our understanding of the synapse, by Young's model, or by other biological models. However, pattern recognition and learning can also be achieved by programming, using computers of conventional architecture. Programs already exist which allow computers to understand both handwriting and human speech; and a recent chess-playing program was able to learn by studying a large number of championship games. Having optimized its parameters by means of this learning experience, the chess-playing program was able to win against grand masters!

Like nuclear physics and genesplicing, artificial intelligence presents a challenge: Will society use its new powers wisely and humanely? The computer technology of the future can liberate us from dull and repetitive work, and allow us to use our energies creatively; or it can produce unemployment and misery, depending on how we organize our society. Which will we choose?

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Chapter 9

CINEMA AND TELEVISION

9.1 Cinema

The technology of films has a long history, and very many people contributed to its development. Here is a timeline showing some of the more important events:

1645	Athanasius Kircher publishes “Ars Magna Lucis et Umbrae”
1659	Christiaan Huygens invents the magic lantern with moving images
1664	T.R. Walgensten demonstrates the magic lantern in Paris
1670	Walgensten demonstrates magic lantern to Frederick III of Denmark
1709	German optician Themme makes moving magic lantern slides
1807	Multiple projectors and dissolving views
1823	Magic lanterns very widely used in education
1824	Peter Mark Roget describes persistence of vision
1833	Simon Stampler develops the Stroboscope
1861	Coleman Sellers II builds the Kinematoscope
1866	J. Beale: Choreotoscope using synchronized shutter action
1868	Simple and convenient flip book patented
1878	Eadweard Muybridge: moving picture sequence of a running horse
1882	Étienne-Jules Marey invents the chronophotographic gun
1887	Louis Le Prince develops first motion picture camera
1889	William Friese-Greene uses celluloid film for motion pictures
1891	W.K.L. Dickson in Thomas Edison’s lab. develops 35 mm. film technique

Wikipedia states that “In or before 1659 the magic lantern was developed by Christiaan Huygens. It projected slides that were usually painted in color on glass. A 1659 sketch by Huygens indicates that moving images may have been part of the earliest screenings. Around 1790 multi-media phantasmagoria spectacles were developed. Rear projection, animated slides, multiple projectors (superimposition), mobile projectors (on tracks or hand-held), projection on smoke, sounds, odors and even electric shocks were used to frighten

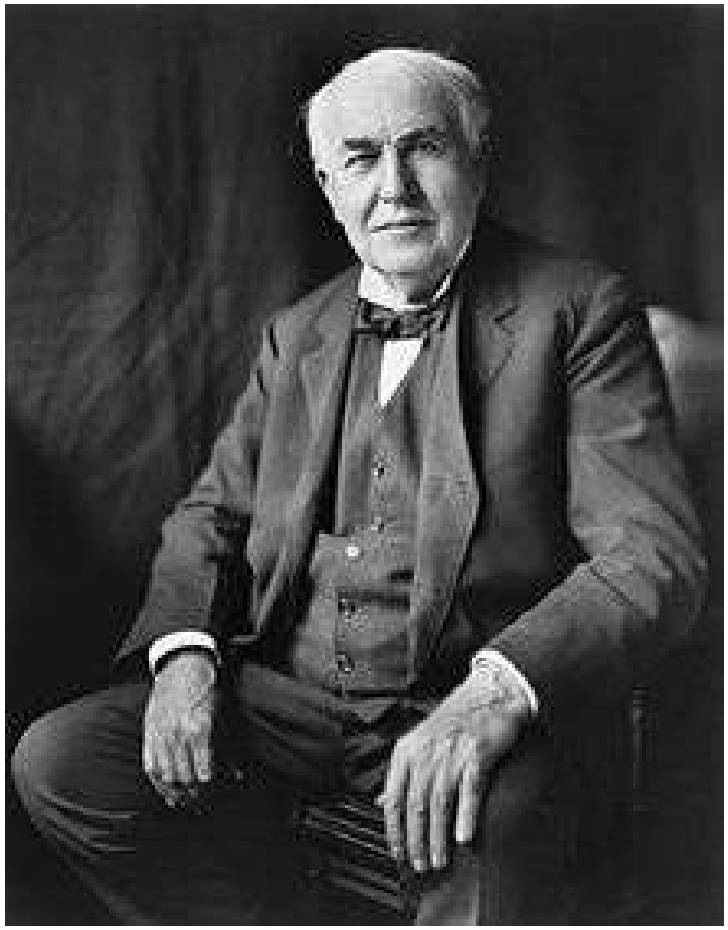

Figure 9.1: **Thomas Alva Edison (1837-1931).**

audiences with a convincing ghost horror experience. In the 19th century several other popular magic lantern techniques were developed, including dissolving views and several types of mechanical slides that created dazzling abstract effects (chromatrope, et cetera) or that showed for instance falling snow or the planets and their moons revolving..."

"[Thomas] Edison was... granted a patent for the motion picture camera or 'Kinetograph'. He did the electromechanical design while his employee W. K. L. Dickson, a photographer, worked on the photographic and optical development. Much of the credit for the invention belongs to Dickson. In 1891, Thomas Edison built a Kinetoscope or peep-hole viewer. This device was installed in penny arcades, where people could watch short, simple films. The kinetograph and kinetoscope were both first publicly exhibited May 20, 1891."

"Edison's film studio made close to 1,200 films. The majority of the productions were short films showing everything from acrobats to parades to fire calls including titles such as Fred Ott's Sneeze (1894), The Kiss (1896), The Great Train Robbery (1903), Alice's Adventures in Wonderland (1910), and the first Frankenstein film in 1910."

9.2 The invention of television

A television timeline

1843	Alexander Bain introduces the facsimile machine
1851	Frederick Bakewell demonstrates a working facsimile machine
1856	Giovanni Caselli: first practical facsimile system, working on telegraph lines
1873	Willoughby Smith discovers the photoconductivity of the element selenium
1884	Paul Julius Gottlieb Nipkow proposes and patents the Nipkow disc
1900	Constantin Perskyi coins the word “television” at the Paris World’s Fair
1907	Lee de Forest and Arthur Korn develop amplification tube technology
1909	Georges Rignoux and A. Fournier: first instantaneous transmission of images
1911	Boris Rosing and Vladimir Zworykin: mechanical mirror-drum transmitter
1913	Charles Francis Jenkins publishes article on “Motion Pictures by Wireless”
1922	First commercial cathode ray tube developed by Western Electric
1923	Vladimir Zworykin experiments with cathode ray tube TV at Western Electric
1925	Kenjiro Takayanagi demonstrates a television system using Nipkow disk
1925	Lèon Theremin develops mirror drum-based television in Soviet Union
1925	John Logie Baird uses the Nipkow disk in his prototype video systems
1926	Hungarian Kálmán Tihanyi designs fully electronic television system
1926	Kenjiro Takayanagi demonstrates a fully electronic television receiver
1927	Baird transmits signal over telephone lines between London and Glasgow
1927	H.E. Ives and F. Gray of Bell Labs: moving images and synchronized sound
1927	Philo Farnsworths image dissector camera tube transmits its first image
1928	World’s first television station opens in Schenectady, NY.
1928	Baird’s company broadcasts first transatlantic television signal
1928	Baird demonstrates first color television
1928	Farnsworth’s first electronic television demonstration
1829	Vladimir Zworykin demonstrates electronic television
1931	Baird makes first outdoor broadcast, showing the Derby
1936	Baird’s system reaches peak of 240 lines resolution on BBC broadcasts

Television has a long history and many people contributed to its development. A timeline is shown above. In the end fully electronic television proved to be greatly superior to mechanical systems that preceded it.

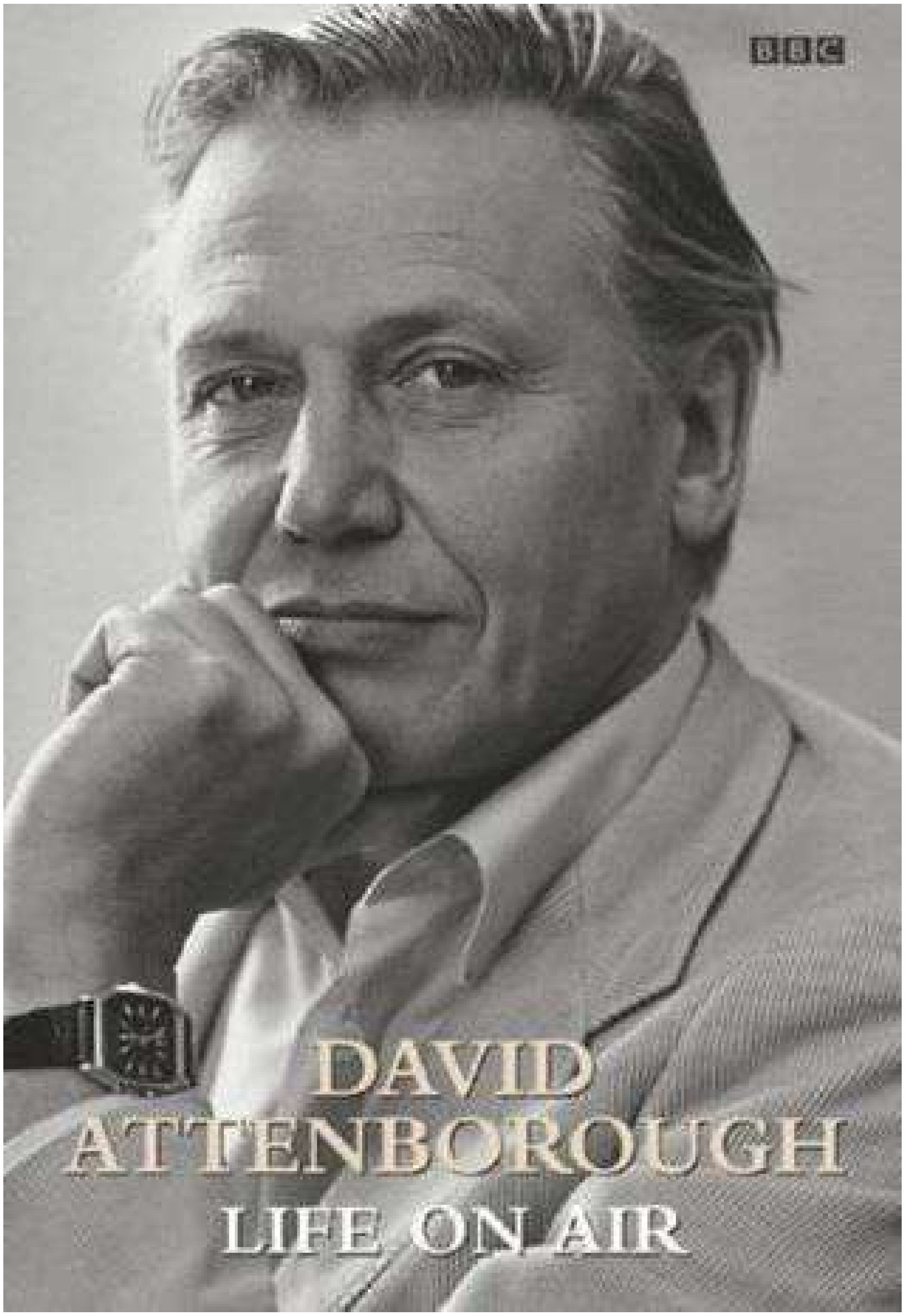

Figure 9.2: **Sir David Attenborough's highly entertaining autobiographical book about his career at the BBC can be read as a history of the development of television.**

Figure 9.3: **The Scottish inventor John Logie Baird (1888-1946).**

Figure 9.4: **Watching a homemade mechanical-scan television receiver in 1928.**

Figure 9.5: **A stamp commemorating Philo T. Farnsworth (1906-1971). The key ideas for electronic television came to him while he was still a schoolboy. Although his demonstration of electronic television came a year before Zworykin's, a patent war developed between them.**

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Chapter 10

AVIATION AND SPACE EXPLORATION

10.1 Aviation history

Wikipedia's timeline of aviation

- **c. 1700 BC Greek myth of Icarus and Daedalus explores the desire to fly and the inherent dangers of it.**
- **c. 1000 BC Flying machines called Vimanas are mentioned in the Vedas with detailed description of its working.[citation needed] Recreation of the technology has not been possible due to lack of materials (like mentioned fuel) are not found.[citation needed]**
- **c. 850 BC Legendary King Bladud attempts to fly over the city of Trinavantum, but falls to his death**
- **c. 500 BC The Chinese start to use kites.**
- **c. 400 BC The Chinese invent an early form of the Bamboo-copter using feathers. The Greek mathematician Archytas of Tarentum demonstrates an artificial pigeon on a wire. It may have been a kite.**
- **c. 200 BC The Chinese invent the sky lantern, the first hot air balloon: from its military use it became known as the Kongming lantern.**
- **c. 100 AD When Wang Mang tried to recruit a specialist scout to Xiong Nu, a man binding himself with bird feathers glides about 100 meters.**
- **c. 559 Yuan Huangtou, Ye, first manned kite glide to take off from a tower.**
- **c. 875 According to the 17th-century historian Ahmed Mohammed al-Maqqari, Abbas Ibn Firnas of the Emirate of Córdoba made an unsuccessful attempt at flight.**
- **c. 1003 Jauhari attempts flight by some apparatus from the roof of a mosque in Nishapur, Khorasan, Iran, and falls to his death as a result.**

- **c. 1010 Eilmer of Malmesbury builds a wooden glider and, launching from a bell tower, glides 200 metres.**
- **c. 1165 During a lavish display of the wonders of the Byzantine Empire by Emperor Manuel I Komnenos in the Hippodrome of Constantinople, a "Turk" attempts to fly by jumping off of one of the central pillars with some form of winged construct, plummeting to his death.**
- **c. 1241 The Mongolian army uses lighted kites in the battle of Legnica.**
- **c. 1250 Roger Bacon writes the first known technical description of flight, describing an ornithopter design in his book Secrets of Art and Nature.**
- **c. 1485 - c. 1513 Leonardo da Vinci designs an ornithopter with control surfaces. He envisions and sketches flying machines such as helicopters and parachutes, and notes studies of airflows and streamlined shapes.**
- **c. 1500 Hieronymus Bosch shows in his triptych The temptation of St. Anthony, among other things, two fighting airships above a burning town.**
- **c. 1558 Giambattista della Porta publishes a theory and a construction manual for a kite.**
- **1595 Fausto Veranzino illustrates a design for a parachute in his book Machinae novae (New machines). His "homo volans" (Flying man) design is based on the sail of a ship.**
- **1630 Evliya Celebi reports that Hezarfen Ahmet Celebi glided with artificial wings from the top of Galata Tower in Istanbul and managed to fly over the Bosphorus, landing successfully on the Dogancilar square in Üsküdar.**
- **1633 Evliya Celebi reports that Lagari Hasan Celebi flew himself in a rocket artificially-powered by gunpowder.**
- **1638 John Wilkins, Bishop of Chester, suggests some ideas to future would-be pilots in his book The Discovery of a World in the Moon.**
- **1644 Italian physicist Evangelista Torricelli manages to demonstrate atmospheric pressure, and also produces a vacuum.**
- **1654 Physicist and mayor of Magdeburg, Otto von Guericke measures the weight of air and demonstrates his famous Magdeburger Halbkugeln (hemispheres of Magdeburg).Sixteen horses are unable to pull apart two completely airless hemispheres which stick to each other only because of the external air pressure.**
- **1670 Jesuit Father Francesco Lana de Terzi describes in his treatise Prodomo a vacuum-airship-project, considered the first realistic, technical plan for an airship. His design is for an aircraft with a boat-like body equipped with a sail, suspended under four globes made of thin copper; he believes the craft would rise into the sky if air was pumped out of the globes. No example is built, and de Terzi writes: God will never allow that such a machine be built... because everybody realises that no city would be safe from raids...**

- 1679 Italian physicist Giovanni Alfonso Borelli, the father of biomechanics, shows in his treatise On the movements of animals that the flapping of wings with the muscle power of the human arm cannot successfully produce flight.
- 1687 Isaac Newton (1642-1727) publishes his Philosophiae Naturalis Principia Mathematica, the basis of classical physics. In book II he presented the theoretical derivation of the essence of the drag equation.
- 1782 December 14, The Montgolfier brothers first test fly an unmanned hot air balloon in France; it floats nearly 2 km (1.2 mi).
- 1783 June 4, Unmanned flight of the Montgolfier brothers 900 m linen Montgolfiere hot air balloon at Annonay near Lyon in the Vivarais region of France as a public demonstration. The flight covers 2 km and lasts 10 minutes, to an estimated altitude of 1600-2000 metres. August 27, Flight of Le Globe, an unmanned experimental hydrogen-balloon, in Paris (built by Professor Charles and the Robert brothers). It flies 25 km (16 mi) from Paris to Gonesse and is destroyed by frightened peasants. September 19, the Montgolfiers launch a sheep, duck and rooster in a hot-air balloon in a demonstration for King Louis XVI of France. The balloon rises some 500 m (1,700 ft) and returns the animals unharmed to the ground. October 15, Pilatre de Rozier and Marquis d'Arlandes rise into the air in a MontgolfiÃ¨re tethered to the ground in Paris. de Rozier becomes the first human passenger in a hot-air balloon, rising 26 m (84 ft). November 21, In a flight lasting 25 minutes, de Rozier and d'Arlandes take the first untethered ride in a Montgolfiere in Paris, the first human passengers carried in free flight by a hot-air balloon. December 1, Jacques Charles and his assistant Nicolas-Louis Robert make the first flight in a hydrogen-filled balloon, La Charlière. They travel from Paris to Nesles-la-VallÃ©e, a distance of 43 km (27 mi). On his second flight the same day, Charles reaches an altitude of about 3,000 meters (9,842 feet) over Nesles-la-VallÃ©e. December 26, Louis-Sébastien Lenormand makes the first ever recorded public demonstration of a parachute descent by jumping from the tower of the Montpellier observatory in France using his rigid-framed model which he intends as a form of fire escape.
- 1784 February 25, The first ascent of a manned balloon in Italy takes place with a hot air balloon carrying Paolo Andreani and two of its builders, the Gerli brothers. March 2, Jean-Pierre Blanchard makes his first flight in a hydrogen balloon. March 13 The first public ascent of a manned balloon in Italy takes place with a hot air balloon at the Villa Sormani in Moncucco carrying Paolo Andreani and two locals. April 15, The first ascent of a manned balloon in the British Isles takes place with a hot air balloon at Navan in Ireland. June 4, Elizabeth Thible becomes the first woman passenger in a hot air balloon, at Lyon in France. August 25 & 27, Scottish apothecary James Tytler makes the first balloon ascents in Great Britain,

in a hot air balloon from Edinburgh. September 15, Italian Vincenzo Lunardi makes the first hydrogen balloon flight in Britain, from Moorfields in London to South Mimms. September 19, Anne-Jean Robert, Nicolas-Louis Robert and Colin Hullin fly La Carolina, a hydrogen balloon, 186 km (115.5 miles) from Paris to Beuvry. October 4, Englishman James Sadler makes the first hot air balloon flight in England, from Oxford to Woodeaton. October 16, Jean-Pierre Blanchard fits a hand-powered propeller to a balloon flow from London, the first recorded means of propulsion carried aloft. Pilatre de Rozier and the chemist Proust rise with a Montgolfière up to 4,000 meters (13,123 feet). Jean Baptiste Meusnier makes an oblong balloon to explore unknown areas, with an airscrew driven by muscle power.

- 1785 January 7, Jean-Pierre Blanchard makes the first flight across the English Channel. He uses a hydrogen balloon and carries John Jeffries as a passenger, flying from Dover, England, to GuÃ®nes, France. January 19, Richard Crosbie successfully flies in a hot air balloon from Ranelagh Gardens to Clontarf, Dublin, Ireland. He goes on to makes several unsuccessful attempts to cross the Irish Sea in a hydrogen-filled balloon. May 10, A hot air balloon collides with a chimney in Tullamore in Ireland, setting light to around 100 houses in the town centre. June 15, Pilatre de Rozier and Pierre Jules Romain become the first known aeronautical fatalities when their balloon crashes during an attempt to cross the English Channel. October 5, Vincenzo Lunardi flies in a gas balloon from George Heriot's School, Edinburgh, across the Firth of Forth in Scotland to Ceres, Fife (51.5 km (32 mi) in 1.5 hrs). November 23, Lunardi flies from St Andrew's Square, Glasgow, to Hawick in Scotland. Ukita Kökichi, Japanese paperhanger, makes artificial wings and tries flying from the top of a bridge.
- 1789 First experiments in Japan to develop an ornithopter-type glider.
- 1793 Military use of a captive balloon at the siege of Mainz, Germany. January 9, Jean-Pierre Blanchard makes probably the first balloon ascent in the Western Hemisphere, lifting off from the prison yard at the Walnut Street Jail in Philadelphia, Pennsylvania, crossing the Delaware River and landing at Deptford, New Jersey, carrying an "aerial passport" endorsed by President George Washington. Washington, John Adams, Thomas Jefferson, James Madison and James Monroe all witness the flight. May 15, inventor Diego MarÃn Aguilera, the "father of aviation" in Spain, flies a glider for about 360 m (1,180 ft). July 30, Jean-Marie-Joseph Coutelle, Louis-Bernard Guyton de Morveau and Antoine-Laurent de Lavoisier complete a military hydrogen balloon ordered by the French Committee of Public Safety. They will present it to the committee in October 1793. November 24, French authorities order Nicolas J. Conte to construct a military balloon capable of lifting two passengers to an

altitude of 1,700 feet (518 meters).

- **1794 April 2, The French National Convention establishes the 50-man Company of Aeronauts, the first airship company in the French Army. It is commanded by Captain Jean-Marie-Joseph Coutelle. May 3, After completing its training, the Company of Aeronauts is assigned to the French Army of Sambre-et-Meuse for operational employment. June 2, The first military aviation sortie in history takes place when the French Company of Aeronauts' balloon l'Entreprenant ("Enterprise") ascends for a reconnaissance of Austrian forces besieging Maubeuge. Austrian artillery fires at the balloon but fails to hit it before it rises out of range. June 23, The French balloon l'Entreprenant resumes flights, helping to prevent Austrian troops from relieving besieged Austrian forces at Charleroi. On the same day, the Committee of Public Safety authorizes the formation of a second balloon company in the French Army. June 26, Jean-Marie-Joseph Coutelle and Major General Antoine Morlot spend nine hours aloft in the balloon l'Entreprenant during the Battle of Fleurus, providing observation that contributes to a French victory over Austrian forces. It is the first battle in history to be affected by aerial observation.**
- **1795 October 29, Observation balloons used in Battle of Mainz.**
- **1797 October 22, André-Jacques Garnerin jumps from a balloon from 975 meters (3,200 feet) over Parc Monceau in Paris in a 7-meter- (23-foot-) diameter parachute made of white canvas with a basket attached. He is declared "official French aeronaut of the state".**
- **1798 At least one balloon of the French army's Company of Aeronauts is transported aboard the French Navy warship Le Patriote for use ashore in conducting a reconnaissance of the coast of Egypt, but Le Patriote strikes a rock and sinks off Alexandria, Egypt, on July 4. August 1 - The French ship-of-the-line Orient has gear of the French Army's Company of Aeronauts on board when she is destroyed during the Battle of the Nile.**
- **1799 Englishman Sir George Cayley (1773-1857) sketches a glider with a rudder unit and an elevator unit. His manuscript is considered to be the starting point of the scientific research on heavier than air flying machines. It is Cayley who helps to sort out the confusion of the time. ..."He knew more than any of his predecessors... and successors up to the end of the 19th century." - Orville Wright. Even so, his ideas do not affect further development very much. January 15, The French Army's Company of Aeronauts is abolished. October 12, Jeanne Geneviève Labrosse becomes the first woman to jump from a balloon with a parachute, from an altitude of 900 m.**
- **1802 5 July - André-Jacques Garnerin and Edward Hawke Locker make a 17-mile (27 km) balloon flight from Lord's Cricket Ground in St John's Wood, London, England, to Chingford in just over 15 minutes. 2 December - A manned illuminated balloon is launched from the front of Notre**

Dame de Paris during the Coronation of Napoleon I.

- **1803 British Rear Admiral Charles Knowles proposes to the Admiralty that the Royal Navy loft an observation balloon from a ship in order to reconnoitre French preparations for the invasion of Britain in Brest. The proposal is ignored. 18 July - Etienne Gaspar Robertson and his copilot Lhoest ascend from Hamburg, Germany, to an altitude of around 7,300 m (24,000 ft) in a balloon. 3-4 October - André-Jacques Garnerin covers a distance of 395 km (245 mi) from Paris, France, to Clausen, Germany. 7-8 October - Francesco Zambeccari and Pasquale Andreoli make a balloon flight which crashes into the Adriatic Sea.**
- **1804 Sir George Cayley builds a model glider with a main wing and separate, adjustable vertical and horizontal tail surfaces. August/September - The scientists Joseph Louis Gay-Lussac and Jean Baptiste Biot use a balloon to conduct experiments on the earth's magnetic field and the composition of the upper atmosphere. 23 August - Francesco Zambeccari and Pasquale Andreoli make a second balloon flight which crashes into the Adriatic Sea.**
- **1806 Lord Cochrane flies kites from the Royal Navy 32-gun frigate HMS Pallas to spread propaganda leaflets along the coast of France. It is the first use of an aerial device in European maritime warfare.**
- **1807 Jakob Degen, a clockmaker from Vienna, experiments with an ornithopter with flap-valve wings.**
- **1809 Degen propels a hydrogen-filled balloon by flapping large ornithopter-style wings. September - Sir George Cayley publishes the first part of his seminal paper On Aerial Navigation, setting out for the first time the scientific principles of heavier-than-air flight.**
- **1810 September - Frenchwoman Sophie Blanchard makes a flight starting from Frankfurt, making her the first woman to fly in a balloon in Germany. Chemist Johann Gottfried Reichard makes his first flight in a self-constructed gas balloon from Berlin, making him the second person to fly in a gas balloon in Germany.[8]**
- **1811 16 April - Wilhelmine Reichard makes her first solo flight, starting in Berlin, making her the first native German woman to fly in a balloon. 31 May - Albrecht Berblinger crashes a hang glider (possibly a copy of Degen's[citation needed]) into the Danube. A reproduction built according to the design drawing in 1986 is capable of flight.**

  Harris jumps from his balloon to save his fiancÃ©e. Illustration from the late 19th Century.
- **1812 21 September - Francesco Zambeccari dies when his balloon catches fire on landing.**
- **1819 6 July - Sophie Blanchard launches fireworks from her balloon in flight during an exhibition at the Tivoli Gardens in Paris. The fireworks**

ignite the gas in the balloon, which crashes on the roof of a house. She falls to her death, becoming the first woman to die in an aviation accident.

- **1824 Englishman Thomas Harris dies when his balloon crashes near Carshalton. His female passenger survives. The exact cause is not determined but is apparently due to a valve Harris has designed to release gas from the balloon becoming stuck open. Despite dropping all ballast Harris is unable to stop a precipitous plunge.**
- **1836 7-8 November - Flight of a coal gas balloon (named The Great Balloon of Nassau) by Charles Green covering 722 km (449 mi) from London to Weilburg, Germany, in 18 hours with passengers Robert Hollond and Thomas Monck Mason.[12] It is the first overnight balloon flight, and it sets a world ballooning distance record that will stand until 1907.**
- **1837 Robert Cocking jumps from a balloon piloted by Charles Green at a height of 2,000 m (6,600 ft) to demonstrate a parachute of his own design, and is killed in the attempt.**
- **1838 4 September - Charles Green, George Rush, and Edward Spencer ascend to an altitude of 19,335 feet (5,893 meters) over England in the Great Balloon of Nassau before landing at Thaxted. 10 September - Green and Rush ascend to a world record altitude of 27,146 feet (8,274 meters) over England in the Great Balloon of Nassau, reaching speeds of 80 to 100 mph (130 to 160 km/h) during the flight.**
- **1839 The American John Wise introduces the ripping panel which is still used today. The panel solved the problem of the balloon dragging along the ground at landing and needing to be stopped with the help of anchors. Charles Green and the astronomer Spencer Rush ascend to 7,900 m (25,900 ft) in a free balloon. Francisque Arban is rescued by Italian fishermen.**
- **1840 Louis Anslem Lauriat makes the first manned flight in Canada, at Saint John, New Brunswick, in his balloon Star of the East.**
- **1841 An ironsmith kalfa (journeyman) named Manojlo who "came to Belgrade from Vojvodina" attempts to fly an ornithopter. Forbidden to take off from the belfry of St. Michael's Cathedral by the authorities, he clandestinely climbs to the rooftop of the Import Tax Head Office and jumps off, landing in a heap of snow and surviving.**
- **1842 November - English engineer William Samuel Henson makes the first complete drawing of a power-driven aeroplane with steam-engine drive. The patent follows the works of Cayley. The English House of Commons rejects the motion for the formation of an "Aerial Transport Company" with great laughter.**
- **1843 William Samuel Henson and John Stringfellow file articles of incorporation for the world's first air transport company, the Aerial Transit Company**

- **1845 William Samuel Henson and John Stringfellow build a steam-powered model aircraft, with a wingspan of 10 ft (3.0 m).**
- **1846 French balloonist Francisque Arban makes his twelfth flight from Rome in April, and is rescued from the sea after a flight from Trieste later in the year.**
- **1848 John Stringfellow flies a powered monoplane model a few dozen feet in a powered glide at an exhibition at Cremorne Gardens in London.**
- **1849 12-25 July - While blockading Venice, the Austrians launch unmanned incendiary balloons equipped with explosive charges from land and as well as from the steamship SMS Vulcano in an attempt to bombard Venice. Although the experiment is mostly unsuccessful, it is both the first use of balloons for bombardment and the first time a warship makes offensive use of an aerial device. 2-3 September - French balloonist Francisque Arban makes the first (and until 1924 only) balloon flight over the Alps, flying a hydrogen balloon from Marseille to Turin. 7 October - Francisque Arban takes off from Barcelona, but his balloon is blown over the Mediterranean Sea and is lost. Sir George Cayley launches a 10-year-old boy in a small glider being towed by a team of people running down a hill. This is the first known flight by a person in a heavier-than-air machine.**
- **1852 24 September - French engineer Henri Giffard flies 27 km (17 mi) from the Paris Hippodrome to Trappes in a steam-powered dirigible, reaching a speed of about 10 km/h (6.2 mph).**
- **1853 Late June or early July - Sir George Cayley's coachman successfully flies a glider, designed by his employer, some proportion of the distance across Brompton Dale in Yorkshire, becoming the world's first adult aeroplane pilot. Unimpressed with this honour, the coachman promptly resigns his employment.**
- **1856 December - French Captain Jean Marie Le Bris is towed into the air in his Artificial Albatross glider, flying 600 ft (180 m).**
- **1857 Félix Du Temple flies clockwork and steam-powered model aircraft, the first sustained powered flights by heavier-than-air machines. French brothers du Temple de la Croix apply after successful attempts with models for a patent for a power-driven aeroplane.**
- **1858 John Wise and three companions complete a Montgolfière flight over a distance of 802 miles (1,291 km), (St. Louis - Henderson, USA). French airman Nadar takes the first aerial photographs.**
- **1860 13 October - Ascending in Samuel Archer King's balloon The Queen of the Air, James Wallace Black takes eight photographs of Boston, Massachusetts, from an altitude of 1,200 ft (370 m). The single clear print is the first successful aerial photograph in the United States and the first clear aerial photograph of a city ever taken anywhere.**

- **1861 The first use of observation balloons in naval warfare takes place during the American Civil War (1861-1865). The United States Navy barge George Washington Parke Custis becomes the first ship configured to conduct air operations, transporting and towing observation balloons along the Potomac River. She continues these operations into early 1862. 16 June - Floating 500 ft (150 m) above the National Mall in Washington, D.C., the balloon Enterprise with a telegraph key wired directly to the White House, Thaddeus Lowe sends a telegram to President Abraham Lincoln to demonstrate the value of balloons in military reconnaissance. It is the first telegram to be sent from the air. The Union Army Balloon Corps will be formed under Lowe's command, for observation and artillery direction, and balloons will see major use in the American Civil War over the next four years. 3 August - The United States Army steamship Fanny becomes the first ship to loft a captive manned balloon when a civilian aeronaut, John La Mountain, ascends from her deck to observe Confederate military positions at Hampton Roads, Virginia. He ascends again a few days later either from Fanny or a ship named Adriatic.**
- **1862 With the permission of the British War Office, British Army Captain F. Beaumont and Lieutenant George Grover perform observation balloon trials at Aldershot, assisted by the civilian aeronaut Henry Tracey Coxwell. It is the first balloon experiment in the British armed forces, although the first official experimentation will not occur until 1878. Late March - Civilian aeronaut John H. Steiner takes United States Navy officers aloft in an observation balloon from the deck of a flatboat on the Mississippi River so that they can direct the fire of U.S. Navy mortar boats against the Confederate-held Island Number Ten It will be the last aerial guidance of naval gunfire anywhere in the world until 1904. March-May - The George Washington Parke Custis transports and tows observation balloons along the York River in Virginia during the Peninsula Campaign. April - John B. Starkweather ascends several times in a balloon from the deck of the Union paddle steamer May Flower to observe Confederate positions at Port Royal, South Carolina. June - The Confederate States Navy chooses the steamer CSS Teaser to embark a balloon for use in observation of Union Army positions along the James River in Virginia. 1-3 July - The Confederate States Navy steamer Teaser operates a coal-gas silk observation balloon to reconnoitre Union Army positions along the James River in Virginia, the only use of a balloon by the Confederate States Navy. Her capture on 4 July by the steamer USS Maratanza ends Confederate naval balloon operations. 5 September - Aeronaut Henry Tracey Coxwell and English physicist James Glaisher officially reach a height of 29,527 ft (9,000 m) in a coal gas balloon according to their balloon's barometer,[33] although later estimates place the maximum altitude they attained at between 35,000 and 37,000 feet**

(11,000 and 11,000 meters). The two men nearly die of hypoxia during the flight, Glaisher falling unconscious and Coxwell losing all feeling in his hands.

- 1863 The Union Army Balloon Corps is disbanded early in the year.[32] Dirigible airship flown by Solomon Andrews over Perth Amboy, New Jersey. John H. Steiner takes Ferdinand von Zeppelin, an officer from the Army of WÃ¼rttemberg assigned to the Union Army as an observer, aloft in a balloon. Zeppelin later will credit this ascent as his inspiration to create the rigid airship, which he first flies in 1900.
- 1864 Outbreak of the Paraguayan War between the Alliance of Argentina, Brazil and Uruguay against Paraguay. The Alliance forces made much use of balloon reconnaissance over the next six years. English philosopher-scientist Matthew Piers Watt Boulton of the UK writes his short paper, On Aerial Locomotion, detailing several inventions, including that of the aileron almost as an afterthought (he later patents them in 1868). Boulton's inspiration has been attributed to French Count Ferdinand Charles Honore Phillipe d'Esterno, whose detailed analysis of flapping and soaring bird flight, Du Vol des Oiseaux (On the flight of birds) was published as a pamphlet in 1864.
- 1865 Solomon Andrews flies a dirigible twice over New York City. German experimenter Paul Haenlein takes out a patent for the ”Earliest Known Airship With a Semi-rigid Frame,” envisioned to have a coal-gas-burning engine which draws its fuel from the craft's envelope, which is filled with coal gas. He later will construct the craft in Germany.[35] Jules Verne describes in his novel The Journey to the Moon the launch of a rocket from Florida, from which many years later American space flights actually will start. The Frenchman Le Comte Ferdinand Charles Honore Phillipe d'Esterno writes in his book About the Flight of Birds, “Gliding seems to be characteristic for heavy birds; there are no odds which are stacked against that humans can not do the same at fair wind.” He had earlier published the 1864 pamphlet Du Vol des Oiseaux (On the flight of birds). French artist and farmer Louis Pierre Mouillard makes a tentative gliding flight. After years of studies of bird flight he publishes his book L'Empire de l'Air in 1881. He thinks that imitation of gliding and soaring flight of birds is possible, but not the imitation of the flapping of wings. 20 September - Jacob Brodbeck, in his coil-spring-driven airship, flies 100 feet before crashing in a field near Luckenbach, Texas, USA.
- 1866 First South American military balloon reconnaissance ascent. On 6 July, Lieutenant Colonel Roberto A. Chodasiewicz, an Argentine Army military engineer, makes the first South American military observation ascent, manning a Brazilian Army's captive ballon over Paraguayan troops, during the Paraguayan War. Foundation (12 January in London) of the Aeronautical Society of Great Britain later to become the Royal Aero-

nautical Society, the world's oldest society devoted to all aspects of aeronautics and astronautics. Francis Herbert Wenham, British, presents his paper on "Aerial Locomotion" to the RAeS. Patented superposed wing design (biplane, multiplane). Jan Wnek claims gliding flights (1866-1869) from the Odporyszów church tower. Kraków Museum of Ethnography, the source of claims of documentary evidence, refuse to allow independent researchers access to these. First exhibition of aviation in London's Crystal Palace.

- 1868 British inventor Matthew Piers Watt Boulton patents the aileron in its modern form.
- 1869 Frederick Marriott designs flying machines and attempts to start an airline.
- 1870 Balloons are used by the French to transport letters and passengers out of besieged Paris during the Franco-Prussian War. Between September 1870 and January 1871, 66 flights - of which 58 land safely - carry 110 passengers and up to three million letters out of Paris, as well as 500 carrier pigeons to deliver messages back to Paris. One balloon accidentally sets a world distance record by ending up off the coast of Norway.
- 1871 The Englishmen Wenham and Browning construct the first wind tunnel and conduct airflow experiments. Alphonse Pénaud flies his Planophore, a small rubber-powered model which is designed to have automatic pitch and roll stability.
- 1872 2 February - French naval architect Henri Dupuy de Lome achieves 9 to 11 km/h (5.6 to 6.8 mph) with his airship driven by a propeller turned by eight men. 13 December - The German experimenter Paul Haenlein tests the first airship with an internal combustion engine in Brünn, Austria-Hungary, achieving 19 km/h (12 mph); the engine burns coal gas drawn from its balloon. The tests are stopped because of a shortage of money.
- 1873 The New York Daily Graphic sponsors the first attempt in history to fly across the Atlantic Ocean, using a 400,000-cubic foot (11,327-cubic meter) balloon carrying a lifeboat. The attempt is abandoned when the balloon rips and collapses during inflation.
- 1874 20 September - Felix and Louis du Temple de la Croix build a piloted steam-powered monoplane which achieves a short hop after gaining speed by rolling down a ramp.
- 1875 Englishman Thomas Moy tests a tethered aeroplane with a wing span of 4 metres (13 feet) powered by a steam engine. German experimenter Paul Haenlein improves his airship by providing it with a car suspended below its framework to accommodate the crew and engine. This will become a standard practice in the design of later dirigibles. 15 April - In the balloon Zenith, the French Navy officer Théodore Henri Sivel, the French journalist Joseph Crocé-Spinelli, and the French scientist and

editor Gaston Tissandier ascend to an altitude of 8,600 metres (28,200 feet). Hypoxia kills Sivel and Crocé-Spinelli during the flight and leaves Tissandier deaf.

- **1876 Alphonse Pénaud and Paul Gauchot apply for a patent for a power-driven aeroplane with a retractable undercarriage, wings with dihedral and joystick control. Experimental helicopter by Enrico Forlanini (1877) (Museo nazionale della scienza e della tecnologia Leonardo da Vinci, Milan)**
- **1877 First flight of a steam-driven model helicopter built by Enrico Forlanini. Imperial Japanese Army flying experience begins with the use of balloons.**
- **1878 Charles F. Ritchel publicly demonstrates of his hand-powered, one-man rigid airship, and eventually sells five of them. At the Balloon Equipment Store at the Royal Arsenal, Woolwich, British Army Captain James Templer conducts the British Army's first official experiments with an observation balloon. It is considered the birth of British military aviation.**
- **1879 The British Army gains its first balloon, the Pioneer. Frenchman Victor Tatin builds a power-driven model aeroplane with airscrews and a compressed air motor, successfully flying it off the ground. American scientist Edmund Clarence Stedman proposes a rigid airship inspired by the anatomy of a fish, with a framework of steel, brass, or copper tubing and a tractor propeller mounted on the front of the envelope, later changed to an engine with two propellers suspended beneath the framework. The airship never is built, but Stedman's design foreshadows that of the Zeppelins of World War I. Biot makes short hops in the Biot-Massia glider.**
- **1880 The Russian naval officer Alexander Fjodorowitsch Mozhaiski patents a steam-powered aircraft. Friedrich WÃ¶lfert and Ernst Baumgarten attempt to fly a powered dirigible in free flight, but crash. Balloons are used in British military manoeuvres for the first time at Aldershot.**
- **1883 M.A. Goupil proposes a steam-powered monoplane with tractor propeller. His full-size test rig lifts itself and two men in a light breeze, but the design is never built. The first electric-powered flight is made by Gaston Tissandier who fits a Siemens AG electric motor to a dirigible. Airships with electric engines (Tissandier brothers, Renard and Krebs). Wölfert unsuccessfully tests a balloon powered by a hand-cranked propeller The Berlin-based "German Society for Promoting Aviation" publishes a magazine, the "Zeitschrift für Luftschiffahrt" (Magazine of Aviation).**
- **1884 9 August - The first fully controllable free-flight is made in the French Army dirigible La France by Charles Renard and Arthur Krebs. The flight covers 8 km (5.0 mi) in 23 minutes. It was the first flight to return to the starting point. Mozhaiski finishes his monoplane (span 14 m, or 46 ft). It makes a short flight, taking off after running down a launching ramp. John**

J. Montgomery makes first controlled heavier-than-air unpowered flight in America. The British Army deploys observation balloons in combat for the first time, when it takes balloons subordinated to the Royal Engineers along on the Bechuanaland Expedition in South Africa. The Imperial Russian Army adopts the balloon for military service. Englishman Horatio Phillipps has a patent issued for curved aerofoil sections. Goupil publishes his book on La Locomotion Aérienne.

- 1885 The Prussian Airship Arm (Preussische Luftschiffer Abteilung) becomes a permanent unit of the army. The British Army deploys observation balloons in Sudan to take part in the expedition to Suakin during the Mahdist War. Frenchmen Hervé and Alluard achieve a hot air balloon flight of over 24 hours. John J. Montgomery experiments with a second glider in California.
- 1886 John J. Montgomery conducts studies on the flow of water and air over angles surfaces and experiments with a third glider in California.
- 1888 Wölfert flies a petrol powered dirigible at Seelburg, the first use of a petrol-fuelled engine for aviation purposes. The engine was built by Gottlieb Daimler.
- 1889 Percival G. Spencer makes a successful parachute jump from a balloon at Drumcondra, Ireland Otto Lilienthal publishes in his book Der Vogelflug als Grundlage der Fliegekunst (Bird Flight as the Basis for the Art of Aviation) measurements on wings, so called polar diagrams, which are the concept of description of artificial wings even today. The book gives a reference for the advantages of the arched wing. Pichancourt develops a mechanical bird which aimed to imitate the motion of a bird's wings in flight. Lawrence Hargrave, a British immigrant to Australia, constructs a rotary engine driven by compressed air. A British Army observation balloon section takes part in the Army Manoeuvres at Aldershot.
- 1890 The British Army establishes a Balloon Section of the Royal Engineers, commanded by Lieutenant H. B. Jones. A balloon factory and a ballooning school support the new section. 9 October - The first brief flight of ClÃ©ment Ader's steam-powered fixed-wing aircraft Eole takes place in Satory, France. It flies uncontrolled approximately 50 metres (160 feet) at a height of 20 cm (7.9 in) before crashing, but it is the first take-off of a powered airplane solely under its own power.
- 1891 Otto Lilienthal flies about 25 m (82 ft) in his Derwitzer Glider. Clément Ader makes a second flight in Eole, an uncontrolled 100-meter (330-foot) hop that ends in a crash. Ader later will experiment with an even less successful twin-engined steam-powered aircraft before giving up his aircraft experiments. 29 April - Chuhachi Ninomiya flies the first model airplane in Japan, a rubber-band-powered monoplane with a four-bladed pusher propeller and three-wheeled landing gear. It makes flights

of 3 and 10 meters (9.8 and 32.8 ft). The next day it flies 36 metres (118 feet).

- 1892 February - The first contract is awarded for the construction of a military airplane: Clément Ader is contracted by the French War Ministry to build a two-seater aircraft to be used as a bomber, capable of lifting a 75-kilogram (165-pound) bombload. August - Clément Ader later claims to have made an uncontrolled flight of 200 metres (660 feet) in the Avion II (also referred to as the Zephyr or Éole II) at a field in Satory in this month. Otto Lilienthal flies over 82 metres (90 yards) in his Südende-Glider. Austria-Hungary's army gains a permanent air corps, the Kaiserlich und Königliche Militäraeronautische Anstalt ("Imperial and Royal Military Aeronautical Group")
- 1893 Otto Lilienthal flies about 250 m (820 ft) in his Maihöhe-Rhinow-Glider. Lawrence Hargrave demonstrates a human-carrying glider in Australia at an aeronautical congress in Sydney. It is based on the box kite, an invention of Hargrave's. It becomes an example for several scientific kites and aeroplane constructions. British Army Captain Baden Baden-Powell begins experiments with man-lifting kites. Horatio Phillips builds a steam-powered test rig at Harrow. A "venetian blind" style multiplane with a stack of wings each with a span of 5.8 metres (19 ft) and a chord of only 4 cm (1.5 in). Tethered to the centre of a circular track, its rear wheels rose 60-90 cm (2.0-3.0 ft) while front wheels remained on ground.
- 1894 Czeslaw Tanski successfully flies powered models in Poland and begins work on full-size gliders. Railway engineer Octave Chanute publishes Progress in Flying Machines, describing the research completed so far into flight. Chanute's book, a summary of many articles published in the "American Engineer and Railroad Journal", is a comprehensive account on the stage of development worldwide on the way to the aeroplane. Otto Lilienthal's Normal soaring apparatus is the first serial production of a glider. Using different aircraft constructions he covers distances of up to 250 metres (820 ft). The British Army forms a kiting section for the operation of man-lifting kites within the Royal Engineers. 31 July - Hiram Maxim launches an enormous biplane test rig with a wingspan of 32 m (105 ft) propelled by two steam engines. It lifts off and engages the restraining rails, which prevent it from leaving the track. November - Lawrence Hargrave demonstrates stable flight with a tethered box kite. 4 December - German meteorologist and Aerologist Arthur Berson ascends to 9,155 metres (30,036 feet) in a balloon, setting a new world altitude record for human flight.
- 1895 Percy Pilcher makes his first successful flight in a glider named the Bat.[68] Pablo Suarez flies his Suarez Glider in Argentina, following correspondence with Lilienthal. The Sanskrit scholar Shivkar Bapuji Talpade designed an unmanned aircraft called Marutsakthi or Marutsakha (mean-

ing Power of Air), supposedly based on Vedic technology. It is claimed that it took off before a large audience in the Chowpathy beach of Bombay and flew to a height of 1,500 feet but the claim has not been verified. By the mid-1890s, the Imperial Russian Navy has established "aerostatic parks" on the coasts of the Baltic Sea and Black Sea.

- 1896 6 May - Samuel Pierpont Langley flies the unmanned Aerodrome No. 5 from a houseboat on the Potomac River a distance of 3,300 ft (1,000 m), the first truly successful flight of one of his powered models.[71] June - Octave Chanute organises a flyer camp at Lake Michigan during which both a copy of one of Lilienthal's designs and a biplane built by Chanute are tested.[72] 9 August - Otto Lilienthal crashes after a stall caused by a gust, breaking his back. He dies the following day. October - Ground testing of an all-aluminium airship designed by the Austro-Hungarian engineer David Schwarz and built by Carl Berg, begins in Berlin. Schwarz will die of a heart attack before seeing it fly.[74] November - Samuel Pierpont Langley flies the unmanned Aerodrome No. 6 a distance of 4,200 ft (1,300 m). Germans August von Parseval and Hans Bartsch von Sigsfeld invent the kite balloon for observations in strong winds. William Paul Butusov, a Russian immigrant to U.S, with the Chanute group, construct the Albatross Soaring Machine which achieves an unmanned unpowered uncontrolled hop from a ramp. William Frost, Welsh, flies the Frost Airship Glider 500 meters, possibly with balloon assist.
- 1897 11 June - Salomon Andráe, Nils Strindberg, and Knut Frænkel attempt an expedition to the North Pole by free balloon from Spitsbergen. They crash within three days but manage to survive for several months in the pack ice. Their remains are discovered in 1930 on White Island. It was possible to develop the preserved film material. 12 June - Friedrich Hermann Wölfert and his mechanic are killed when their petrol-powered airship catches fire during a demonstration at the Tempelhof field. 14 October - Clément Ader later asserts that on this date he made a 300 m (980 ft) flight in his steam-powered uncontrolled Avion III also referred to as Aquilon or the Éole III. His claim is disputed. The French Army is not impressed and withdraws funding. 3 November - The first flight in a rigid airship is made by Ernst Jägels, flying the all-aluminium craft designed by David Schwarz and built by Carl Berg. It reaches an altitude of 24 m (79 ft), proving metal-framed airships can become airborne, but after an engine failure is damaged beyond repair in an emergency landing. Carl Rickard Nyberg starts working on his Flugan.
- 1898 2 September - Alberto Santos-Dumont flies his first airship design. 22 October - Augustus Herring flies his heavier-than-air vehicle. The Langley Aerodrome is commissioned by the United States Army Signal Corps. The Aéro-Club de France is founded. The French Navy torpedo boat tender Foudre operates a spherical balloon experimentally during

naval maneuvers in the Mediterranean Sea. March - Assistant Secretary of the Navy Theodore Roosevelt calls for the creation of a four-officer board to study the utility of Samuel P. Langley's "flying machine," the Langley Aerodrome. Roosevelt asserts that "the machine has worked." It is the first documented United States Navy expression of interest in aviation. Augustus Moore Herring, United States, claims a flight along the beach at St. Joseph, Michigan of 70 feet (21 m) by attaching a compressed air motor to a biplane hang glider. However, he does not repeat the flight with anyone present. Lyman Wiswell Gilmore, Jr., American, builds a steam driven monoplane. Edson Fessenden Gallaudet, American, builds a hydroplane.

- **1899 The Hague Convention of 1899 prohibits military aircraft from discharging projectiles and explosives, but permits the wartime use of aircraft for reconnaissance and other purposes. The Wright brothers begin experimenting with wing-warping as a means of controlling an aircraft. Samuel Cody begins experiments with kites big enough to lift a person. Percy Pilcher flies various gliders and is close to completing a powered machine but is killed when his glider crashes at Stanford Hall, England after a tail strut fails. Pilcher used a team of horses to pull the glider into the air. April - Gustave Whitehead claims to have flown his steam-powered aircraft a distance of 500 m (1,600 ft) in Pennsylvania with a passenger. 22 November - The first of three British Army observation balloon sections arrives in South Africa to take part in the Second Boer War. The war will see the first large-scale use of observation balloons by the British armed forces. 11 December - A British Army observation balloon section takes part in the Battle of Magersfontein during the Second Boer War.**
- **1900 February - In the Second Boer War, a British Army observation balloon section takes part in the relief of Ladysmith. 2 July - Count Ferdinand von Zeppelin pilots his experimental first Zeppelin, LZ 1, over Lake Constance, reaching an altitude of 400 metres (1,300 feet) with five men on board. Although the flight lasts only 18 minutes, covers only 5.6 kilometers (3.5 mi), and ends in an emergency landing on the lake, it is the first flight of a truly successful rigid airship. 12 September - The Wright brothers arrive at Kitty Hawk, North Carolina, to begin their first season of glider experiments there. 3 October - Probably on this date, Wilbur Wright makes the Wright brothers' first glider flight at Kitty Hawk. During their tests, they will fly the 1900 glider both as a glider and as a kite under various wind conditions. 17 October - On her second flight, the Zeppelin LZ 1 remains aloft for 80 minutes.[88] 23 October - The Wright brothers abandon their 1900 glider in a sand hollow and break camp at Kitty Hawk to return home to Dayton, Ohio. November - The British Army's observation balloon section's duty in the Second Boer War comes to an end. It is ordered home from South Africa because the**

Boers have switched to guerrilla tactics, making the balloons unsuitable for supporting British operations.

- 1901
- July 31 - German meteorologists Berson and Süring climb to 10,800 m in a free balloon.
- August 14 - in Fairfield, Connecticut, Gustave Whitehead reportedly flew his engine-powered Whitehead No. 21 800 meters at a height of 15 meters, after taking off unaided. This claim is accepted by one editor of Jane's All the World's Aircraft as the first sustained powered, controlled flight of a heavier-than-air craft, although the majority of authorities disagree.
- October 19 - Alberto Santos-Dumont, a Brazilian, flies his dirigible Number 6 around the Eiffel Tower to collect an FF100,000 prize. October 29 - the Royal Aero Club of Great Britain is established. Wilhelm Kress trials a triplane seaplane that makes a short hop before capsizing.
- November-Secember: The Wright brothers optimize their No. 3 Glider wing design with the help of wind tunnel measurements.
- 1902
- January 17 - Gustave Whitehead purports to fly a motorized airplane with a boat-shaped hull on a supposed 11 km (6.8 mi) flight over Long Island Sound and states he landed safely in the water close to the starting point. The No.22, if it existed, is said to have had wheels and could land on water as well as on the ground. It reportedly was rebuilt from his Whitehead Aeroplane No. 21 of the previous year. No.21 had a 20 hp motor, No.22 had a 40 hp motor. There is only Whitehead's written statement that No.22 existed.
- February 4 - First balloon flight in Antarctica when Robert Falcon Scott and Ernest Shackleton ascend to 800 feet (240 m) in a tethered hydrogen balloon to take the first Antarctic aerial photographs. February 4 - Future pilot Charles Lindbergh is born.
- March: Professor Erich von Drygalski's 1901-1903 German Antarctic Expedition uses a balloon to survey the Antarctic coast of Wilhelm II Land.
- April 30 - The St Louis Aeronautical Exposition opens in Missouri. A highlight is Octave Chanute launching a replica of his 1896 glider.
- 1903
- January: Léon Levavasseur demonstrates his Antoinette engine, designed as a lightweight powerplant specifically for aircraft. Konstantin Tsiolkovski deduces the Basic Rocket Equation in his article Explorations of outer space with the help of reaction apparatuses.
- February 16 Traian Vuia presented to the Académie des Sciences of Paris the possibility of flying with a heavier-than-air mechanical machine and his procedure for taking off, but it was rejected for being a utopia, adding the comments: The problem of flight with a machine which weighs more than air can not be solved and it is only a dream.

- **March 31 - Richard Pearse is reputed to have made a powered flight in a heavier-than-air craft, a monoplane of his own construction, that crash lands on a hedge. This date is computed from circumstantial evidence of eyewitnesses as the flight was not well documented at the time. The machine made a flight claimed to be around 150 feet (45 m) on his farm at Upper Waitohi, near Timaru in south Canterbury, New Zealand.**
- **May 11 - Richard Pearse is claimed to have made a flight of around 1,000 yards (900 m), landing in the semi-dry bed of the Opihi River.**
- **August 18 - Karl Jatho makes a flight with his motored aircraft in front of four people. His craft flies up to 200 feet (60 m) a few feet above the ground in a powered heavier-than-air craft.**
- **October 7 - Samuel Langley conducts the first tests of his full-sized man-carrying version of his earlier model aerodromes. The pilot Charles Manly nearly drowned when the machine slid off its launch apparatus atop a houseboat and fell into the Potomac River.**
- **November 12 - The Lebaudy brothers make a controlled dirigible flight of 54 km (34 mi) from Moisson to Paris.**
- **December 8 - second attempt by Charles Manly to fly Langley's repaired full-sized aerodrome. As with the October 7 attempt the machine failed to fly tripping on its launch gear and somersaulting into the Potomac River nearly killing Manly. A surviving photograph captures the machine upended on its side as it falls off the houseboat. Langley himself was absent at this attempt but the machine's failure to fly ended his government(aka U.S. Army) funded attempts at building a successful full sized man-carrying flying machine. December 17 - The Wright Brothers make four flights in their Flyer at Kitty Hawk, North Carolina following years of research and development. Orville Wright takes off first and flies 120 ft (37 m)in 12 seconds. This is frequently considered the first controlled, powered heavier-than-air flight and is the first such flight photographed. On the fourth effort, which is considered by some to be the first true controlled, powered heavier-than-air flight, Wilbur flies 852 ft (260 m) in 59 seconds.**

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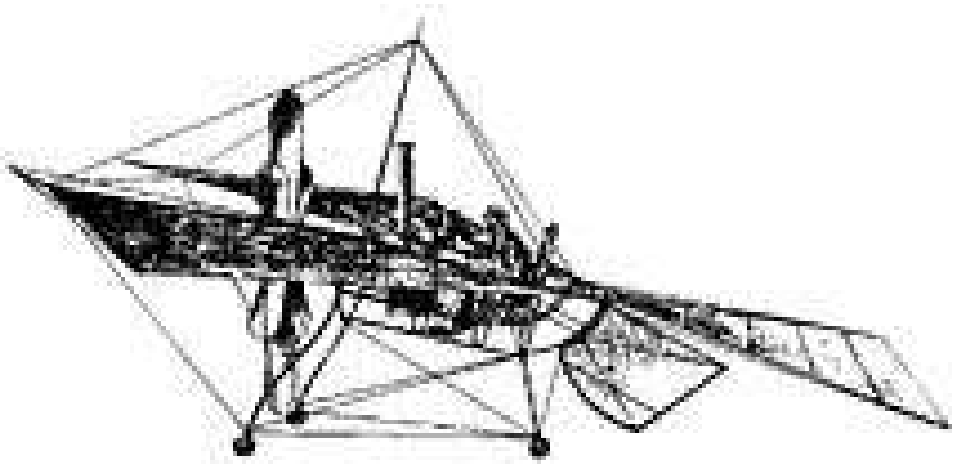

Figure 10.1: **Félix du Temple's 1874 Monoplane.**

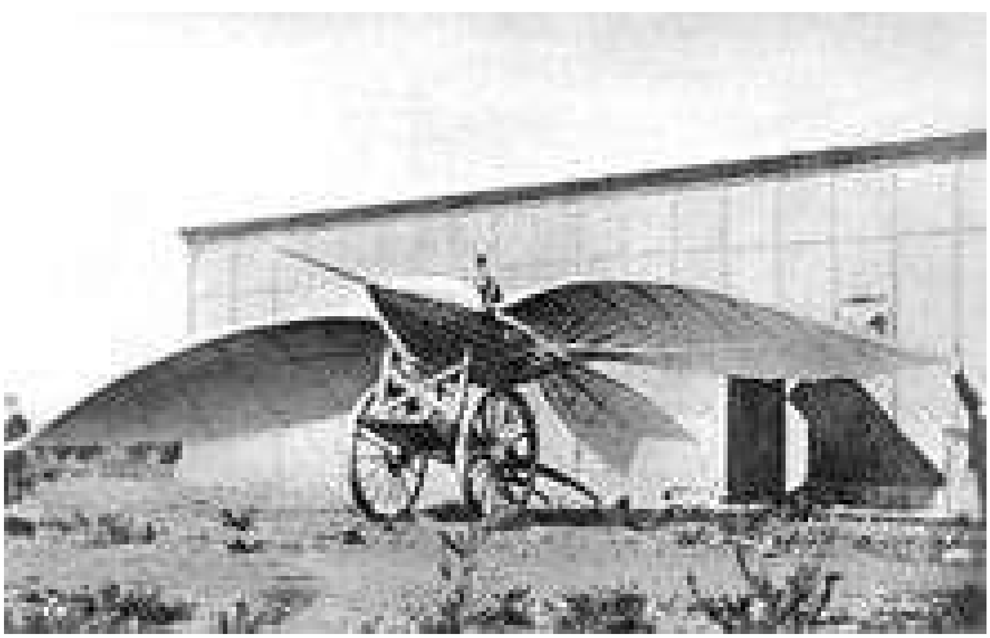

Figure 10.2: **Jean-Marie Le Bris and his flying machine, Albatros II, 1868.**

Figure 10.3: **The Aeroplane of Victor Tatin, 1879.**

Figure 10.4: **The Biot-Massia glider, restored and on display in the Musee de l'Air.**

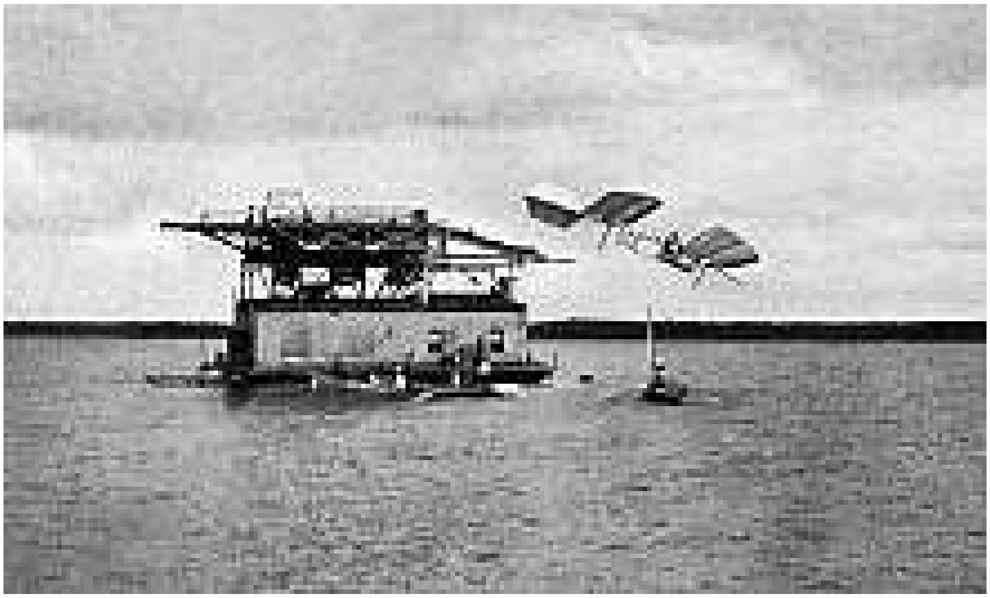

Figure 10.5: **First failure of Langley's manned Aerodrome on the Potomac River, October 7, 1903.**

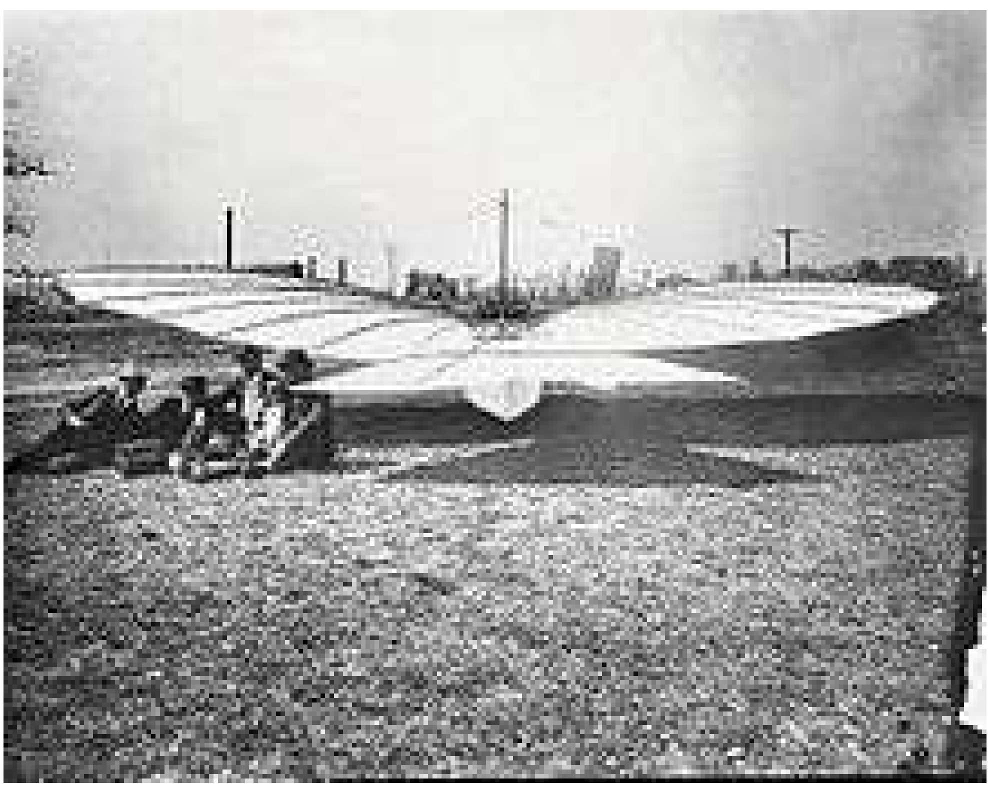

Figure 10.6: **The No. 21 monoplane seen from the rear. Whitehead sits beside it with daughter Rose in his lap; others in the photo are not identified.**

Figure 10.7: **The Wright Flyer: the first sustained flight with a powered, controlled aircraft.**

10.2 The history of space exploration

Rocket timeline from Wikipedia

- **11th century AD - The first documented record of gunpowder and the fire arrow, an early form of rocketry, appears in the Chinese text Wujing Zongyao.**
- **1650 - Artis Magnae Artilleriae pars prima ("Great Art of Artillery, the First Part") is printed in Amsterdam, about a year before the death of its author, Kazimierz Siemienowicz.**
- **1664 - A "space rocket" is imagined as a future technology to be studied in France and its drawing is ordered by French finance minister Colbert; designed by Le Brun on a Gobelins tapestry.**
- **1798 - Tipu Sultan, the King of the state of Mysore in India, develops and uses iron rockets against the British Army.**
- **1801 - The British Army develops the Congreve rocket based on weapons used against them by Tipu Sultan.**
- **1806 - Claude Ruggieri, an Italian living in France, launched animals on rockets and recovered them using parachutes. He was prevented from launching a child by police.**
- **1813 - "A Treatise on the Motion of Rockets" by William Moore - first appearance of the rocket equation.**

- **1818 - Henry Trengrouse demonstrates his rocket apparatus for projecting a lifeline from a wrecked ship to the shore, later widely adopted.**
- **1844 - William Hale invents the spin-stabilized rocket**
- **1861 - William Leitch publishes an essay "A Journey Through Space" as a humorous science fantasy story about a space gun launching a manned spacecraft equipped with rockets for landing on the Moon, but eventually used for another orbital maneuver.**
- **1902 - French cinema pioneer Georges Méliés directs A Trip to the Moon, the first film about space travel.**
- **1903 - Konstantin Tsiolkovsky begins a series of papers discussing the use of rocketry to reach outer space, space suits, and colonization of the Solar System. Two key points discussed in his works are liquid fuels and staging.**
- **1913 - Without knowing the work of Russian mathematician Konstantin Tsiolkovsky, French engineer Robert Esnault-Pelterie derived the equations for space flight, produced a paper that presented the rocket equation and calculated the energies required to reach the Moon and nearby planets.**
- **1916 - first use of rockets (with the solid fuel Le Prieur rocket) for both air-to-air attacks, and air to ground.**
- **1922 - Hermann Oberth publishes his scientific work about rocketry and space exploration: Die Rakete zu den Planetenräumen ("By Rocket into Planetary Space").**
- **1924 - Society for Studies of Interplanetary Travel founded in Moscow by Konstantin Tsiolkovsky, Friedrich Zander and 200 other space and rocket experts**
- **1926 - Robert Goddard launches the first liquid fuel rocket. This is considered by some to be the start of the Space Age.**
- **1927 - Verein fÃ¼r Raumschiffahrt (VfR - "Spaceflight Society") founded in Germany.**
- **1929 - Woman in the Moon, considered to be one of the first "serious" science fiction films.**
- **1931 - Friedrich Schmiedl attempts the first rocket mail service in Austria**
- **1933 - Sergei Korolev and Mikhail Tikhonravov launch the first liquid-fueled rocket in the Soviet Union.**
- **1935 - Emilio Herrera Linares from Spain designed and made the first full-pressured astronaut suit, called the escafandra estratonáutica. The Russians then used a model of Herrera's suit when first flying into space of which the Americans would then later adopt when creating their own space program.**
- **1936 - Research on rockets begins at the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT), the predecessor to the Jet Propulsion Laboratory, under the direction of Frank Malina and Theodore von KármÃ¡n.**

- **1937 - Peenemünde Army Research Center founded in Germany.**
- **1938 - The Projectile Development Establishment founded at Fort Halstead for the United Kingdom's research into military solid-fuel rockets.**
- **1939 - Katyusha multiple rocket launchers are a type of rocket artillery first built and fielded by the Soviet Union.**
- **1941 - French rocket EA-41 is launched, being the first European liquid propellant working rocket[8](It was, however, preceded by the Peenemunde A5 and Soviet experiments.)**
- **1941 - Jet Assisted Take Off JATO installed on US Army Air Corp Ercoupe aircraft occurred on 12 August in March Field, California.**
- **1942 - Wernher von Braun and Walter Dornberger launch the first V-2 rocket at Peenemünde in northern Germany.**
- **1942 - A V-2 rocket reaches an altitude of 85 km.**
- **1944 - The V-2 rocket MW 18014 reaches an altitude of 176 km, becoming the first man-made object in space.**
- **1945 - Lothar Sieber dies after the first vertical take-off manned rocket flight in a Bachem Ba 349 "Natter".**
- **1945 - Operation Paperclip takes 1,600 German rocket scientists and technicians to the United States.**
- **1945 - Operation Osoaviakhim takes 2,000 German rocket scientists and technicians to the Soviet Union.**
- **1946 - First flight of the Nike missile, later the first operational surface-to-air guided missile.**
- **1947 - Chuck Yeager achieves the first manned supersonic flight in a Bell X-1 rocket-powered aircraft.**
- **1949 - Willy Ley publishes The Conquest of Space.**
- **1952 - 22 May, French Véronique 1 rocket is launched from the Algerian desert.**
- **1952 - Wernher von Braun discusses the technical details of a manned exploration of Mars in Das Marsprojekt.**
- **1953 - Colliers magazine publishes a series of articles on man's future in space, igniting the interest of people around the world. The series includes numerous articles by Ley and von Braun, illustrated by Chesley Bonestell.**
- **1956 - First launch of PGM-17 Thor, the first US ballistic missile and forerunner of the Delta space launch rockets.**
- **1957 - Launch of the first ICBM, the USSR's R-7 (8K71), known to NATO as the SS-6 Sapwood.**
- **1957 - The USSR launches Sputnik 1, the first artificial satellite.**
- **1958 - The U.S. launches Explorer 1, the first American artificial satellite, on a Jupiter-C rocket.**
- **1958 - US launches their first ICBM, the Atlas-B (the Atlas-A was a test article only).**

- **1961 - the USSR launches Vostok 1, Yuri Gagarin reached a height of 327 km above Earth and was the first man to orbit Earth.**
- **1961 - US, a Mercury capsule named Freedom 7 with Alan B. Shepard, spacecraft was launched by a Redstone rocket on a ballistic trajectory suborbital flight. It was the first human space mission that landed with pilot still in spacecraft, thus the first complete human spaceflight by FAI definitions.**
- **1962 - The US launches Mercury MA-6 (Friendship 7) on an Atlas D booster, John Glenn puts America in orbit.**
- **1963 - The USSR launches Vostok 6, Valentina Tereshkova was the first woman (and first civilian) to orbit Earth. She remained in space for nearly three days and orbited the Earth 48 times.**
- **1963 - US X-15 rocket-plane, the first reusable manned spacecraft (suborbital) reaches space, pioneering reusability, carried launch and glide landings.**
- **1965 - USSR Proton rocket, highly successful launch vehicle with notable payloads, Salyut 6 and Salyut 7, Mir, and ISS components.**
- **1965 - Robert Salked investigates various single stage to orbit spaceplane concepts.**
- **1966 - USSR Luna 9, the first soft landing on the Moon.**
- **1966 - USSR launches Soyuz spacecraft, longest-running series of spacecraft, eventually serving Soviet, Russian and International space missions.**
- **1968 - USSR Zond 5, two tortoises and smaller biological Earthlings circle the Moon and return safely to Earth.**
- **1968 - US Apollo 8, the first men to reach and orbit the Moon.**
- **1969 - US Apollo 11, first men on the Moon, first lunar surface extravehicular activity.**
- **1981 - US Space Shuttle pioneers reusability and glide landings.**
- **1998 - US Deep Space 1 is first deep space mission to use an ion thruster for propulsion.**
- **1998 - Russia launch Zarya module which is the first part of the International Space Station.**
- **2001 - Russian Soyuz spacecraft sent the first space tourist Dennis Tito to International Space Station.**
- **2004 - US-based, first privately developed, manned (suborbital) spaceflight, SpaceShipOne demonstrates reusability.**
- **2008 - SpaceX - with their Falcon 1 rocket - became the first private entity to successfully launch a rocket into orbit.**
- **2012 - The SpaceX Dragon space capsule - launched aboard a Falcon 9 launch vehicle - was the first private spacecraft to successfully dock with another spacecraft, and was also the first private capsule to dock at the International Space Station.**

Figure 10.8: **A jet-driven steam engine invented by Hero of Alexandria in the 1st century A.D..**

- **2014 - First booster rocket returning from an orbital trajectory to achieve a zero-velocity-at-zero-altitude propulsive vertical landing. The first-stage booster of Falcon 9 Flight 9 made the first successful controlled ocean soft touchdown of a liquid-rocket-engine orbital booster on April 18, 2014.**
- **2015 - SpaceX's Falcon 9 Flight 20 was the first time that the first stage of an orbital rocket made a successful return and vertical landing.**
- **2017 - SpaceX's Falcon 9 SES-10 was the first time a used orbital rocket made a successful return.**

Figure 10.9: **Rockets were used in warfare in China in the 11th century.**

Figure 10.10: **Congreve rockets were used in the bombardment of Copenhagen in 1807. It was a terror attack on the civilian population, carried out although no state of war existed between Denmark and England.**

Figure 10.11: **Nazi V2 rockets, which launched the space age, were also used for the terror bombardment of civilians.**

Figure 10.12: **Cosmonaut Yuri Gagarin (1934-1968) was the first man in space. On 12 April, 1961, his space capsule, Vostok 1, completed an orbit of the Earth. Gagarin became an international celebrity, and was awarded many honors and medals. He died in the crash of a routine MIG-15UTI training flight.**

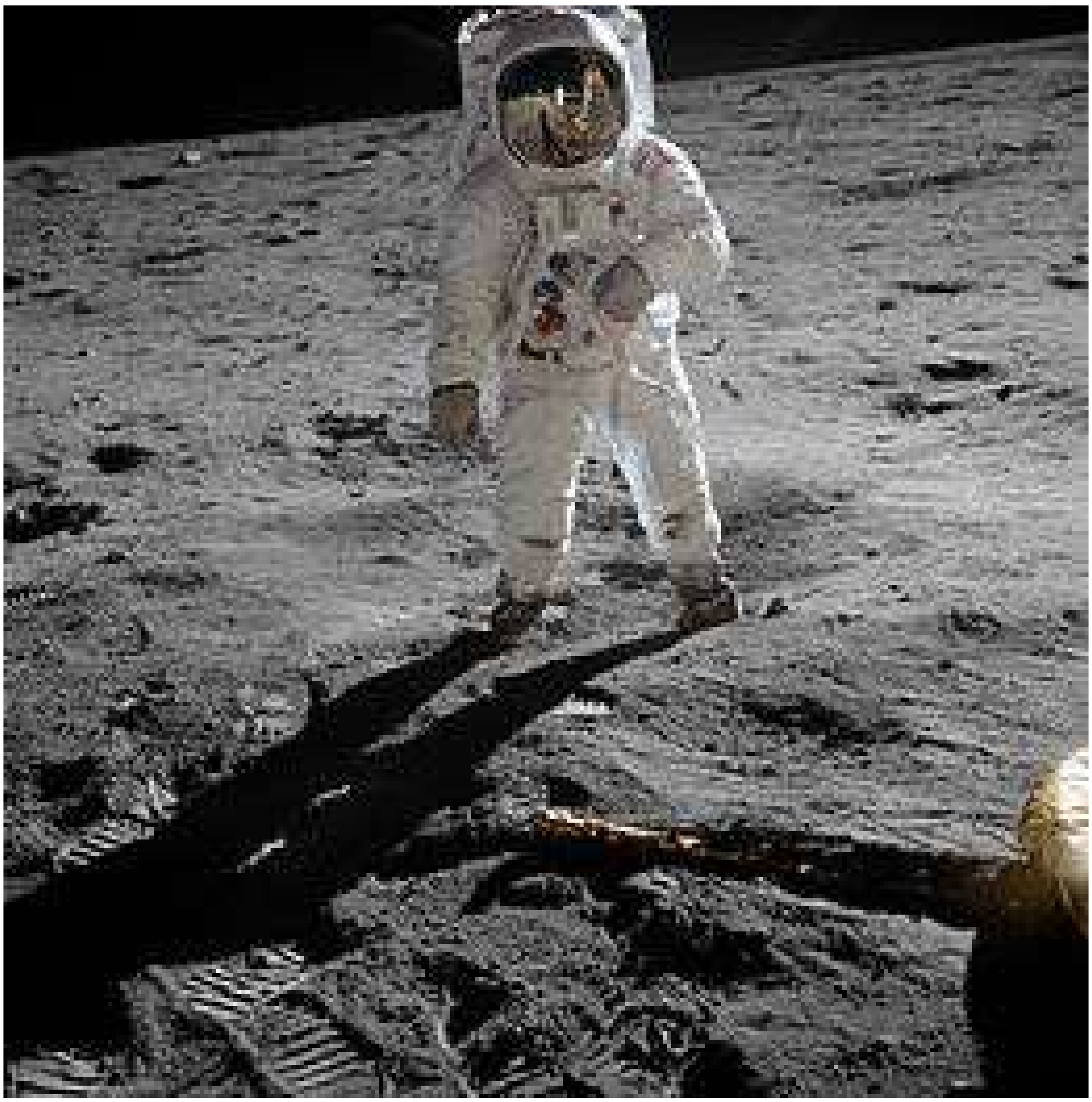

Figure 10.13: **Buzz Aldrin on the Moon as photographed by Neil Armstrong.**

Suggestions for further reading

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16. Brandon R. Brown, *The Apollo Chronicles: Engineering America's First Moon Missions.*
17. Roger D. Launius, *Reaching for the Moon: A Short History of the Space Race*
18. *Apollo 11*, a documentary film directed by Todd Douglas Miller.
19. Michael Collins, *Carrying the Fire: An Astronaut's Journeys (50th Anniversary Edition)]*, The New York Review of Books, vol. LXVI, no. 13 (15 August 2019), pp. 54-58. "'If we can put a man on the moon, why can's we...?' became a clichÃ© even before Apollo succeeded.... Now... the missing predicate is the urgent one: why can't we stop destroying the climate of our own planet?... I say leave it [the moon] alone for a while." (pp. 57-58.)
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Chapter 11

ECOLOGICAL ENGINEERING

11.1 The UK declares a climate emergency

Introducing the motion in the House of Commons, Labour leader Jeremy Corbyn said: **"We have no time to waste. We are living in a climate crisis that will spiral dangerously out of control unless we take rapid and dramatic action now. This is no longer about a distant future. We're talking about nothing less than the irreversible destruction of the environment within our lifetimes of members of this house."**

Here are some excerpts from an article by Amy Goodman and Nermeen Shaikh of Democracy now published in Truthout on May 2, 2019.[1]:

On Wednesday, the House of Commons became the first parliament in the world to declare a climate emergency. The resolution came on the heels of the recent Extinction Rebellion mass uprising that shut down Central London last month in a series of direct actions. Activists closed bridges, occupied public landmarks and even superglued themselves to buildings, sidewalks and trains to demand urgent action to combat climate change. Police arrested more than 1,000 protesters. Labour Party Leader Jeremy Corbyn told Parliament, "We are witnessing an unprecedented upsurge of climate activism, with groups like Extinction Rebellion forcing the politicians in this building to listen. For all the dismissive and defensive column inches the processes have provoked, they are a massive and, I believe, very necessary wake-up call. Today we have the opportunity to say, 'We hear you.'" We speak with George Monbiot, British journalist, author and columnist with The Guardian. His recent piece for The Guardian is headlined "Only rebellion will prevent an ecological apocalypse." Monbiot says capitalism "is like a gun pointed at the heart of the planet. It will essentially, necessarily destroy our life-support systems. Among those characteristics is the drive for perpetual economic growth on a finite planet."

[1] https://truthout.org/video/george-monbiot-on-the-uk-climate-emergency/

11.2 The 2018 IPCC report

Excerpts from an article summarizing the report

Here are excerpts from an article entitled **UN Experts Warn of 'Climate Catastrophe' by 2040** by Jesica Corbett. The article was published in Common Dreams on Monday, October 8, 2018.[2]:

"The climate crisis is here and already impacting the most vulnerable," notes 350.org's program director. "Staying under 1.5^{o}C is now a matter of political will."

Underscoring the need for "rapid, far-reaching, and unprecedented" changes to life as we know it to combat the global climate crisis, a new report from the Intergovernmental Panel on Climate Change (IPCC) - the United Nations' leading body for climate science - details what the world could look like if the global temperature rises to 1.5^{o}C versus 2^{o}C (2.7^{o}F versus 3.6^{o}F) above pre-industrial levels, and outlines pathways to reducing greenhouse gas emissions in the context of sustainable development and efforts to eradicate poverty.

"Climate change represents an urgent and potentially irreversible threat to human societies and the planet," the report reads. "Human-induced warming

[2]https://www.commondreams.org/news/2018/10/08/un-experts-warn-climate-catastrophe-2040-without-rapid-and-unprecedented-global

has already reached about 1^{o}C (1.8^{o}F) above pre-industrial levels at the time of writing of this Special Report... If the current warming rate continues, the world would reach human-induced global warming of 1.5^{o}C around 2040."

Approved by the IPCC in South Korea on Saturday ahead of COP24 in Poland in December, Global Warming of 1.5^{o}C was produced by 91 authors and reviewers from 40 countries. Its release has elicited calls to action from climate campaigners and policymakers the world over.

"This is a climate emergency. The IPCC 1.5 report starkly illustrates the difference between temperature rises of 1.5^{o}C and 2^{o}C - for many around the world this is a matter of life and death," declared Karin Nansen, chair of Friends of the Earth International (FOEI). "It is crucial to keep temperature rise well below 1.5 degrees ... but the evidence presented by the IPCC shows that there is a narrow and shrinking window in which to do so."

The report was requested when the international community came together in December of 2015 for the Paris agreement, which aims to keep global warming within this century "well below" 2^{o}C, with an ultimate target of 1.5^{o}C. President Donald Trump's predecessor supported the accord, but Trump has vowed to withdraw the United States, even as every other nation on the planet has pledged their support for it. In many cases, however, sworn support hasn't led to effective policy.

"It's a fresh reminder, if one was needed, that current emissions reduction pledges are not enough to meet the long-term goals of the Paris agreement. Indeed, they are not enough for any appropriately ambitious temperature target, given what we know about dangerous climate impacts already unfolding even at lower temperature thresholds," Rachel Cleetus, lead economist and climate policy manager for the Union of Concerned Scientists (UCS), wrote ahead of its release.

"The policy implications of the report are obvious: We need to implement a suite of policies to sharply limit carbon emissions and build climate resilience, and we must do all this is in a way that prioritizes equitable outcomes particularly for the world's poor and marginalized communities," Cleetus added.

"We want a just transition to a clean energy system that benefits people not corporations," Nansen emphasized. "Only with a radical transformation of our energy, food and economic systems, embracing environmental, social, gender and economic justice, can we prevent climate catastrophe and temperature rises exceeding 1.5^{o}C."

Today we are faced with multiple interrelated crises, for example the threat of catastrophic climate change or equally catastrophic thermonuclear war, and the threat of widespread famine. These threats to human existence and to the biosphere demand a prompt and rational response; but because of institutional and cultural inertia, we are failing to take the steps that are necessary to avoid disaster.

11.3 Greta Thunberg

Only immediate climate action can save the future

Immediate action to halt the extraction of fossil fuels and greatly reduce the emission of CO_2 and other greenhouse gasses is needed to save the long-term future of human civilization and the biosphere.

At the opening ceremony of United Nations-sponsored climate talks in Katowice, Poland, Sir David Attenborough said “Right now, we are facing a man-made disaster of global scale. Our greatest threat in thousands of years. Climate change. If we don’t take action, the collapse of our civilizations and the extinction of much of the natural world is on the horizon. The world’s people have spoken. Their message is clear. Time is running out. They want you, the decision-makers, to act now.”

Antonio Guterres, UN Secretary-General, said climate change was already “a matter of life and death” for many countries. He added that the world is “nowhere near where it needs to be” on the transition to a low-carbon economy.

Swedish student Greta Thunberg, is a 16-year-old who has launched a climate protest movement in her country. She said, in a short but very clear speech after that of UN leader Antonio Guterres: “Some people say that I should be in school instead. Some people say that I should study to become a climate scientist so that I can ‘solve the climate crisis’. But the climate crisis has already been solved. We already have all the facts and solutions.”

She added: “Why should I be studying for a future that soon may be no more, when no one is doing anything to save that future? And what is the point of learning facts when the most important facts clearly mean nothing to our society?”

Thunberg continued: “Today we use 100 million barrels of oil every single day. There are no politics to change that. There are no rules to keep that oil in the ground. So we can’t save the world by playing by the rules. Because the rules have to be changed.”

She concluded by saying that “since our leaders are behaving like children, we will have to take the responsibility they should have taken long ago.”

Appearing among billionaires, corporate CEO’s and heads of state at the Davos Economic Forum in Switzerland, like a new Joan of Arc, 16-year-old Swedish climate activist Greta Thunberg called on decision-makers to fulfil their responsibilities towards future generations. Here are some excerpts from her speech:

Greta’s speech at Davos

Our house is on fire. I am here to say, our house is on fire. According to the IPCC, we are less than 12 years away from not being able to undo our mistakes. In that time, unprecedented changes in all aspects of society need to have taken place, including a reduction of our CO_2 emissions by at least 50%...

Here in Davos - just like everywhere else - everyone is talking about money. It seems money and growth are our only main concerns.

And since the climate crisis has never once been treated as a crisis, people are simply not aware of the full consequences on our everyday life. People are not aware that there is such a thing as a carbon budget, and just how incredibly small that remaining carbon budget is. That needs to change today.

No other current challenge can match the importance of establishing a wide, public awareness and understanding of our rapidly disappearing carbon budget, that should and must become our new global currency and the very heart of our future and present economics.

We are at a time in history where everyone with any insight of the climate crisis that threatens our civilization - and the entire biosphere - must speak out in clear language, no matter how uncomfortable and unprofitable that may be.

We must change almost everything in our current societies. The bigger your carbon footprint, the bigger your moral duty. The bigger your platform, the bigger your responsibility.

Figure 11.1: **Greta Thunberg on the cover of Time Magazine, The Intergovernmental Panel on Climate Change, in their October 2018 report, used strong enough language to wake up at least part of the public: the children whose future is at stake. Here is an excerpt from a speech which 16-year-old Swedish climate activist Greta Thunberg made at the Davos Economic Forum in January, 2019: "Our house is on fire. I am here to say, our house is on fire. According to the IPCC, we are less than 12 years away from not being able to undo our mistakes. In that time, unprecedented changes in all aspects of society need to have taken place, including a reduction of our CO2 emissions by at least 50%..."**

11.4 Worldwide school strike, 15 March, 2019

Over 1.4 million young students across all continents took to the streets on Friday March 15th for the first ever global climate strike. Messages in more than 40 languages were loud and clear: world leaders must act now to address the climate crisis and save our future. The school strike was the largest climate action in history. Nevertheless it went almost unmentioned in the media,

Here are some of the statements by the students explaining why they took part in the strikes:

In India, no one talks about climate change. You don't see it on the news or in the papers or hear about it from government. We want global leaders to declare a climate emergency. If we don't act today, then we will have no tomorrow. - Vidit Baya, 17, Udaipur, India.

We face heartbreaking loss due to increasingly extreme weather events. We urge the Taiwanese government to implement mitigation measures and face up to the vulnerability of indigenous people, halt construction projects in the indigenous traditional realm, and recognize the legal status of Plains Indigenous People, in order to implement environmental protection as a bottom-up approach - Kaisanan Ahuan, Puli City, Taiwan.

We have reached a point in history when we have the technical capacities to solve poverty, malnutrition, inequality and of course global warming. The deciding factors for whether we take advantage of our potential will be our activism, our international unity and our ability to develop the art of making the impossible possible. Whether we succeed or not depends on our political will - Eyal Weintraub, 18, and Bruno Rodriguez, 18, Argentina.

The damage done by multinationals is enormous: the lack of transparency, dubious contracts, the weakening of the soil, the destruction of flora and fauna, the lack of respect for mining codes, the contamination of groundwater. In Mali, the state exercises insufficient control over the practices of the multinationals, and it is us, the citizens, who suffer the consequences. The climate alarm has sounded, and the time has come for us all to realize that there is still time to act locally, in our homes, our villages, our cities - Mone Fousseny, 22, Mali.

11.5 Solar energy

Before the start of the industrial era, human society relied exclusively on renewable energy sources - but can we do so again, with our greatly increased population and greatly increased demands? Will we ultimately be forced to reduce the global population or our per capita use of energy, or both? Let us now try to examine these questions.

Biomass, wind energy, hydropower and wave power derive their energy indirectly from the sun, but in addition, various methods are available for utilizing the power of sunlight directly. These include photovoltaic panels, solar designs in architecture, solar systems for heating water and cooking, concentrating photovoltaic systems, and solar thermal power plants.

Photovoltaic cells and concentrating photovoltaic systems

Solar power was the fastest-growing source of new energy in 2016, surpassing the net growth of all other energy sources including coal, according to a new report from the International Energy Agency (IEA).

The IEA report found new solar capacity increased by 50 percent in 2016, and IEA executive director Fatih Birol hailed solar's rapid growth. "What we are witnessing is the birth of a new era in solar photovoltaics [PV]. We expect that solar PV capacity growth will be higher than any other renewable technology up to 2022."[3]

The report also shows renewables as a whole accounted for two-thirds of all new energy capacity in 2016. "We see renewables growing by about 1,000 GW (gigawatts) by 2022, which equals about half of the current global capacity in coal power, which took 80 years to build," Birol said in a statement accompanying the report.[4]

Solar photovoltaic cells[5] are thin coated wafers of a semiconducting material (usually silicon). The coatings on the two sides are respectively charge donors and charge acceptors. Cells of this type are capable of trapping solar energy and converting it into direct-current electricity. The electricity generated in this way can be used directly (as it is, for example, in pocket calculators) or it can be fed into a general power grid. Alternatively it can be used to split water into hydrogen and oxygen. The gases can then be compressed and stored, or exported for later use in fuel cells. In the future, we may see solar photovoltaic arrays in sun-rich desert areas producing hydrogen as an export product. As their petroleum reserves become exhausted, the countries of the Middle East and Africa may be able to shift to this new technology and still remain energy exporters.

It is interesting to notice that the primary process of photosynthesis in plants is closely similar to the mechanism by which solar cells separate charges and prevent the back-reaction. We can see why a back-reaction must be prevented if we consider the excitation of a single atom. An absorbed photon lifts an electron from a filled atomic orbital to an empty one, leaving a positively-charged hole in the orbital from which the electron came. However, a back-reaction occurs almost immediately: The excited electron falls back into

[3]https://www.theguardian.com/environment/2017/oct/04/solar-power-renewables-international-energy-agency

[4]https://www.iea.org/newsroom/news/2017/october/solar-pv-grew-faster-than-any-other-fuel-in-2016-opening-a-new-era-for-solar-pow.html

[5]https://www.iea.org/renewables/

the orbital from which it came, and the absorbed energy is re-emitted. One can say that the electron and hole have recombined.

In higher plants, the back reaction is prevented because the photon is absorbed in a membrane which has a sandwich-like structure. Dye molecules (usually chlorophyll molecules) are sandwiched between a layer of charge donor molecules on one side of the membrane, and a layer of charge acceptor molecule on the other side. The electron quickly migrates to the acceptors, which are molecules with low-lying unfilled orbitals. Meanwhile the hole has quickly moved to the opposite side of the membrane. where it combines with an electron from a donor molecule. A donor molecule is a molecule whose highest filled orbital is high in energy. In this process, the back.reaction is prevented. The electron and hole are on opposite sides of the membrane, and they can only recombine after they have driven the metabolism of the plant.

In a photovoltaic solar cell, the mechanism by which the back-reaction is prevented is exactly similar. It too has a sandwich-like structure, with charge donors on one side, charge-acceptors on the other, and photon absorbers in the middle. Here too, the electron and hole quickly migrate to opposite sides. They can only recombine by traveling through the external circuit, which is analogous to a plant's metabolism, and performing useful work.

The cost of manufacturing photovoltaics continues to fall rapidly. In 2017, a homeowner paid approximately \$3,360 per kilowatt to have rooftop solar panels installed Usually photovoltaic panels are warranted for a life of 20 years, but they are commonly still operational after 30 years or more. Using the fact that there are 8760 hours in a year, and thus 175200 hours in 20 years, we can calculate that the cost of electricity to a solar-using homeowner today is about 1.92 cents per kilowatt hour. This can be compared with electricity generated from coal, which in 2011 cost 3.23 cents per kilowatt hour, while electricity generated from natural gas cost 4.51 cents per kilowatt hour. We must also remember that photovoltaics are falling rapidly in price, and that the fossil fuel costs do not include externalities, such as their contribution to climate change.

Concentrating photovoltaic systems are able to lower costs still further by combining silicon solar cells with reflectors that concentrate the sun's rays. The most inexpensive type of concentrating reflector consists of a flat piece of aluminum-covered plastic material bent into a curved shape along one of its dimensions, forming a trough-shaped surface. (Something like this shape results when we hold a piece of paper at the top and bottom with our two hands, allowing the center to sag.) The axis of the reflector can be oriented so that it points towards the North Star. A photovoltaic array placed along the focal line will then receive concentrated sunlight throughout the day.

Photovoltaic efficiency is defined as the ratio of the electrical power produced by a cell to the solar power striking its surface. For commercially available cells today, this ratio is between 9% and 14%. If we assume 5 hours of bright sunlight per day, this means that a photo cell in a desert area near to the equator (where 1 kW/m^2 of peak solar power reaches the earth's surface) can produce electrical energy at the average rate of 20-30 W_e/m^2, the average being taken over an entire day and night. The potential power per unit area for photovoltaic systems is far greater than for biomass. However, the mix of renewable energy sources most suitable for a particular country depends on many factors. We will see below that biomass is a promising future source of energy for Sweden, because of Sweden's low population density and high rainfall. By contrast, despite the high initial investment required, photovoltaics are undoubtedly a more promising future energy source for southerly countries with clear skies.

In comparing photovoltaics with biomass, we should be aware of the difference between electrical energy and energy contained in a the chemical bonds of a primary fuel such as wood or rapeseed oil. If Sweden (for example) were to supply all its energy needs from biomass, part of the biomass would have to be burned to generate electricity. The efficiency of energy conversion in electricity generation from fuel is 20%-35%. Of course, in dual use power plants, part of the left-over heat from electrical power generation can be used to heat homes or greenhouses. However, hydropower, wind power and photovoltaics have an advantage in generating electrical power, since they do so directly and without loss, whereas generation of electricity from biomass involves a loss from the inefficiency of the conversion from fuel energy to electrical energy. Thus a rational renewable energy program for Sweden should involve a mixture of biomass for heating and direct fuel use, with hydropower and wind power for generation of electricity. Perhaps photovoltaics will also play a role in Sweden's future electricity generation, despite the country's northerly location and frequently cloudy skies.

The global market for photovoltaics is expanding at the rate of 30% per year. This development is driven by rising energy prices, subsidies to photovoltaics by governments, and the realization of the risks associated with global warming and consequent international commitments to reduce carbon emissions. The rapidly expanding markets have resulted in lowered photovoltaic production costs, and hence further expansion, still lower costs, etc. - a virtuous feedback loop.

Solar thermal power plants

Solar Parabolic Troughs can be used to heat a fluid, typically oil, in a pipe running along the focal axis. The heated fluid can then be used to generate electrical power. The liquid that is heated in this way need not be oil. In a solar thermal power plant in California, reflectors move in a manner that follows the sun's position and they concentrate solar energy onto a tower, where molten salt is heated to a temperature of 1050 degrees F (566 ^{o}C). The molten salt stores the heat, so that electricity can be generated even when the sun is not shining. The California plant generates 10 MW_e.

Solar designs in architecture

At present, the average global rate of use of primary energy is roughly 2 kW_t per person. In North America, the rate is 12 kW_t per capita, while in Europe, the figure is 6 kW_t. In Bangladesh, it is only 0.2 kW_t. This wide variation implies that considerable energy savings are possible, through changes in lifestyle, and through energy efficiency.

Figure 11.2: **A rooftop array of photovoltaic cells.**

Figure 11.3: **A solar thermal power plant. Arrays of heliostatic reflectors concentrate the sun's rays onto molten salt in the tower. The plant produces electricity at night because the salt remains hot..**

Figure 11.4: **A solar cooker.**

Figure 11.5: **A rooftop solar thermal array for domestic water heating.**

Important energy savings can be achieved through solar design in architecture. For example, insulation can be improved in walls, and insulating shutters can be closed at night.

In double envelope construction, a weatherproof shell surrounds the inner house. Between the outer shell and the house, sun-heated air circulates. A less extreme example of this principle is the construction of south-facing conservatories. The sun-heated air in the conservatories acts as a thermal buffer, and reduces heat loss from the house.

Solar design aims at making houses cool in the summer and warm in the winter. Awnings can be spread out in the summer to shade windows, and rolled together in the winter to allow sunshine to enter the house. Alternatively, deciduous trees can be planted in front of south-facing windows. During the summer, the leaves of the trees shade the windows, while in the winter, the leaves fall, allowing the sun to enter.

During daylight hours, houses can be illuminated by fiber optic light pipes, connected to a parabolic collector on the roof. The roof can also contain arrays of solar photovoltaic cells and solar water heaters.

Houses can be heated in the winter by heat pumps connected to a deeply buried network of pipes. Heat pumps function in much the same way as refrigerators or air conditioners. When they are used to warm houses in the winter, a volatile liquid such as ammonia is evaporated underground, where the temperature is relatively constant, not changing much between summer and winter. In the evaporation process, heat is absorbed from the ground. The gas is then compressed and re-liquefied within the house, and in this process, it releases the heat that was absorbed underground. Electricity is of course required to drive a heat pump, but far less electrical power is needed to do this than would be required to heat the house directly.

In general, solar design of houses and other buildings requires an initial investment, but over time, the investment is amply repaid through energy savings.

Solar systems for heating water and cooking

Solar heat collectors are are already in common use to supply hot water for families or to heat swimming pools. A common form of the solar heat collector consists of a flat, blackened heat-collecting plate to which tubes containing the fluid to be heated are connected. The plate is insulated from the atmosphere by a layer of air (in some cases a partial vacuum) above which there is a sheet of glass. Water flowing through the tubes is collected in a tank whenever it is hotter than the water already there. In cases where there is a danger of freezing, the heated fluid may contain antifreeze, and it may then exchange heat with water in the collection tank. Systems of this kind can function even in climates as unfavorable as that of Northern Europe, although during winter months they must be supplemented by conventional water-heaters.

In the developing countries, wood is often used for cooking, and the result is sometimes deforestation, soil erosion and desertification. In order to supply an alternative, many designs for solar cooking have been developed. Often the designs are very simple, and many are both easy and inexpensive to build, the starting materials being aluminum foil and cardboard boxes.

11.6 Wind energy

Wind parks in favorable locations, using modern wind turbines, are able to generate 10 MW_e/km^2 or 10 W_e/m^2. Often wind farms are placed in offshore locations. When they are on land, the area between the turbines can be utilized for other purposes, for example for pasturage. For a country like Denmark, with good wind potential but cloudy skies, wind turbines can be expected to play a more important future role than photovoltaics. Denmark is already a world leader both in manufacturing and in using wind turbines. Today, on windy days, 100% of all electricity used in Denmark is generated by wind power, and the export of wind turbines makes a major contribution to the Danish economy. The use of wind power is currently growing at the rate of 38% per year. In the United States, it is the fastest-growing form of electricity generation.

The location of wind parks is important, since the energy obtainable from wind is proportional to the cube of the wind velocity. We can understand this cubic relationship by remembering that the kinetic energy of a moving object is proportional to the square of its velocity multiplied by the mass. Since the mass of air moving past a wind turbine is proportional to the wind velocity, the result is the cubic relationship just mentioned.

Before the decision is made to locate a wind park in a particular place, the wind velocity is usually carefully measured and recorded over an entire year. For locations on land, mountain passes are often very favorable locations, since wind velocities increase with altitude, and since the wind is concentrated in the passes by the mountain barrier. Other favorable locations include shorelines and offshore locations on sand bars. This is because onshore winds result when warm air rising from land heated by the sun is replaced by cool marine air. Depending on the season, the situation may be reversed at night, and an offshore wind may be produced if the water is warmer than the land.

The cost of wind-generated electrical power is currently lower than the cost of electricity generated by burning fossil fuels.

The "energy payback ratio" of a power installation is defined as the ratio of the energy produced by the installation over its lifetime, divided by the energy required to manufacture, construct, operate and decommission the installation. For wind turbines, this ratio is 17-39, compared with 11 for coal-burning plants. The construction energy of a wind turbine is usually paid back within three months.

Besides the propeller-like design for wind turbines there are also designs where the rotors turn about a vertical shaft. One such design was patented in 1927 by the French aeronautical engineer Georges Jean Marie Darrieus. The blades of a Darrieus wind turbine are airfoils similar to the wings of an aircraft. As the rotor turns in the wind, the stream of air striking the airfoils produces a force similar to the "lift" of an airplane wing. This force pushes the rotor in the direction that it is already moving. The Darrieus design has some advantages over conventional wind turbine design, since the generator can be placed

Figure 11.6: **Rows of wind turbines.**

Figure 11.7: **Vertical axis wind turbines.**

Figure 11.8: **Wind turbines on the Danish island of Samsø The island was the first in the world to achieve 100% renewable energy.**

at the bottom of the vertical shaft, where it may be more easily serviced. Furthermore, the vertical shaft can be lighter than the shaft needed to support a conventional wind turbine.

One problem with wind power is that it comes intermittently, and demand for electrical power does not necessarily come at times when the wind is blowing most strongly. To deal with the problem of intermittency, wind power can be combined with other electrical power sources in a grid. Alternatively, the energy generated can be stored, for example by pumped hydroelectric storage or by using hydrogen technology, as will be discussed below.

Bird lovers complain that birds are sometimes killed by rotor blades. This is true, but the number killed is small. For example, in the United States, about 70,000 birds per year are killed by turbines, but this must be compared with 57 million birds killed by automobiles and 97.5 million killed by collisions with plate glass.

The aesthetic aspects of wind turbines also come into the debate. Perhaps in the future, as wind power becomes more and more a necessity and less a matter of choice, this will be seen as a "luxury argument".

A Danish island reaches 100% renewable energy

The Danish island of Samsø is only 112 square kilometers in size, and its population numbers only 4,300. Nevertheless, it has a unique distinction. Samsø was the first closed land area to declare its intention of relying entirely on renewable energy, and it has now achieved this aim, provided that one stretches the definitions slightly.

In 1997, the Danish Ministry of Environment and Energy decided to sponsor a renewable-energy contest. In order to enter, communities had to submit plans for how they could make a transition from fossil fuels to renewable energy. An engineer (who didn't live there) thought he knew how Samsø could do this, and together with the island's mayor he submitted a plan which won the contest. As a result, the islanders became interested in renewable energy. They switched from furnaces to heat pumps, and formed cooperatives for the construction of windmill parks in the sea near to the island. By 2005, Samsø was producing, from renewable sources, more energy than it was using. The islanders still had gasoline-driven automobiles, but they exported from their windmill parks an amount of electrical energy that balanced the fossil fuel energy that they imported. This is a story that can give us hope for the future, although a farming community like Samsø cannot serve as a model for the world.

11.7 Hydroelectric power

In 2015, hydroelectric power supplied 16.6% of all electrical power, and 70% of the electrical power generated from renewable energy. In the developed countries, the potential for increasing this percentage is small, because most of the suitable sites for dams are already in use. Mountainous regions of course have the greatest potential for hydroelectric power, and this correlates well with the fact that virtually all of the electricity generated in Norway comes from hydro, while in Iceland and Austria the figures are respectively 83% and 67%. Among the large hydroelectric power stations now in use are the La Grande complex in Canada (16 GW_e) and the Itapú station on the border between Brazil and Paraguay (14 GW_e). The Three Gorges Dam in China produces 18.2 GW_e.

Even in regions where the percentage of hydro in electricity generation is not so high, it plays an important role because hydropower can be used selectively at moments of peak demand. Pumping of water into reservoirs can also be used to store energy.

The creation of lakes behind new dams in developing countries often involves problems, for example relocation of people living on land that will be covered by water, and loss of the land for other purposes[6]. However the energy gain per unit area of lake can be very large - over 100 W_e/m^2. Fish ladders can be used to enable fish to reach their spawning grounds above dams. In addition to generating electrical power, dams often play useful roles in flood control and irrigation.

At present, hydroelectric power is used in energy-intensive industrial processes, such as the production of aluminum. However, as the global energy crisis becomes more severe, we can expect that metals derived from electrolysis, such as aluminum and magnesium, will be very largely replaced by other materials, because the world will no longer be able to afford the energy needed to produce them.

[6] Over a million people were displaced by the construction of the Three Gorges Dam in China, and many sites of cultural value were lost

Table 11.1: Technical potential and utilization of hydropower. (Data from World Energy Council, 2003.)

Region	Technical potential	Annual output	Percent used
Asia	0.5814 TW_e	0.0653 TW_e	11%
S. America	0.3187 TW_e	0.0579 TW_e	18%
Europe	0.3089 TW_e	0.0832 TW_e	27%
Africa	0.2155 TW_e	0.0091 TW_e	4%
N. America	0.1904 TW_e	0.0759 TW_e	40%
Oceania	0.0265 TW_e	0.0046 TW_e	17%
World	1.6414 TW_e	0.2960 TW_e	18%

Figure 11.9: **Hydroelectric power does not suffer from the problem of intermittency, but may sometimes produce undesirable social and ecological impacts.**

11.8 Energy from the ocean

Tidal power

The twice-daily flow of the tides can be harnessed to produce electrical power. Ultimately tidal energy comes from the rotation of the earth and its interaction with the moon's gravitational field. The earth's rotation is very gradually slowing because of tidal friction, and the moon is gradually receding from the earth, but this process will take such an extremely long time that tidal energy can be thought of as renewable.

There are two basic methods for harnessing tidal power. One can build barriers that create level differences between two bodies of water, and derive hydroelectric power from the head of water thus created. Alternatively it is possible to place the blades of turbines in a tidal stream. The blades are then turned by the tidal current in much the same way that the blades of a wind turbine are turned by currents of air.

There are plans for using the second method on an extremely large scale in Cook Strait, near New Zealand. A company founded by David Beach and Chris Bathurst plans to anchor 7,000 turbines to the sea floor of Cook Strait in such a way that they will float 40 meters below the surface. Beach and Bathurst say that in this position, the turbines will be safe from the effects of earthquakes and storms. The tidal flow through Cook Strait is so great that the scheme could supply all of New Zealand's electricity if the project is completed on the scale visualized by its founders.

Choosing the proper location for tidal power stations is important, since the height of tides depends on the configuration of the land. For example, tides of 17 meters occur in the Bay of Fundy, at the upper end of the Gulf of Maine, between New Brunswick and Nova

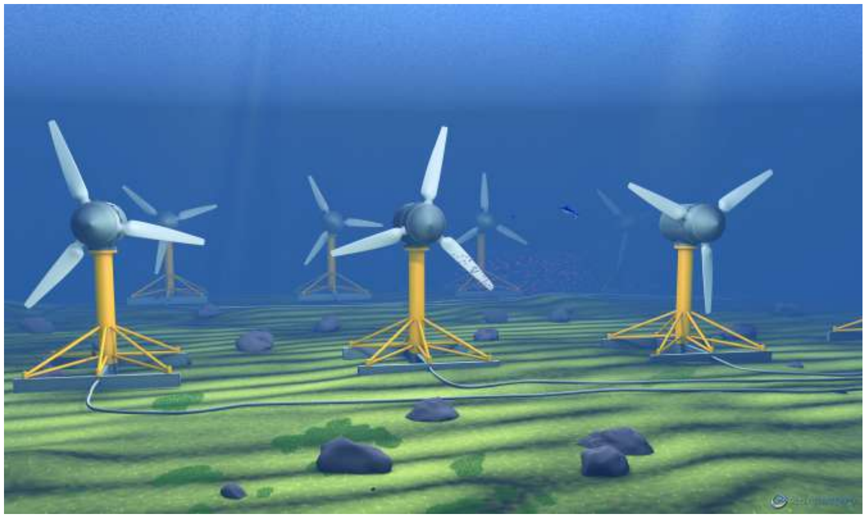

Figure 11.10: **Underwater turbines can make use of the energy of ocean currents.**

Scotia. Here tidal waves are funneled into the bay, creating a resonance that results in the world's greatest level difference between high an low tides. An 18 MW_e dam-type tidal power generation station already exists at Annapolis River, Nova Scotia, and there are proposals to increase the use of tidal power in the Bay of Fundy. Some proposals involve turbines in the tidal stream, similar to those proposed for use in the Cook Strait.

In the future, favorable locations for tidal power may be exploited to their full potentialities, even thought the output of electrical energy exceeds local needs. The excess energy can be stored in the form of hydrogen (see below) and exported to regions deficient in renewable energy resources.

Wave energy

At present, the utilization of wave energy is in an experimental stage. In Portugal, there are plans for a wave farm using the Pelamis Wave Energy Converter. The Pelamis is a long floating tube with two or more rigid sections joined by hinges. The tube is tethered with its axis in the direction of wave propagation. The bending between sections resulting from passing waves is utilized to drive high pressure oil through hydraulic motors coupled to electrical generators. Each wave farm in the Portuguese project is planned to use three Pelamis converters, each capable of producing 750 kW_e. Thus the total output of each wave farm will be 2.25 MW_e.

Another experimental wave energy converter is Salter's Duck, invented in the 1970's by Prof. Stephen Salter of the University of Edinburgh, but still being developed and improved. Like the Pelamis, the Duck is also cylindrical in shape, but the axis of the cylinder is parallel to the wave front, i.e. perpendicular to the direction of wave motion. A floating cam, attached to the cylinder, rises and falls as a wave passes, driving hydraulic motors within the cylinder. Salter's Duck is capable of using as much as 65% of the wave's

Figure 11.11: **The Pelamis wave energy transformer floats on the ocean like a giant sea snake. It consists of several segments which move against each other and build up hydraulic pressure. This in turn drives a turbine. A new Pelamis generation is currently under construction.**

energy.

The energy potentially available from waves is very large, amounting to as much as 100 kilowatts per meter of wave front in the best locations.

Ocean thermal energy conversion

In tropical regions, the temperature of water at the ocean floor is much colder than water at the surface. In ocean thermal energy conversion, cold water is brought to the surface from depths as great as 1 km, and a heat engine is run between deep sea water at a very low temperature and surface water at a much higher temperature.

According to thermodynamics, the maximum efficiency of a heat engine operating between a cold reservoir at the absolute temperature T_C and a hot reservoir at the absolute temperature T_H is given by 1-T_C/T_H. In order to convert temperature on the centigrade scale to absolute temperature (degrees Kelvin) one must add 273 degrees. Thus the maximum efficiency of a heat engine operating between water at the temperature of 25 ^{o}C and water at 5 ^{o}C is 1-(5+273)/(25+273)=0.067 = 6.7%. The efficiency of heat engines is always less than the theoretical maximum because of various losses, such as the loss due to friction. The actual overall efficiencies of existing ocean thermal energy conversion (OTEC) stations are typically 1-3%. On the other hand, the amount of energy potentially available from differences between surface and bottom ocean temperatures is extremely large.

Since 1974, OTEC research has been conducted by the United States at the Natural

Energy Laboratory of Hawaii. The Japanese government also supports OTEC research, and India has established a 1 MW_e OTEC power station floating in the ocean near to Tamil Nadu.

Renewable energy from evaporation

A September 26, 2017 article by Ahmet-Hamdi Cavusoglu et al. in *Nature Communications* points to evaporation as a future source of renewable energy. Here are some excerpts from the article:

"About 50% of the solar energy absorbed at the Earth's surface drives evaporation, fueling the water cycle that affects various renewable energy resources, such as wind and hydropower. Recent advances demonstrate our nascent ability to convert evaporation energy into work, yet there is little understanding about the potential of this resource.

"Here we study the energy available from natural evaporation to predict the potential of this ubiquitous resource. We find that natural evaporation from open water surfaces could provide power densities comparable to current wind and solar technologies while cutting evaporative water losses by nearly half. We estimate up to 325 GW of power is potentially available in the United States. Strikingly, water's large heat capacity is sufficient to control power output by storing excess energy when demand is low, thus reducing intermittency and improving reliability. Our findings motivate the improvement of materials and devices that convert energy from evaporation...

"Recent advances in water responsive materials and devices demonstrate the ability to convert energy from evaporation into work. These materials perform work through a cycle of absorbing and rejecting water via evaporation. These water-responsive materials can be incorporated into evaporation-driven engines that harness energy when placed above a body of evaporating water. With improvements in energy conversion efficiency, such devices could become an avenue to harvest energy via natural evaporation from water reservoirs."

Ozgur Sahin, a biophysicist at Columbia, has developed technology that uses spores from the harmless soil-dwelling bacterium *B. subtilis* to absorb and release water when the relative humidity of the surrounding air changes. At high humidity, the spores take in water and expand, and at low humidity they release water and contract, acting like a muscle.

11.9 Biomass

Biomass is defined as any energy source based on biological materials produced by photosynthesis - for example wood, sugar beets, rapeseed oil, crop wastes, dung, urban organic wastes, processed sewage, etc. Using biomass for energy does not result in the net emission of CO_2, since the CO_2 released by burning the material had previously been absorbed from the atmosphere during photosynthesis. If the biological material had decayed instead of being burned, it would released the same amount of CO_2 as in the burning process.

Figure 11.12: **Rapeseed is grown in several countries, including Denmark and the UK. Experimental Danish buses are already running on rapeseed oil.**

The solar constant has the value 1.4 kilowatts/m^2. It represents the amount of solar energy per unit area[7] that reaches the earth, before the sunlight has entered the atmosphere. Because the atmosphere reflects 6% and absorbs 16%, the peak power at sea level is reduced to 1.0 kW/m^2. Clouds also absorb and reflect sunlight. Average cloud cover reduces the energy of sunlight a further 36%. Also, we must take into account the fact that the sun's rays do not fall perpendicularly onto the earth's surface. The angle that they make with the surface depends on the time of day, the season and the latitude.

In Sweden, which lies at a northerly latitude, the solar energy per unit of horizontal area is less than for countries nearer the equator. Nevertheless, Göran Persson, during his term as Prime Minister of Sweden, announced that his government intends to make the country independent of imported oil by 2020 through a program that includes energy from biomass.

In his thesis, *Biomass in a Sustainable Energy System*, the Swedish researcher Pål Börjesson states that of various crops grown as biomass, the largest energy yields come from short-rotation forests (Salix viminalis, a species of willow) and sugar beet plantations. These have an energy yield of from 160 to 170 GJ$_t$ per hectare-year. (The subscript t means "thermal". Energy in the form of electricity is denoted by the subscript e). One can calculate that this is equivalent to about 0.5 MW$_t$/km^2, or 0.5 W$_t$/m^2. Thus, although 1.0 kW/m^2 of solar energy reaches the earth at noon at the equator, the trees growing in northerly Sweden can harvest a day-and-night and seasonal average of only 0.5 Watts of thermal energy per horizontal square meter[8]. Since Sweden's present primary energy use is approximately 0.04 TW$_t$, it follows that if no other sources of energy were used, a square area of Salix forest 290 kilometers on each side would supply Sweden's present energy needs. This corresponds to an area of 84,000 km^2, about 19% of Sweden's total

[7]The area is assumed to be perpendicular to the sun's rays.

[8]In tropical regions, the rate of biomass production can be more than double this amount.

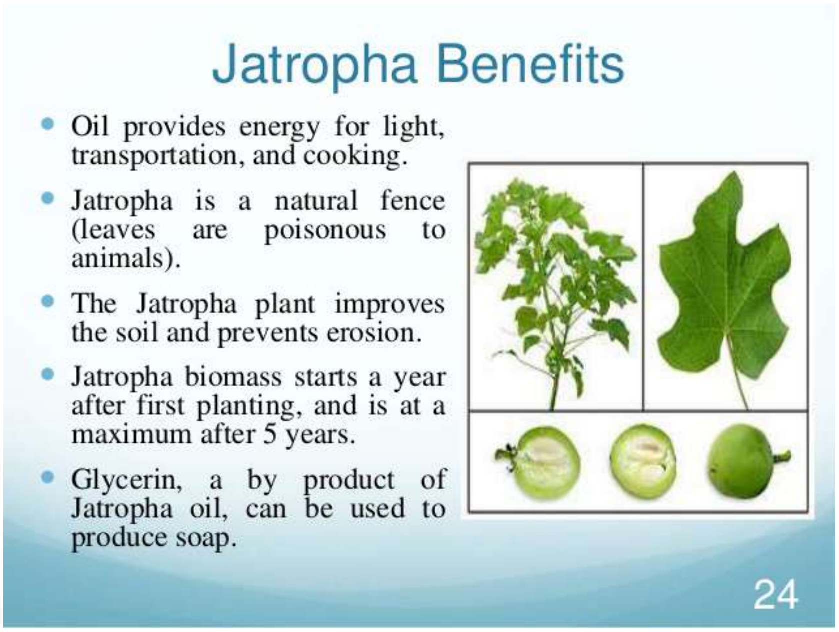

Figure 11.13: **In some countries, Jatropha is a promising source of biomass..**

area[9]. Of course, Sweden's renewable energy program will not rely exclusively on energy crops, but on a mixture of sources, including biomass from municipal and agricultural wastes, hydropower, wind energy and solar energy.

At present, both Sweden and Finland derive about 30% of their electricity from biomass, which is largely in the form of waste from the forestry and paper industries of these two countries.

Despite their northerly location, the countries of Scandinavia have good potentialities for developing biomass as an energy source, since they have small population densities and adequate rainfall. In Denmark, biodiesel oil derived from rapeseed has been used as fuel for experimental buses. Rapeseed fields produce oil at the rate of between 1,000 and 1,300 liters per hectare-crop. The energy yield is 3.2 units of fuel product energy for every unit of fuel energy used to plant the rapeseed, and to harvest and process the oil. After the oil has been pressed from rapeseed, two-thirds of the seed remains as a protein-rich residue which can be fed to cattle.

Miscanthus is a grassy plant found in Asia and Africa. Some forms will also grow in Northern Europe, and it is being considered as an energy crop in the United Kingdom. Miscanthus can produce up to 18 dry tonnes per hectare-year, and it has the great advantage that it can be cultivated using ordinary farm machinery. The woody stems are very suitable for burning, since their water content is low (20-30%).

For some southerly countries, honge oil, derived from the plant *Pongamia pinnata* may prove to be a promising source of biomass energy. Studies conducted by Dr. Udishi

[9]Additional land area would be needed to supply the energy required for planting, harvesting, transportation and utilization of the wood.

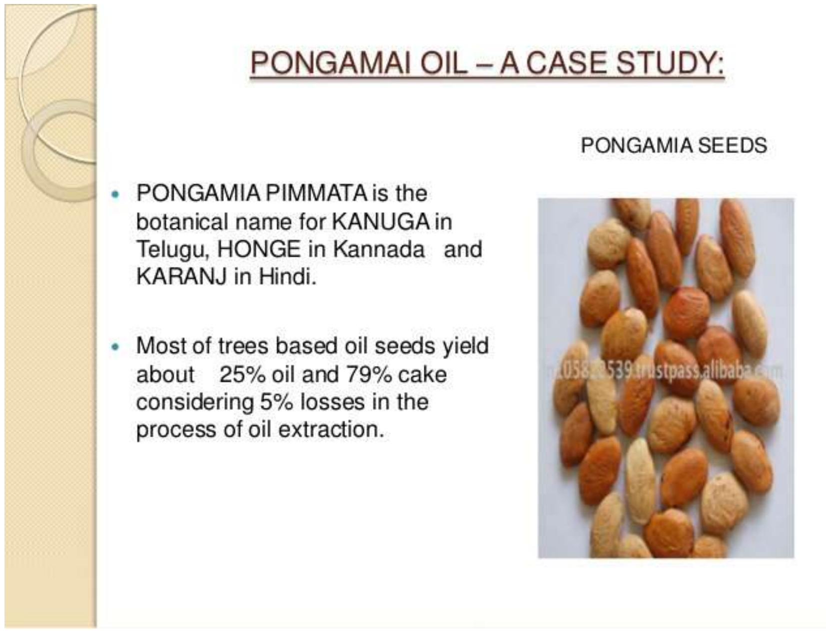

Figure 11.14: **The price of honge oil is quite competitive with other forms of oil.**

Shrinivasa at the Indian Institute of Sciences in Bangalore indicate that honge oil can be produced at the cost of $150 per ton. This price is quite competitive when compared with other potential fuel oils.

Recent studies have also focused on a species of algae that has an oil content of up to 50%. Algae can be grown in desert areas, where cloud cover is minimal. Farm waste and excess CO_2 from factories can be used to speed the growth of the algae.

It is possible that in the future, scientists will be able to create new species of algae that use the sun's energy to generate hydrogen gas. If this proves to be possible, the hydrogen gas may then be used to generate electricity in fuel cells, as will be discussed below in the section on hydrogen technology. Promising research along this line is already in progress at the University of California, Berkeley.

Biogas is defined as the mixture of gases produced by the anaerobic digestion of organic matter. This gas, which is rich in methane (CH_4), is produced in swamps and landfills, and in the treatment of organic wastes from farms and cities. The use of biogas as a fuel is important not only because it is a valuable energy source, but also because methane is a potent greenhouse gas, which should not be allowed to reach the atmosphere. Biogas produced from farm wastes can be used locally on the farm, for cooking and heating, etc. When biogas has been sufficiently cleaned so that it can be distributed in a pipeline, it is known as "renewable natural gas". It may then be distributed in the natural gas grid, or it can be compressed and used in internal combustion engines. Renewable natural gas can also be used in fuel cells, as will be discussed below in the section on Hydrogen Technology.

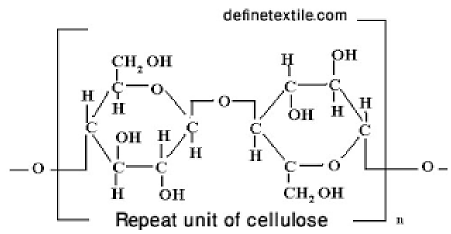

Figure 11.15: **Cellulose is a polysacheride. In other words, it is a long polymer whose subunits are sugars. The links between the sugar subunits in the chain can be broken, for example by the action of enzymes or acids. After this has been done, the resulting sugars can be fermented into alcohols, and these can be used to fuel motor vehicles or aircraft.**

Cellulostic ethanol

The fact that alcohols such as ethanol can be produced from cellulose has long been known.[10] In 1819, the French chemist Henri Braconnot demonstrated that cellulose could be broken down into sugars by treating it with sulfuric acid. The sugars thus produced could then be fermented into alcohols which could be used as liquid fuels.

In 1898, Germany built factories to commercialize this process, and shortly afterwards the same was done in the United States using a slightly different technique. These plants producing cellulostic ethanol operated during World War I, but the plants closed after the end of the war because of the cheapness and easy availability of fossil fuels. The production of cellulostic ethanol was revived during World War II.

During the last two decades, development of enzymatic techniques has supplied a better method of breaking the long cellulose polymer chain into sugars. In fact, it has recently become possible to use microbial enzymes both for this step and for the fermentation step.

In a September 9, 2008 article in the *MIT Technology Review.* Prachi Patal wrote: "New genetically modified bacteria could slash the costs of producing ethanol from cellulostic biomass, such as corn cobs and leaves, switchgrass, and paper pulp. The microbes produce ethanol at higher temperatures than are possible using yeast, which is currently employed to ferment sugar into the biofuel. The higher temperature more than halves the quantity of the costly enzymes needed to split cellulose into the sugars that the microbes can ferment. What's more, while yeast can only ferment glucose, 'this microorganism is good at using all the different sugars in biomass and can use them simultaneously and rapidly,' says Lee Lynd, an engineering professor at Dartmouth College, who led the microbe's development...

"Lynd wants to create microbes that would do it all: efficiently break down the cellulose and hemicellulose, and then ferment all the resulting sugars. Lynd, a cofounder of Mascoma, is working with colleagues at the startup, based in Cambridge, MA, to develop a simple one-step process for making cellulostic ethanol. In the combined process, a mixture of biomass and the microbes would go into a tank, and ethanol would come out."

Cellulostic ethanol has several advantages over alcohol derived from grain;

[10]See the Wikipedia article on *Cellulostic Ethanol*

- Cellulostic ethanol avoids the food-fuel competition.
- The net greenhouse-gas-reducing effect of ethanol derived from grain is questionable.
- Cellulostic ethanol can use cardboard and paper waste as starting substances, thus reducing the quantity of trash in waste dumps.

11.10 Geothermal energy

The ultimate source of geothermal energy is the decay of radioactive nuclei in the interior of the earth. Because of the heat produced by this radioactive decay, the temperature of the earth's core is 4300 ^{o}C. The inner core is composed of solid iron, while the outer core consists of molten iron and sulfur compounds. Above the core is the mantle, which consists of a viscous liquid containing compounds of magnesium, iron, aluminum, silicon and oxygen. The temperature of the mantle gradually decreases from 3700 ^{o}C near the core to 1000 ^{o}C near the crust. The crust of the earth consists of relatively light solid rocks and it varies in thickness from 5 to 70 km.

The outward flow of heat from radioactive decay produces convection currents in the interior of the earth. These convection currents, interacting with the earth's rotation, produce patterns of flow similar to the trade winds of the atmosphere. One result of the currents of molten conducting material in the interior of the earth is the earth's magnetic field. The crust is divided into large sections called "tectonic plates", and the currents of molten material in the interior of the earth also drag the plates into collision with each other. At the boundaries, where the plates collide or split apart, volcanic activity occurs. Volcanic regions near the tectonic plate boundaries are the best sites for collection of geothermal energy.

The entire Pacific Ocean is ringed by regions of volcanic and earthquake activity, the so-called Ring of Fire. This ring extends from Tierra del Fuego at the southernmost tip of South America, northward along the western coasts of both South America and North America to Alaska. The ring then crosses the Pacific at the line formed by the Aleutian Islands, and it reaches the Kamchatka Peninsula in Russia. From there it extends southward along the Kurile Island chain and across Japan to the Philippine Islands, Indonesia and New Zealand. Many of the islands of the Pacific are volcanic in nature. Another important region of volcanic activity extends northward along the Rift Valley of Africa to Turkey, Greece and Italy. In the Central Atlantic region, two tectonic plates are splitting apart, thus producing the volcanic activity of Iceland. All of these regions are very favorable for the collection of geothermal power.

The average rate at which the energy created by radioactive decay in the interior of the earth is transported to the surface is 0.06 W_t/m^2. However, in volcanic regions near the boundaries of tectonic plates, the rate at which the energy is conducted to the surface is much higher - typically 0.3 W_t/m^2. If we insert these figures into the thermal conductivity law

$$q = K_T \frac{\Delta T}{z}$$

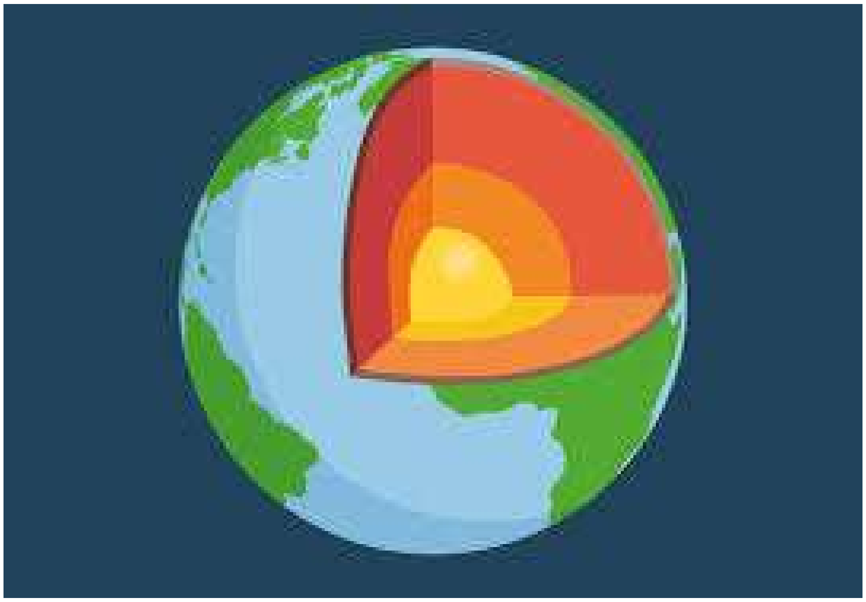

Figure 11.16: **The source of geothermal energy is the radioactive decay of elements deep within the earth.**

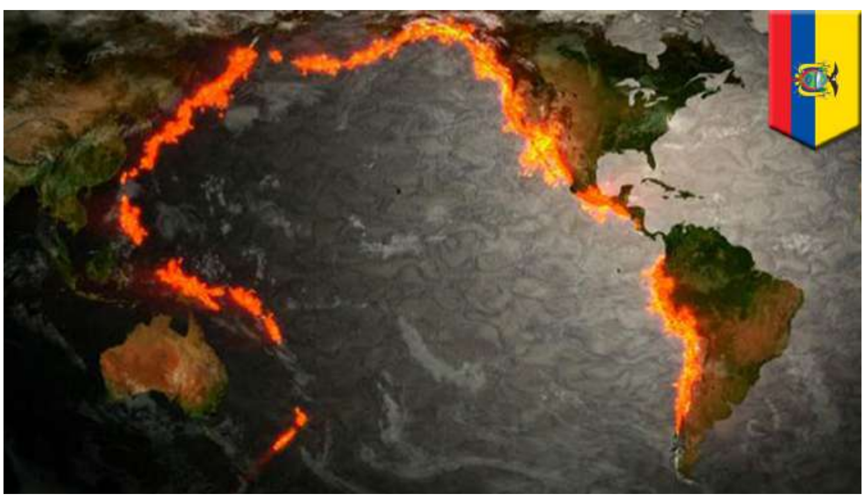

Figure 11.17: **The "ring of fire" is especially favorable for geothermal energy installations. The ring follows the western coasts of South America and North America to Alaska, After crossing the Bering Sea, it runs southward past Japan and Indonesia to New Zealand. Earthquakes and volcanic activity along this ring are produced by the collision of tectonic plates. Another strip-like region very favorable for geothermal installations follows Africa's Rift Valley northward through Turkey and Greece to Italy, while a third pass through Iceland.**

we can obtain an understanding of the types of geothermal resources available throughout the world. In the thermal conductivity equation, q is the power conducted per unit area, while K_T is the thermal conductivity of the material through the energy is passing. For sandstones, limestones and most crystalline rocks, thermal conductivities are in the range 2.5-3.5 $W_t/(m\ ^oC)$. Inserting these values into the thermal conductivity equation, we find that in regions near tectonic plate boundaries we can reach temperatures of 200 ^oC by drilling only 2 kilometers into rocks of the types named above. If the strata at that depth contain water, it will be in the form of highly-compressed steam. Such a geothermal resource is called a *high-enthalpy* resource[11].

In addition to high-enthalpy geothermal resources there are *low-enthalpy* resources in nonvolcanic regions of the world, especially in basins covered by sedimentary rocks. Clays and shales have a low thermal conductivity, typically 1-2 $W_t/(m\ ^oC)$. When we combine these figures with the global average geothermal power transmission, $q = 0.06\ W_t/m^2$, the thermal conduction equation tells us that $\Delta T/z = 0.04\ ^oC/m$. In such a region the geothermal resources may not be suitable for the generation of electrical power, but nevertheless adequate for heating buildings. The Creil district heating scheme north of Paris is an example of a project where geothermal energy from a low enthalpy resource is used for heating buildings.

The total quantity of geothermal electrical power produced in the world today is 8 GW_e, with an additional 16 GW_t used for heating houses and buildings. In the United States alone, 2.7 GW_e are derived from geothermal sources. In some countries, for example Iceland and Canada, geothermal energy is used both for electrical power generation and for heating houses.

There are three methods for obtaining geothermal power in common use today: Deep wells may yield dry steam, which can be used directly to drive turbines. Alternatively water so hot that it boils when brought to the surface may be pumped from deep wells in volcanic regions. The steam is then used to drive turbines. Finally, if the water from geothermal wells is less hot, it may be used in binary plants, where its heat is exchanged with an organic fluid which then boils. In this last method, the organic vapor drives the turbines. In all three methods, water is pumped back into the wells to be reheated. The largest dry steam field in the world is The Geysers, 145 kilometers north of San Francisco, which produces 1,000 MW_e.

There is a fourth method of obtaining geothermal energy, in which water is pumped down from the surface and is heated by hot dry rocks. In order to obtain a sufficiently large area for heat exchange the fissure systems in the rocks must be augmented, for example by pumping water down at high pressures several hundred meters away from the collection well. The European Union has established an experimental station at Soultz-sous-Forets in the Upper Rhine to explore this technique. The experiments performed at Soultz will determine whether the "hot dry rock" method can be made economically viable. If so, it can potentially offer the world a very important source of renewable energy.

[11]Enthalpy $\equiv H \equiv U + PV$ is a thermodynamic quantity that takes into account not only the internal energy U of a gas, but also energy PV that may be obtained by allowing it to expand.

The molten lava of volcanoes also offers a potential source of geothermal energy that may become available in the future, but at present, no technology has been developed that is capable of using it.

11.11 Hydrogen technologies

Electrolysis of water

When water containing a little acid is placed in a container with two electrodes and subjected to an external direct current voltage greater than 1.23 Volts, bubbles of hydrogen gas form at one electrode (the cathode), while bubbles of oxygen gas form at the other electrode (the anode). At the cathode, the half-reaction

$$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^- \qquad E^0 = -1.23\ Volts$$

takes place, while at the anode, the half-reaction

$$4H^+(aq) + 4e^- \rightarrow 2H_2(g) \qquad E^0 = 0$$

occurs.

Half-reactions differ from ordinary chemical reactions in containing electrons either as reactants or as products. In electrochemical reactions, such as the electrolysis of water, these electrons are either supplied or removed by the external circuit. When the two half-reactions are added together, we obtain the total reaction:

$$2H_2O(l) \rightarrow O_2(g) + 2H_2(g) \qquad E^0 = -1.23\ Volts$$

Notice that $4H^+$ and $4e^-$ cancel out when the two half-reactions are added. The total reaction does not occur spontaneously, but it can be driven by an external potential E, provided that the magnitude of E is greater than 1.23 volts.

When this experiment is performed in the laboratory, platinum is often used for the electrodes, but electrolysis of water can also be performed using electrodes made of graphite.

Electrolysis of water to produce hydrogen gas has been proposed as a method for energy storage in a future renewable energy system. For example, it might be used to store energy generated by photovoltaics in desert areas of the world. Compressed hydrogen gas could then be transported to other regions and used in fuel cells. Electrolysis of water and storage of hydrogen could also be used to solve the problem of intermittency associated with wind energy or solar energy.

Half reactions

Chemical reactions in which one or more electrons are transferred are called *oxidation-reduction reactions*. Any reaction of this type can be used in a fuel cell. As an example,

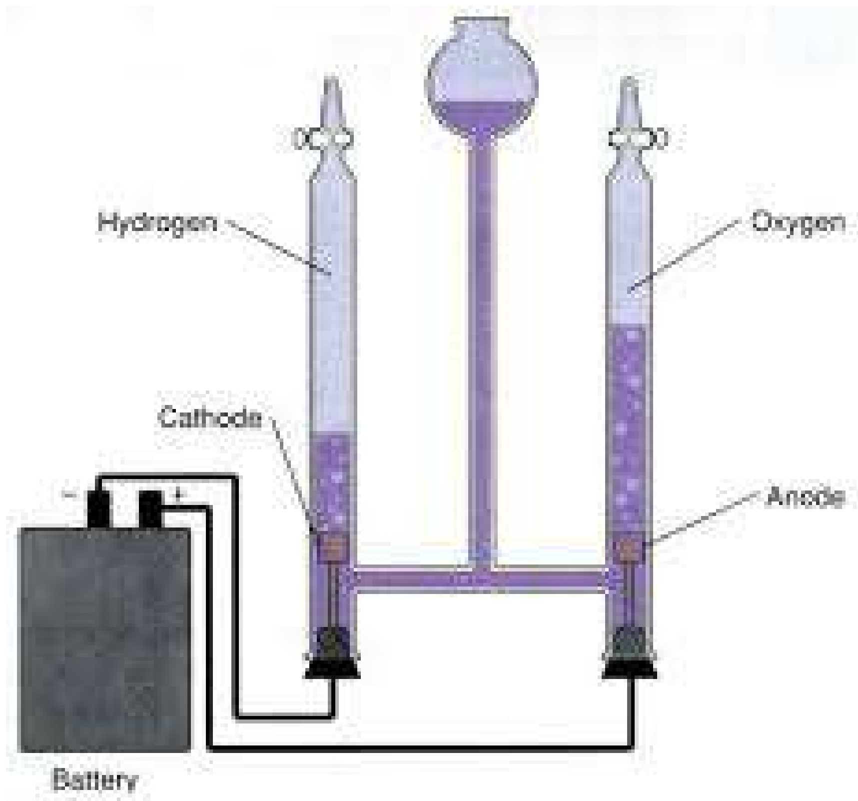

Figure 11.18: **Electrolysis of water.**

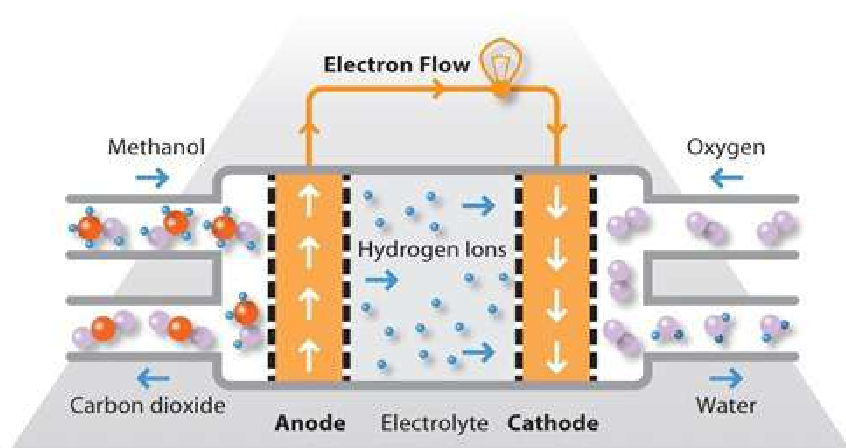

Figure 11.19: **A methanol fuel cell.**

we can consider the oxidation-reduction reaction in which solid lithium metal reacts with fluorine gas;

$$2Li_{(s)} + F_{2(g)} \rightarrow 2LiF_{(s)}$$

This reaction can be split into two half-reactions,

$$Li_{(s)} \rightarrow Li^{+} + e^{-} \qquad\qquad E_0 = -3.040\ V$$

and

$$F_{2(g)} \rightarrow 2F^{+} + 2e^{-} \qquad\qquad E_0 = 2.87\ V$$

The quantity E_0 which characterizes these half-reactions is called *standard potential* of the half-reaction, and it is measured in Volts. If the oxidation-reduction reaction is used as the basis of a fuel cell, the voltage of the cell is the difference between the two standard potentials. In the lithium fluoride example, it is

$$2.87\ V - (-3.040\ V) = 5.91\ V$$

Here are a few more half-reactions and their standard potentials:

$$\begin{array}{cl}
K^{+} + e^{-} \rightarrow\ K_{(s)} & E_0 = -2.924\ V \\
Na^{+} + e^{-} \rightarrow Na_{(s)} & E_0 = -2.7144\ V \\
2H_2O + 2e^{-} \rightarrow H_20 + 2OH^{-} & E_0 = -0.828\ V \\
Zn^{2+} + 2e^{-} \rightarrow Zn_{(s)} & E_0 = -0.7621\ V \\
Fe^{2+} + 2e^{-} \rightarrow Fe_{(s)} & E_0 = -0.440\ V \\
Pb^{2+} + 2e^{-} \rightarrow Pb_{(s)} & E_0 = -0.1266\ V \\
2H^{+} + 2e^{-} \rightarrow H_{2(g)} & E_0 \equiv 0.0000\ V \\
Cu^{2+} + 2e^{-} \rightarrow Cu_{(s)} & E_0 = +0.3394\ V \\
I_{2(s)} + 2e^{-} \rightarrow 2I^{-} & E_0 = +0.535\ V \\
Fe^{3+} + e^{-} \rightarrow Fe^{2+} & E_0 = +0.769\ V \\
Br_{2(l)} + 2e^{-} \rightarrow 2Br^{-} & E_0 = +1.0775\ V \\
O_{2(g)} + 4H^{+} + 4e^{-} \rightarrow 2H_2O & E_0 = +1.2288\ V \\
Cl_{2(g)} + 2e^{-} \rightarrow 2Cl^{-} & E_0 = +1.3601\ V
\end{array}$$

Fuel cells are closely related to storage batteries. Essentially, when we recharge a storage battery we are just running a fuel cell backwards, applying an electrical potential which is sufficient to make a chemical reaction run in a direction opposite to the way that it would run spontaneously. When the charged battery is afterwards used to drive a vehicle or to power an electronic device, the reaction runs in the spontaneous direction, but the energy of the reaction, instead of being dissipated as heat, drives electrons through an external circuit and performs useful work.

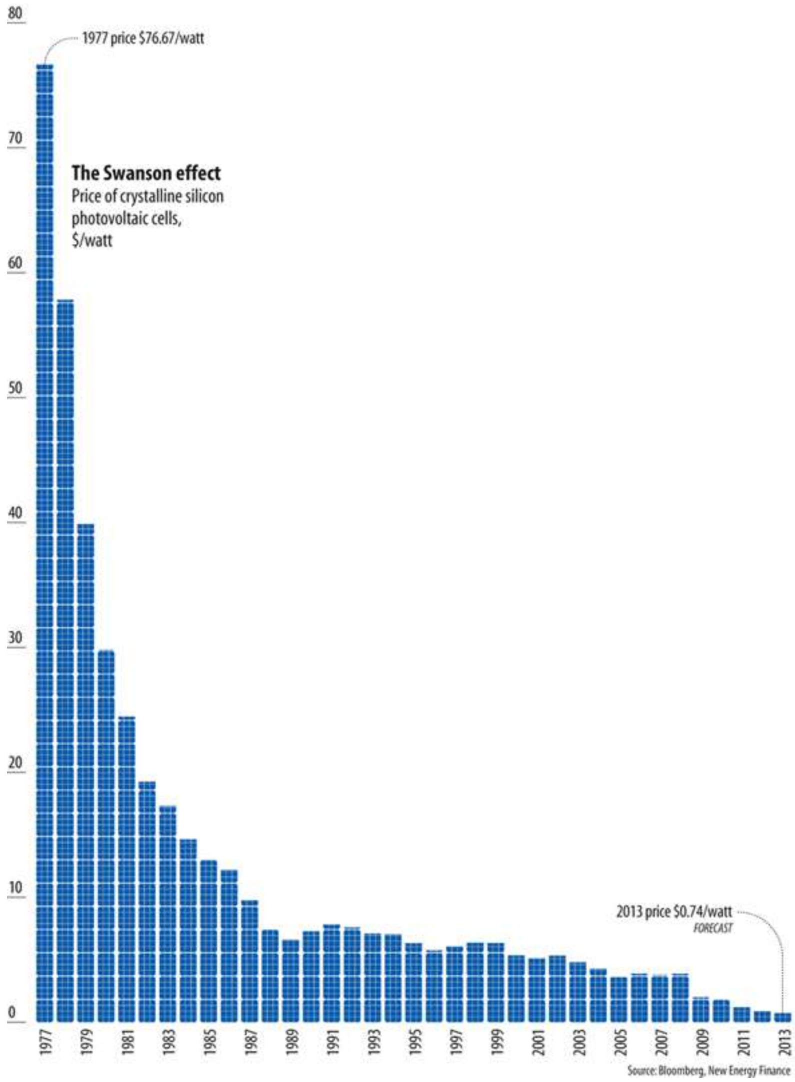

Figure 11.20: **The cost of photovoltaic cell panels is falling rapidly**

11.12 Renewables are now much cheaper than fossil fuels!

According to an article written by Megan Darby and published in *The Guardian* on 26 January, 2016, "Solar power costs are tumbling so fast the technology is likely to fast outstrip mainstream energy forecasts.

"That is the conclusion of Oxford University researchers, based on a new forecasting model published in Research Policy[12].

"Commercial prices have fallen by 58% since 2012 and by 16

"Since the 1980s, panels to generate electricity from sunshine have got 10% cheaper

[12]http://www.sciencedirect.com/science/article/pii/S0048733315001699

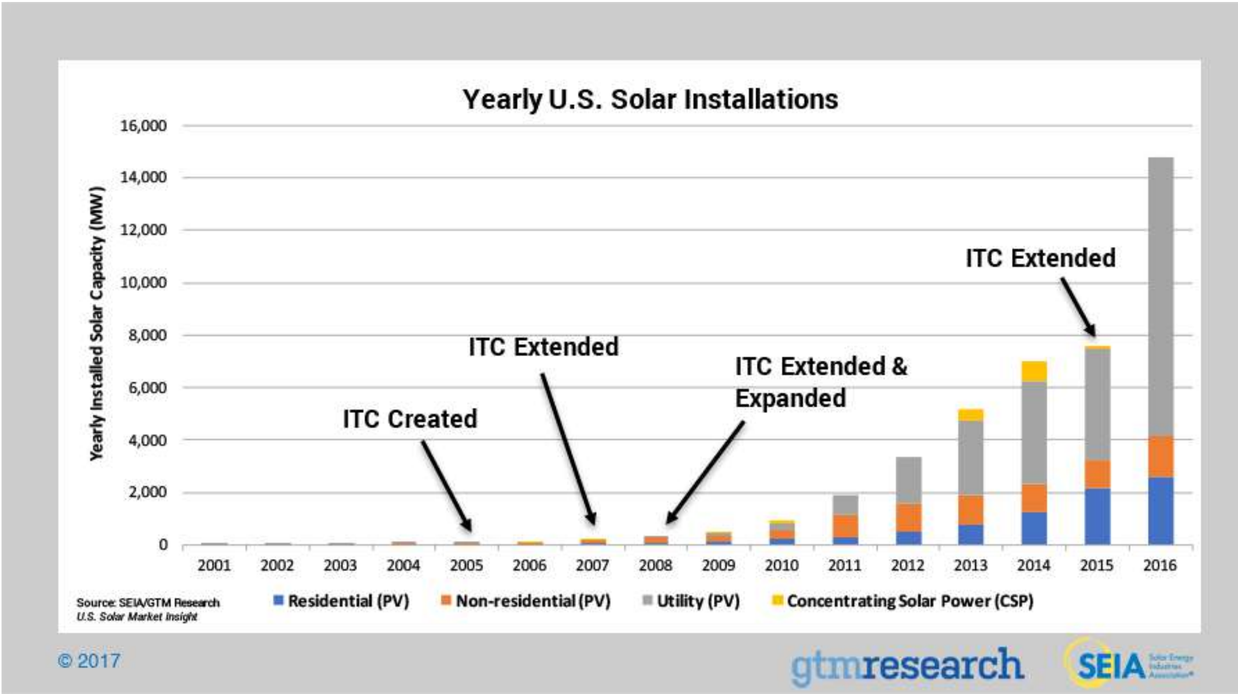

Figure 11.21: **Driven by falling prices, new solar installations in the United States are increasing rapidly. The acronym ITC stands for Solar Investment Tax Credit. Commercial prices have fallen by 58% since 2012 and by 16% in the last year**

each year. That is likely to continue, the study said, putting solar on course to meet 20% of global energy needs by 2027.' '

11.13 Lester R. Brown

In December 2008, Lester R. Brown called attention to the following facts:

- The renewable energy industry - wind, solar, geothermal - are expanding by over 30 percent yearly;
- There are now, in the U.S., 24,000 megawatts of wind generating capacity online, but there is a staggering 225,000 megawatts of planned wind farms;
- What is needed is a World War II-type mobilization to produce electric-powered cars that will operate at an equivalent gas cost of $1 per gallon (Replacing each SUV with a plug-in hybrid could save $20,000 of oil imports over its lifetime);

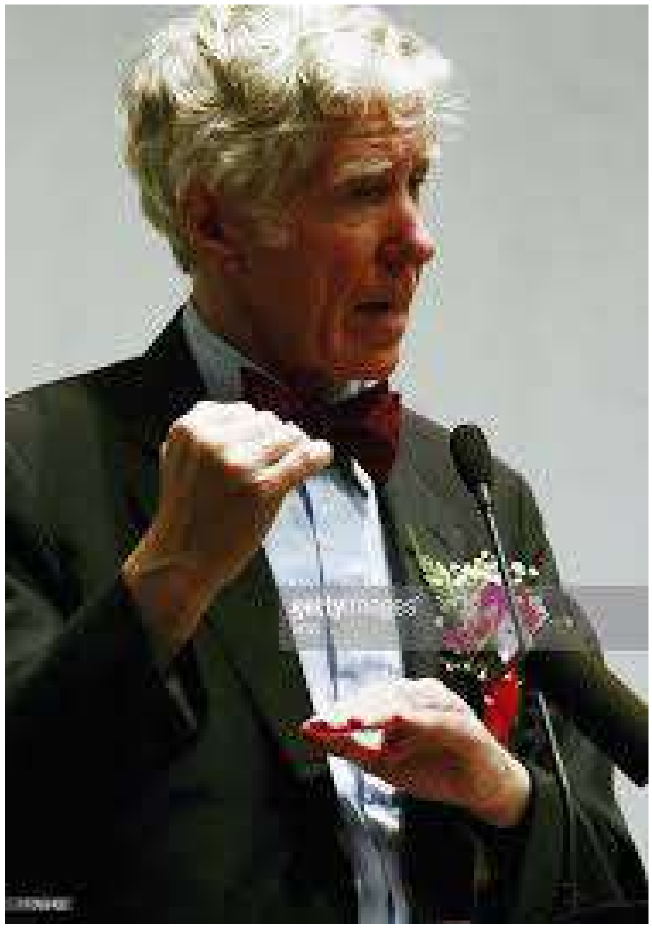

Figure 11.22: **Lester R. Brown, born in 1934, is the author of more than 50 books, and he has been called "...one of the world's most influential thinkers" (Washington Post). He is the founder of the Worldwatch Institute and the Earth Policy Institute. Books produced by Brown and his coworkers at the EPI can be freely downloaded and circulated. The 2015 book *The Great Transition: Shifting From Fossil Fuels to Solar and Wind Energy* can be freely downloaded from the following link: http://www.earth-policy.org/books/tgt**

11.14 We must create a livable future world

We give our children loving care, but it makes no sense to do so unless we do everything in our power to give them a future world in which they can survive. We also have a duty to our grandchildren, and to all future generations.

The amazingly rapid growth of science, technology, agriculture and industry has given the world many benefits, but indefinite growth on a finite planet is a logical impossibility, and we have now reached the point where the human success story has become a threat. Today we are faced with the threat of an environmental megacatastrophe, of which the danger of catastrophic climate change is a part. Human ingenuity also produced nuclear weapons, but the development of international law, governance and ethics has not kept pace, and we face the threat of an all-destroying nuclear war. Finally, because of population growth, the effect of climate change on agriculture, and the end of the fossil fuel era, there is a danger that by the middle of the present century a very large-scale famine could take the lives of as many as a billion people.

We owe it to future generations to take urgent action to prevent these threatened catastrophes. In the present chapter, we will focus on the climate emergency, while the dangers of nuclear war and famine will be discussed in chapters 3 and 5.

A United Nations report released Wednesday , 20 November, 2019, warned that worldwide projections for fossil fuel production over the next decade indicate that the international community is on track to fail to rein in planet-heating emissions and prevent climate catastrophe.

The Production Gap[13] is an 80 page report produced by a collaboration between the UN Environmental Programme and a number of academic institutions. It examines the discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5^{o}C or 2^{o}C, and concludes that the necessary policy changes are currently not being made.

The famous economist Nicholas Stern has stated that "This important report shows that governments' projected and planned levels of coal, oil, and gas production are dangerously out of step with the goals of the Paris agreement on climate change. It illustrates the many ways in which governments subsidize and otherwise support the expansion of such production. Instead, governments should implement policies that ensure existing production peaks soon and then falls very rapidly."

In an article published in *Common Dreams* on Wednesday, November 20, 2019, Hoda Baraka, the Chief Communications Officer for 350.org wrote: "The disconnect between Paris temperature goals and countries' plans and policies for coal, oil, and gas production is massive, worrying and unacceptable...

"The *production gap* is a term used to refer to the difference between a countries' planned levels of fossil fuel production, and what is needed to achieve international climate goals. This is the first time a UN report has looked directly and specifically at fossil fuel production as a key driver of climate breakdown. It shows that countries are planning to

[13]http://productiongap.org/wp-content/uploads/2019/11/Production-Gap-Report-2019.pdf

Figure 11.23: **"Ensuring a livable planet for future generations means getting serious about phasing out coal, oil, and gas," said Christiana Figueres, former executive secretary of the UNFCCC, "Countries such as Costa Rica, Spain, and New Zealand are already showing the way forward, with policies to constrain exploration and extraction and ensure a just transition away from fossil fuels. Others must now follow their lead."**

Figure 11.24: **Today the beautiful city of Venice is flooded. Tomorrow unless urgent climate action is taken, all coastal cities will be under water.**

produce fossil fuels far in excess of the levels needed to fulfil their climate pledges under the Paris Agreement, which themselves are far from adequate. This over investment in coal, oil, and gas supply locks in fossil fuel infrastructure that will make emissions reductions harder to achieve.

"The science is clear, to stay below 1.5 degrees we must stop the expansion of the fossil fuel industry immediately. That means that not a single new mine can be dug, not another pipeline built, not one more emitting powerplant fired up. And we have to get to work transitioning to sustainable renewable energy powered energy systems.

"Across the globe resistance to fossil fuels is rising, the climate strikes have shown the world that we are prepared to take action. Going forward our job is to keep up a steady drumbeat of actions, strikes and protests that gets louder and louder throughout 2020. Governments need to follow through, to act at the source of the flames that are engulfing our planet and phase out coal, oil, and gas production."

Figure 11.25: **On Friday, November 15, 2019, in a speech at the Vatican, Pope Francis railed against corporate crimes and announced consideration of adding "sins against ecology" to the church's official teachings. "The principle of profit maximization, isolated from any other consideration, leads to a model of exclusion which violently attacks those who now suffer its social and economic costs, while future generations are condemned to pay the environmental costs", he said. In his speech, Francis condemned global corporations that are responsible for "countries' over-indebtedness and the plunder of our planet's natural resources." He said that their activities have the "gravity of crimes against humanity," especially when they lead to hunger, poverty and the eradication of indigenous peoples.**

Figure 11.26: **A new report indicates that half of all insects may have been lost since 1970 as a result of the destruction of nature and heavy use of pesticides. The report said 40% of the 1million known species of insect are facing extinction. Unless steps are taken to correct the excessive use of pesticides and loss of habitat, there will be profound consequences for humans and all life on Earth. "We can't be sure, but in terms of numbers, we may have lost 50% or more of our insects since 1970 - it could be much more," said Prof Dave Goulson, at the University of Sussex, UK, who wrote the report for the Wildlife Trusts. Since most crops depend on insect pollination, the insect apocalypse will make it difficult to feed the Earth's growing population unless urgent corrective steps are taken.**

Figure 11.27: **Senator Bernie Sanders and Representative Alexandria Ocasio-Cortez field questions from audience members at the Climate Crisis Summit at Drake University on November 9, 2019, in Des Moines, Iowa. "Faced with the global crisis of climate change, the United States must lead the world in transforming our energy system away from fossil fuel to sustainable energy. The Green New Deal is not just about climate change," Sanders said, "It is an economic plan to create millions of good-paying jobs, strengthen our infrastructure, and invest in our country's frontline and vulnerable communities." The Green New Deal, which is strongly advocated by Sanders and Ocasio-Cortez in the United States, and also currently debated in many other countries, is inspired by the set of programs that Franklin D. Roosevelt used to end the Great Depression. It aims at maintaining full employment by substituting jobs in creating renewable energy infrastructure for jobs lost in the fossil fuel sector.**

Figure 11.28: **The *World Scientists' Warning of a Climate Emergency* was published in Bioscience on 5 November, 2019. The article states that "Scientists have a moral obligation to clearly warn humanity of any catastrophic threat and to 'tell it like it is.' On the basis of this obligation and the graphical indicators presented below, we declare, with more than 11,000 scientist signatories from around the world, clearly and unequivocally that planet Earth is facing a climate emergency...Despite 40 years of global climate negotiations... we have generally conducted business as usual and have largely failed to address this predicament."**

Figure 11.29: **Bush fires in Australia are threatening Sydney and have caused the Australian government to declare a state of emergency. But Australia's politicians continue the policies that have made their nation a climate change criminal, exporting vast quantities of coal and beef. The Deputy Prime Minister Michael McCormack said, of the fire victems: "They don't need the ravings of some pure enlightened and woke capital city greenies at this time when they are trying to save their homes." In other words, let's not talk about climate change.**

Figure 11.30: **A Peoples' Climate March in Amsterdam, calling for an ambitious climate policy. The *World Scientists' Warning of a Climate Emergency* called attention to a number of indicators: "The basic scientific data of these changes is presented simply and with great clarity: a 5 percent rise every 10 years in carbon emissions; a 3.65 percent rise of another powerful greenhouse gas, methane, every 10 years; a global surface temperature rise of .183 degrees Celsius every 10 years; a decline of Arctic sea ice at a rate of 11.7 percent every 10 years; significant drops in the ice mass of Greenland, Antarctica and world glaciers; an increase in ocean acidity and temperatures; an increase of 44 percent in the amount of area burned by wildfires in the U.S. every 10 years; and an 88 percent rise in extreme weather events per 10 years."**

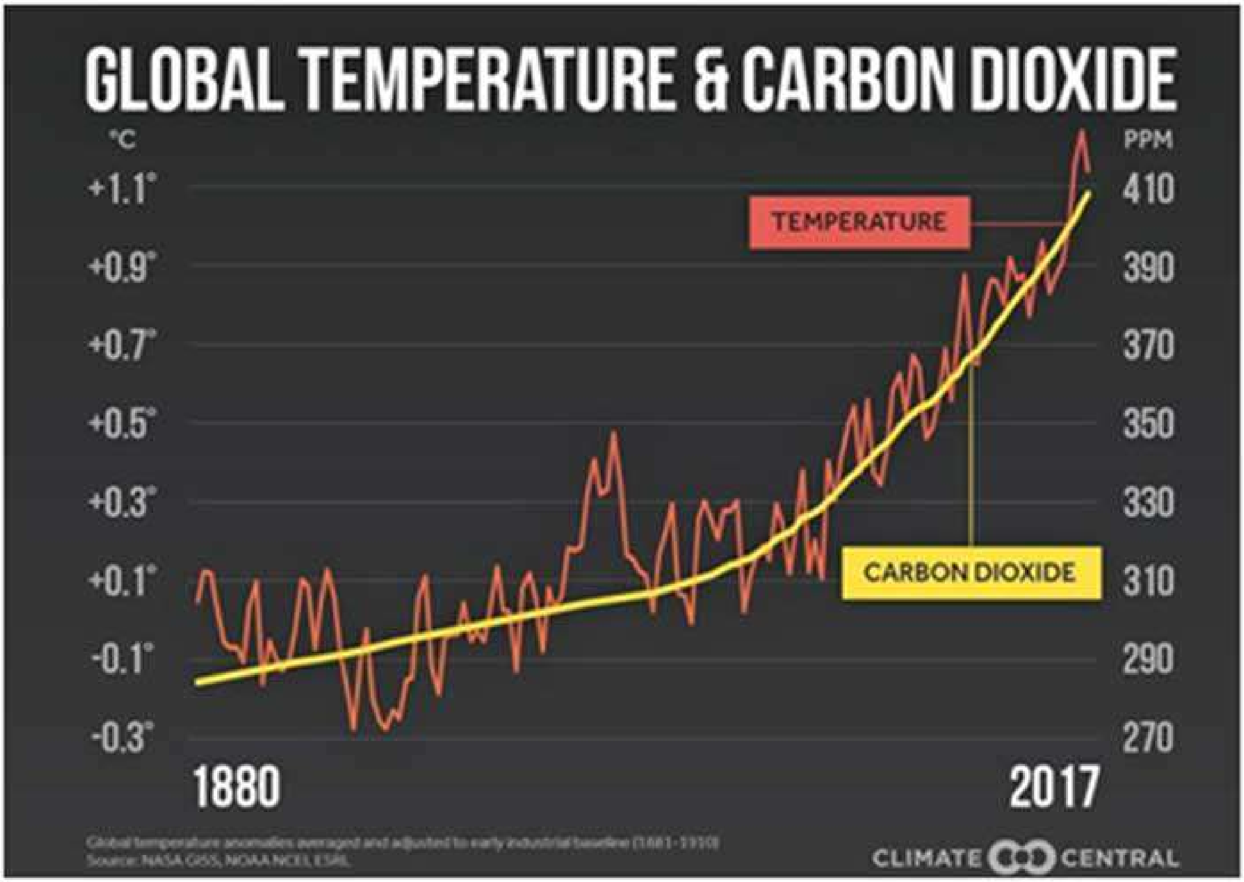

Figure 11.31: **The graphs showing increase in global temperatures and carbon dioxide follow each other closely. In an article published in Countercurrents on November 6, 2019, Dr. Andrew Glickson wrote: "As the concentration of atmospheric CO_2 has risen to 408 ppm and the total greenhouse gas level, including methane and nitrous oxide, combine to near 500 parts per million CO_2-equivalent, the stability threshold of the Greenland and Antarctic ice sheets, currently melting at an accelerated rate, has been exceeded. The consequent expansion of tropics and the shift of climate zones toward the shrinking poles lead to increasingly warm and dry conditions under which fire storms, currently engulfing large parts of South America, California, Alaska, Siberia, Sweden, Spain, Portugal, Greece, Angola, Australia and elsewhere have become a dominant factor in the destruction of terrestrial habitats."**

Figure 11.32: **The Royal Society of the United Kingdom documented ExxonMobil's funding of 39 organizations that promoted "inaccurate and misleading" views of climate science. In an article published by TomDispatch on November 11. 2019, Professor Naomi Oreskes of Harvard University wrote: "Much focus has been put on ExxonMobil's history of disseminating disinformation, partly because of the documented discrepancies between what that company said in public about climate change and what its officials said (and funded) in private. Recently, a trial began in New York City accusing the company of misleading its investors, while Massachusetts is prosecuting ExxonMobil for misleading consumers as well. If only it had just been that one company, but for more than 30 years, the fossil-fuel industry and its allies have denied the truth about anthropogenic global warming. They have systematically misled the American people and so purposely contributed to endless delays in dealing with the issue by, among other things, discounting and disparaging climate science, mispresenting scientific findings, and attempting to discredit climate scientists. These activities are documented in great detail in *How Americans Were Deliberately Misled about Climate Change*, a report I recently co-authored, as well as in my 2010 book and 2014 film, *Merchants of Doubt*."**

Figure 11.33: **A fire burns a tract of the Amazon jungle in Agua Boa, Mato Grosso state, Brazil September 4, 2019. According to a report published by teleSUR on 7 November, 2019, "Deforestation in Brazil's Amazon region increased by 80 percent in September compared to the same month last year, according to a private study released on Wednesday stating that 802 square kilometers of forest was lost in the zone... Environmental and human rights organizations have confirmed that criminal networks are behind the indiscriminate cutting of trees in the region, and that after the illegal lumbering, those deforested zones are burned to make the land suitable for livestock raising and agriculture. In August, fires in the Brazilian Amazon were the worst in a decade, a situation that was denounced worldwide, especially the anti-ecological policies of President Jair Bolsonaro and his poor response to stop the fires."**

Figure 11.34: **In her testimony to the US Congress, Greta Thunberg did not prepare a statement for submission to the record. Instead, she submitted the most recent scientific report, issued by the IPCC three weeks earlier. She said simply, "I am submitting this report as my testimony because I don't want you to listen to me, I want you to listen to the scientists, and I want you to unite behind the science. And then I want you to take real action. Thank you." Here is what the scientists recommend: "Excessive extraction of materials and overexploitation of ecosystems, driven by economic growth, must be quickly curtailed to maintain the long-term sustainability of the biosphere. We need a carbon-free economy that explicitly addresses human dependence on the biosphere and policies that guide economic decisions accordingly. Our goals need to shift from GDP growth and the pursuit of affluence toward sustaining ecosystems and improving human well-being by prioritizing basic needs and reducing inequality."**

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Chapter 12

SOCIETY AS A SUPERORGANISM

12.1 The evolution of cooperation

The explosion of human knowledge

Cultural evolution depends on the non-genetic storage, transmission, diffusion and utilization of information. The development of human speech, the invention of writing, the development of paper and printing, and finally in modern times, mass media, computers and the Internet - all these have been crucial steps in society's explosive accumulation of information and knowledge. Human cultural evolution proceeds at a constantly-accelerating speed, so great in fact that it threatens to shake society to pieces.

Every species changes gradually through genetic evolution; but with humans, cultural evolution has rushed ahead with such a speed that it has completely outstripped the slow rate of genetic change. Genetically we are quite similar to our neolithic ancestors, but their world has been replaced by a world of quantum theory, relativity, supercomputers, antibiotics, genetic engineering and space telescopes - unfortunately also a world of nuclear weapons and nerve gas.

Because of the slowness of genetic evolution in comparison to the rapid and constantly-accelerating rate of cultural change, our bodies and emotions (as Malthus put it, the "passions of mankind") are not completely adapted to our new way of life. They still reflect the way of life of our hunter-gatherer ancestors.

Within rapidly-moving cultural evolution, we can observe that technical change now moves with such astonishing rapidity that neither social institutions, nor political structures, nor education, nor public opinion can keep pace. The lightning-like pace of technical progress has made many of our ideas and institutions obsolete. For example, the absolutely-sovereign nation-state and the institution of war have both become dangerous anachronisms in an era of instantaneous communication, global interdependence and all-destroying weapons.

In many respects, human cultural evolution can be regarded as an enormous success.

However, at the start of the 21st century, most thoughtful observers agree that civilization is entering a period of crisis. As all curves move exponentially upward - population, production, consumption, rates of scientific discovery, and so on - one can observe signs of increasing environmental stress, while the continued existence and spread of nuclear weapons threatens civilization with destruction. Thus while the explosive growth of knowledge has brought many benefits, the problem of achieving a stable, peaceful and sustainable world remains serious, challenging and unsolved.

Tribal emotions and nationalism

In discussing conflicts, we must be very careful to distinguish between two distinct types of aggression exhibited by both humans and animals. The first is intra-group aggression, which is often seen in rank-determining struggles, for example when two wolves fight for pack leadership, or when males fight for the privilege of mating with females. Another, completely different, type of aggression is seen when a group is threatened by outsiders. Most animals, including humans, then exhibit a communal defense response - self-sacrificing and heroic combat against whatever is perceived to be an external threat. It is this second type of aggression that makes war possible.

Arthur Koestler has described inter-group aggression in an essay entitled *The Urge to Self-Destruction* [1], where he writes: "Even a cursory glance at history should convince one that individual crimes, committed for selfish motives, play a quite insignificant role in the human tragedy compared with the numbers massacred in unselfish love of one's tribe, nation, dynasty, church or ideology... Wars are not fought for personal gain, but out of loyalty and devotion to king, country or cause..."

"We have seen on the screen the radiant love of the Führer on the faces of the Hitler Youth... They are transfixed with love, like monks in ecstasy on religious paintings. The sound of the nation's anthem, the sight of its proud flag, makes you feel part of a wonderfully loving community. The fanatic is prepared to lay down his life for the object of his worship, as the lover is prepared to die for his idol. He is, alas, also prepared to kill anybody who represents a supposed threat to the idol." The emotion described here by Koestler is the same as the communal defense mechanism ("militant enthusiasm") described below in biological terms by the Nobel Laureate ethologist Konrad Lorenz.

In *On Aggression*, Lorenz gives the following description of the emotions of a hero preparing to risk his life for the sake of the group: "In reality, militant enthusiasm is a specialized form of communal aggression, clearly distinct from and yet functionally related to the more primitive forms of individual aggression. Every man of normally strong emotions knows, from his own experience, the subjective phenomena that go hand in hand with the response of militant enthusiasm. A shiver runs down the back and, as more exact observation shows, along the outside of both arms. One soars elated, above all the ties of everyday life, one is ready to abandon all for the call of what, in the moment of this specific

[1] in *The Place of Value in a World of Facts*, A. Tiselius and S. Nielsson editors, Wiley, New York, (1970)

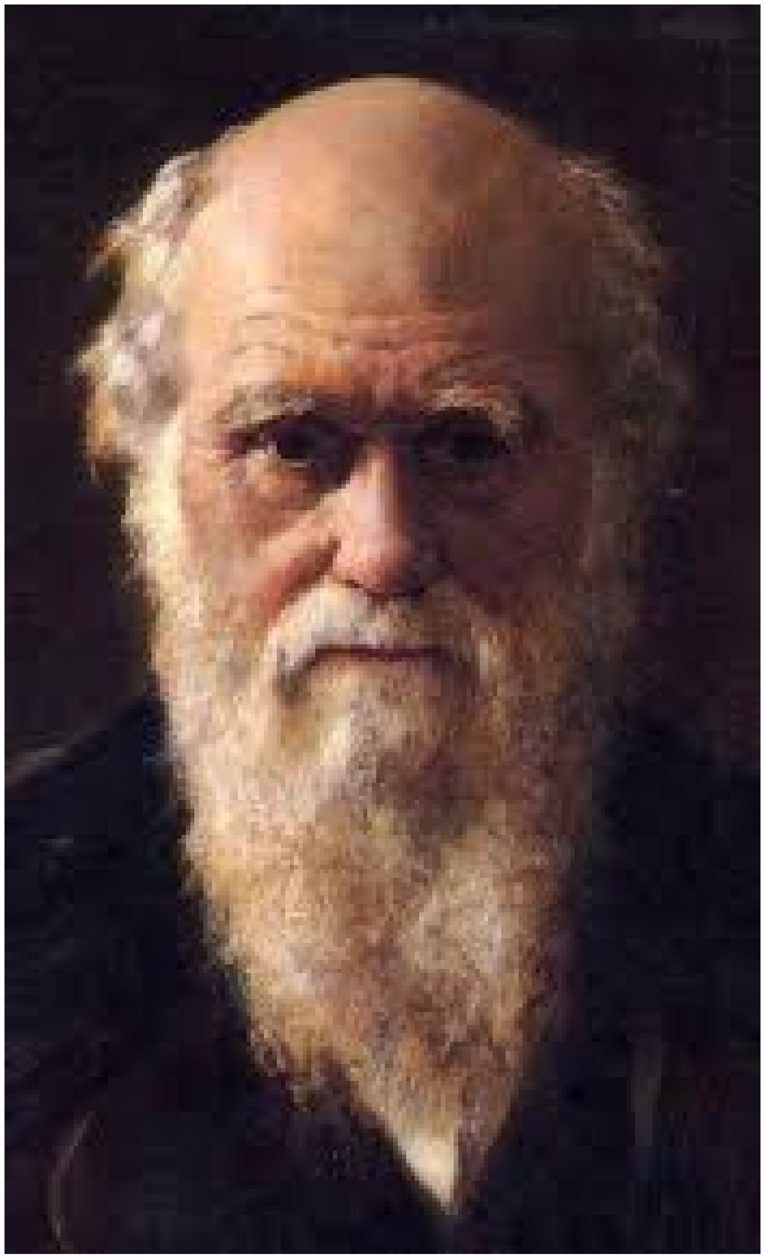

Figure 12.1: **Because of Charles Darwin's book "The Expression of Emotions in Man and Animals", he is considered to be the founder of the field of Ethology, the study of inherited behavior patterns.**

emotion, seems to be a sacred duty. All obstacles in its path become unimportant; the instinctive inhibitions against hurting or killing one's fellows lose, unfortunately, much of their power. Rational considerations, criticisms, and all reasonable arguments against the behavior dictated by militant enthusiasm are silenced by an amazing reversal of all values, making them appear not only untenable, but base and dishonorable. Men may enjoy the feeling of absolute righteousness even while they commit atrocities. Conceptual thought and moral responsibility are at their lowest ebb. As the Ukrainian proverb says: 'When the banner is unfurled, all reason is in the trumpet'."

"The subjective experiences just described are correlated with the following objectively demonstrable phenomena. The tone of the striated musculature is raised, the carriage is stiffened, the arms are raised from the sides and slightly rotated inward, so that the elbows point outward. The head is proudly raised, the chin stuck out, and the facial muscles mime the 'hero face' familiar from the films. On the back and along the outer surface of the arms, the hair stands on end. This is the objectively observed aspect of the shiver!"

"Anybody who has ever seen the corresponding behavior of the male chimpanzee defending his band or family with self-sacrificing courage will doubt the purely spiritual character of human enthusiasm. The chimp, too, sticks out his chin, stiffens his body, and raises his elbows; his hair stands on end, producing a terrifying magnification of his body contours as seen from the front. The inward rotation of the arms obviously has the purpose of turning the longest-haired side outward to enhance the effect. The whole combination of body attitude and hair-raising constitutes a bluff. This is also seen when a cat humps its back, and is calculated to make the animal appear bigger and more dangerous than it really is. Our shiver, which in German poetry is called a 'Heiliger Schauer', a 'holy' shiver, turns out to be the vestige of a prehuman vegetative response for making a fur bristle which we no longer have. To the humble seeker for biological truth, there cannot be the slightest doubt that human militant enthusiasm evolved out of a communal defense response of our prehuman ancestor."

Lorenz goes on to say, "An impartial visitor from another planet, looking at man as he is today - in his hand the atom bomb, the product of his intelligence - in his heart the aggression drive, inherited from his anthropoid ancestors, which the same intelligence cannot control - such a visitor would not give mankind much chance of survival."

Members of tribe-like groups are bound together by strong bonds of altruism and loyalty. Echos of these bonds can be seen in present-day family groups, in team sports, in the fellowship of religious congregations, and in the bonds that link soldiers to their army comrades and to their nation.

Warfare involves not only a high degree of aggression, but also an extremely high degree of altruism. Soldiers kill, but they also sacrifice their own lives. Thus patriotism and duty are as essential to war as the willingness to kill.

Tribalism involves passionate attachment to one's own group, self-sacrifice for the sake of the group, willingness both to die and to kill if necessary to defend the group from its enemies, and belief that in case of a conflict, one's own group is always in the right. Unfortunately these emotions make war possible; and today a Third World War might lead to the destruction of civilization.

Figure 12.2: **Nikolaas Tinbergen (left) and Konrad Lorenz. They and Karl von Frisch shared the 1973 Nobel Prize in Medicine and Physiology for studies of behavior patterns in animals.** (Public domain)

The mystery of self-sacrifice in war

At first sight, the willingness of humans to die defending their social groups seems hard to explain from the standpoint of Darwinian natural selection. After the heroic death of such a human, he or she will be unable to produce more children, or to care for those already born.Therefore one might at first suppose that natural selection would work strongly to eliminate the trait of self-sacrifice from human nature. However, the theory of population genetics and group selection can explain both the willingness of humans to sacrifice themselves for their own group, and also the terrible aggression that they sometimes exhibit towards competing groups. It can explain both intra-group altruism and inter-group aggression.

Fisher, Haldane and Hamilton

The idea of group selection in evolution was proposed in the 1930's by J.B.S. Haldane and R.A. Fisher, and more recently it has been discussed by W.D. Hamilton.

If we examine altruism and aggression in humans, we notice that members of our species exhibit great altruism towards their own children. Kindness towards close relatives is also characteristic of human behavior, and the closer the biological relationship is between two humans, the greater is the altruism they tend to show towards each other. This profile of altruism is easy to explain on the basis of Darwinian natural selection since two closely related individuals share many genes and, if they cooperate, the genes will be more

Figure 12.3: **Sir Ronald Aylmer Fischer (1890-1962). In his book "The Genetical Foundations of Natural Selection", published in 1930, Fischer laid the foundations of population genetics.**

effectively propagated.

To explain from an evolutionary point of view the communal defense mechanism discussed by Lorenz - the willingness of humans to kill and be killed in defense of their communities - we have only to imagine that our ancestors lived in small tribes and that marriage was likely to take place within a tribe rather than across tribal boundaries. Under these circumstances, each tribe would tend to consist of genetically similar individuals. The tribe itself, rather than the individual, would be the unit on which the evolutionary forces of natural selection would act.

According to the group selection model, a tribe whose members showed altruism towards each other would be more likely to survive than a tribe whose members cooperated less effectively. Since several tribes might be in competition for the same territory, successful aggression against a neighboring group could increase the chances for survival of one's own tribe. Thus, on the basis of the group selection model, one would expect humans to be kind and cooperative towards members of their own group, but at the same time to sometimes exhibit aggression towards members of other groups, especially in conflicts over territory. One would also expect intergroup conflicts to be most severe in cases where the boundaries between groups are sharpest - where marriage is forbidden across the boundaries.

Language, religion and tribal markings

In biology, a species is defined to be a group of mutually fertile organisms. Thus all humans form a single species, since mixed marriages between all known races will produce children, and subsequent generations in mixed marriages are also fertile. However, although there is never a biological barrier to marriages across ethnic and racial boundaries, there are often very severe cultural barriers.

Irenäus Eibl-Ebesfeldt, a student of Konrad Lorenz, introduced the word *pseudospeciation* to denote cases where cultural barriers between two groups of humans are so strongly marked that marriages across the boundary are difficult and infrequent. In such cases, she pointed out, the two groups function as though they were separate species, although from a biological standpoint this is nonsense. When two such groups are competing for the same land, the same water, the same resources, and the same jobs, the conflicts between them can become very bitter indeed. Each group regards the other as being "not truly human".

In his book *The Biology of War and Peace*, Eibl-Eibesfeldt discusses the "tribal markings" used by groups of humans to underline their own identity and to clearly mark the boundary between themselves and other groups. One of the illustrations in his book shows the marks left by ritual scarification on the faces of the members of certain African tribes. These scars would be hard to counterfeit, and they help to establish and strengthen tribal identity. Seeing a photograph of the marks left by ritual scarification on the faces of African tribesmen, it is impossible not to be reminded of the dueling scars that Prussian army officers once used to distinguish their caste from outsiders.

Surveying the human scene, one can find endless examples of signs that mark the bearer as a member of a particular group - signs that can be thought of as "tribal markings": tattoos; piercing; bones through the nose or ears; elongated necks or ears; filed teeth; Chinese binding of feet; circumcision, both male and female; unique hair styles; decorations of the tongue, nose, or naval; peculiarities of dress, kilts, tartans, school ties, veils, chadours, and headdresses; caste markings in India; use or non-use of perfumes; codes of honor and value systems; traditions of hospitality and manners; peculiarities of diet (certain foods forbidden, others preferred); giving traditional names to children; knowledge of dances and songs; knowledge of recipes; knowledge of common stories, literature, myths, poetry or common history; festivals, ceremonies, and rituals; burial customs, treatment of the dead and ancestor worship; methods of building and decorating homes; games and sports peculiar to a culture; relationship to animals, knowledge of horses and ability to ride; nonrational systems of belief. Even a baseball hat worn backwards or the professed ability to enjoy atonal music can mark a person as a member of a special "tribe". Undoubtedly there are many people in New York who would never think of marrying someone who could not appreciate the paintings of Jasper Johns, and many in London who would consider

Figure 12.4: **A tattooed face can help to establish tribal identity**

Figure 12.5: **An example of the dueling scars that Prussian army officers once used to distinguish their caste from outsiders.**

anyone had not read all the books of Virginia Wolfe to be entirely outside the bounds of civilization.

By far the most important mark of ethnic identity is language, and within a particular language, dialect and accent. If the only purpose of language were communication, it would be logical for the people of a small country like Denmark to stop speaking Danish and go over to a more universally-understood international language such as English. However, language has another function in addition to communication: It is also a mark of identity. It establishes the boundary of the group.

Within a particular language, dialects and accents mark the boundaries of subgroups. For example, in England, great social significance is attached to accents and diction, a tendency that George Bernard Shaw satirized in his play, *Pygmalion*, which later gained greater fame as the musical comedy, *My Fair Lady*. This being the case, we can ask why all citizens of England do not follow the example of Eliza Doolittle in Shaw's play, and improve their social positions by acquiring Oxford accents. However, to do so would be to run the risk of being laughed at by one's peers and regarded as a traitor to one's own local community and friends. School children everywhere can be very cruel to any child who does not fit into the local pattern. At Eton, an Oxford accent is compulsory; but in a Yorkshire school, a child with an Oxford accent would suffer for it.

Next after language, the most important "tribal marking" is religion. It seems probable that in the early history of our hunter-gatherer ancestors, religion evolved as a mechanism for perpetuating tribal traditions and culture. Like language, and like the innate facial expressions studied by Darwin, religion is a universal characteristic of all human societies. All known races and cultures practice some sort of religion. Thus a tendency to be religious seems to be built into human nature, or at any rate, the needs that religion satisfies seem to be a part of our inherited makeup. Otherwise, religion would not be as universal as it is.

Formation of group identity

Although humans originally lived in small, genetically homogeneous tribes, the social and political groups of the modern world are much larger, and are often multiracial and multiethnic.

There are a number of large countries that are remarkable for their diversity, for example Brazil, Argentina and the United States. Nevertheless it has been possible to establish social cohesion and group identity within each of these enormous nations. India and China too, are mosaics of diverse peoples, but nevertheless, they function as coherent societies. Thus we see that group identity is a social construction, in which artificial "tribal markings" define the boundaries of the group.

As an example of the use of tribal markings to establish social cohesion over a large group of genetically dissimilar humans, one can think of the role of baseball and football in the United States. Affection for these sports and knowledge of their intricacies is able to establish social bonds that transcend racial and religious barriers.

One gains hope for the future by observing how it has been possible to produce both internal peace and social cohesion over very large areas of the globe - areas that contain extremely diverse populations. The difference between making large, ethnically diverse countries function as coherent sociopolitical units and making the entire world function as a unit is not very great.

Since group identity is a social construction, it is not an impossible goal to think of enlarging the already-large groups of the modern world to include all of humanity.

The social insects

The social[2] insects, ants, bees, wasps and termites, exhibit nearly perfect altruism towards members of their own group. This extreme form of altruism towards near relations (kin altruism) is closely connected with the peculiar method of reproduction of the social insects[3]. The workers are sterile or nearly sterile, while the queen is the only reproductive female. The result of this special method of reproduction is that very nearly perfect altruism is possible within a hive or nest, since genetic changes favoring antisocial behavior would be detrimental to the hive or nest as a whole. The hive or nest can, in some sense, be regarded as a superorganism, with the individuals cooperating totally in much the same way that cells cooperate within a multicellular organism. The social insects exhibit aggression towards members of their own species from other hives or nests, and can be said to engage in wars.

From Thomas Huxley to Lynn Margulis and symbiosis

Charles Darwin (1809-1882) was acutely aware of close and mutually beneficial relationships between organisms. For example, in his work on the fertilization of flowers, he studied the ways in which insects and plants can become exquisitely adapted to each other's needs.

On the other hand Thomas Henry Huxley (1825-1895), although he was a strong supporter of Darwin, saw competition as the main mechanism of evolution. In his essay *Struggle for Existence and its Bearing Upon Man* Huxley wrote: "From the point of view of the moralist, the animal world is about on the same level as a gladiators' show. The creatures are fairly well treated and set to fight; hereby the strongest, the swiftest, and the cunningest live to fight another day. The spectator has no need to turn his thumbs down, as no quarter is granted."

Prince Peter Kropotkin (1842-1921) argued strongly against Huxley's point of view in his book *Mutual Aid; A Factor of Evolution*. "If we ask Nature", Kropotkin wrote, "'who are the fittest: those who are continually at war with each other, or those who support one another?', we at once see that those animals that acquire habits of mutual aid are undoubtedly the fittest. They have more chances to survive, and they attain, in their respective classes, the highest development of intelligence and bodily organization."

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[2]The technical term is *eusocial*.

[3]Interestingly a similar method of reproduction, associated with extreme intra-group altruism has evolved among mammals, but is represented by only two species: the naked mole rat and Damaraland mole rat.

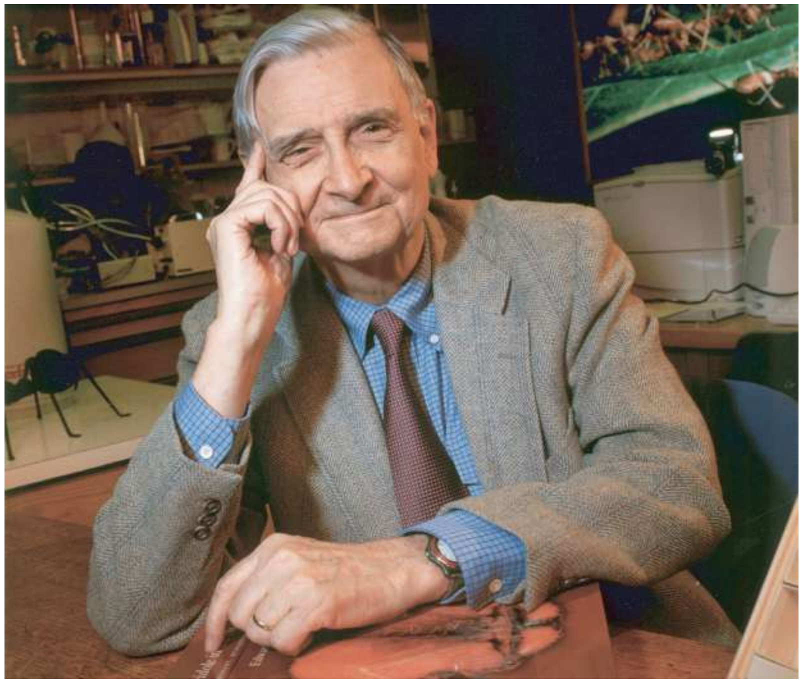


Figure 12.6: **Professor E.O. Wilson of Harvard is famous for his books on the behavior of social insects, such as ants, and on Sociobiology.**

Today, the insights of modern biology show that although competition plays an important role, most of the great upward steps in evolution have involved cooperation. The biologist Lynn Margulis (1938-) has been one of the pioneers of the modern viewpoint which recognizes symbiosis as a central mechanism in evolution.

One-celled organisms seen as examples of cooperation

The first small bacterial cells (prokaryotic cells) can be thought of as cooperative communities in which autocatalytic molecules thrived better together than they had previously done separately.

The next great upward step in evolution, the development of large and complex (eukaryotic) cells, also involved cooperation: Many of their components, for example mitochondria (small granular structures that are needed for respiration) and chloroplasts (the photosynthetic units of higher plants) are believed to have begun their existence as free-living prokaryotic cells. They now have become components of complex cells, cooperating biochemically with the other subcellular structures. Both mitochondria and chloroplasts possess their own DNA, which shows that they were once free-living bacteria-like organisms, but they have survived better in a cooperative relationship.

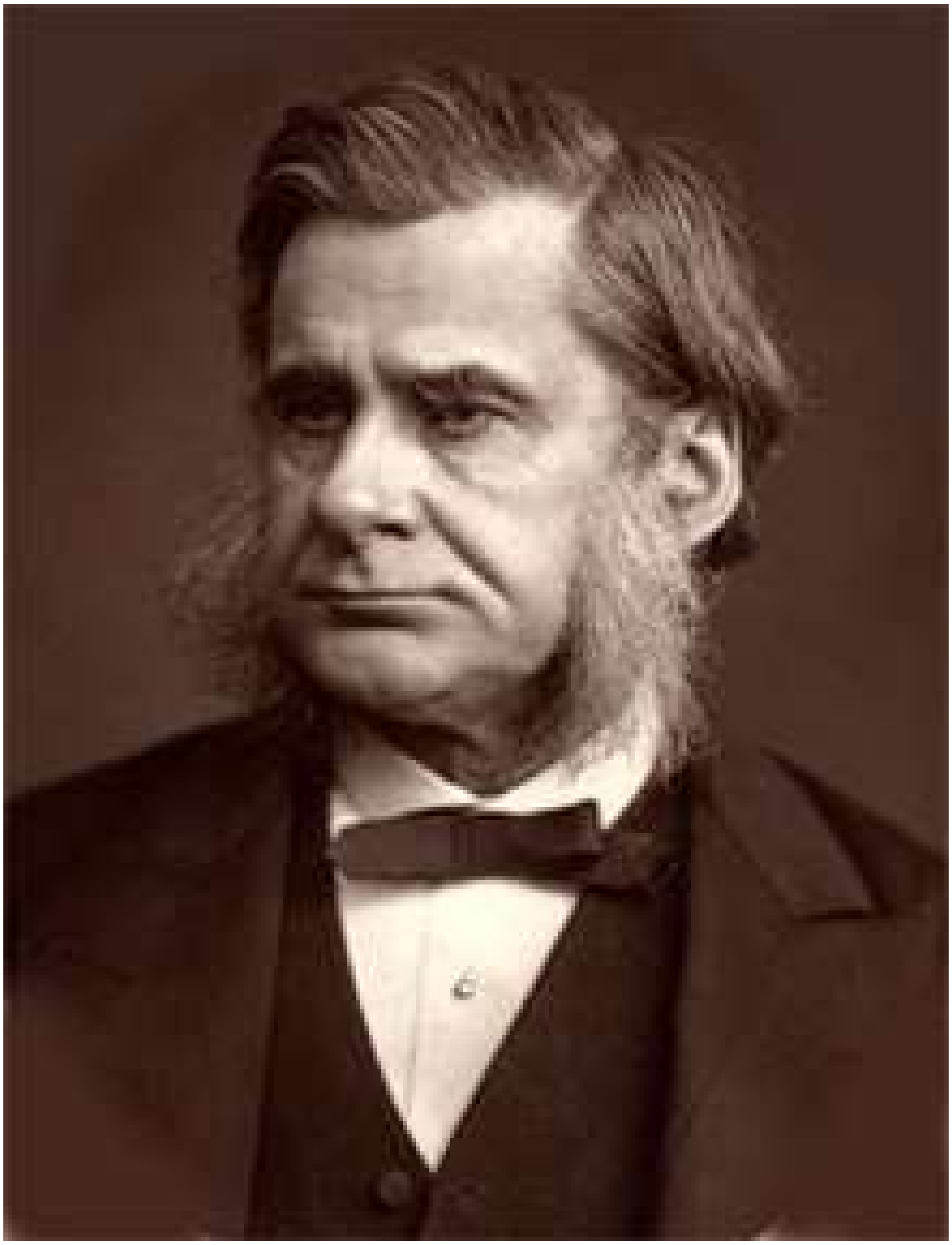


Figure 12.7: **Thomas Henry Huxley (1825-1895). Huxley was a strong supporter of Darwin, but he placed much more emphasis on competition in evolution than Darwin did. In fact, Darwin himself was strongly aware of the great role that cooperation plays.**

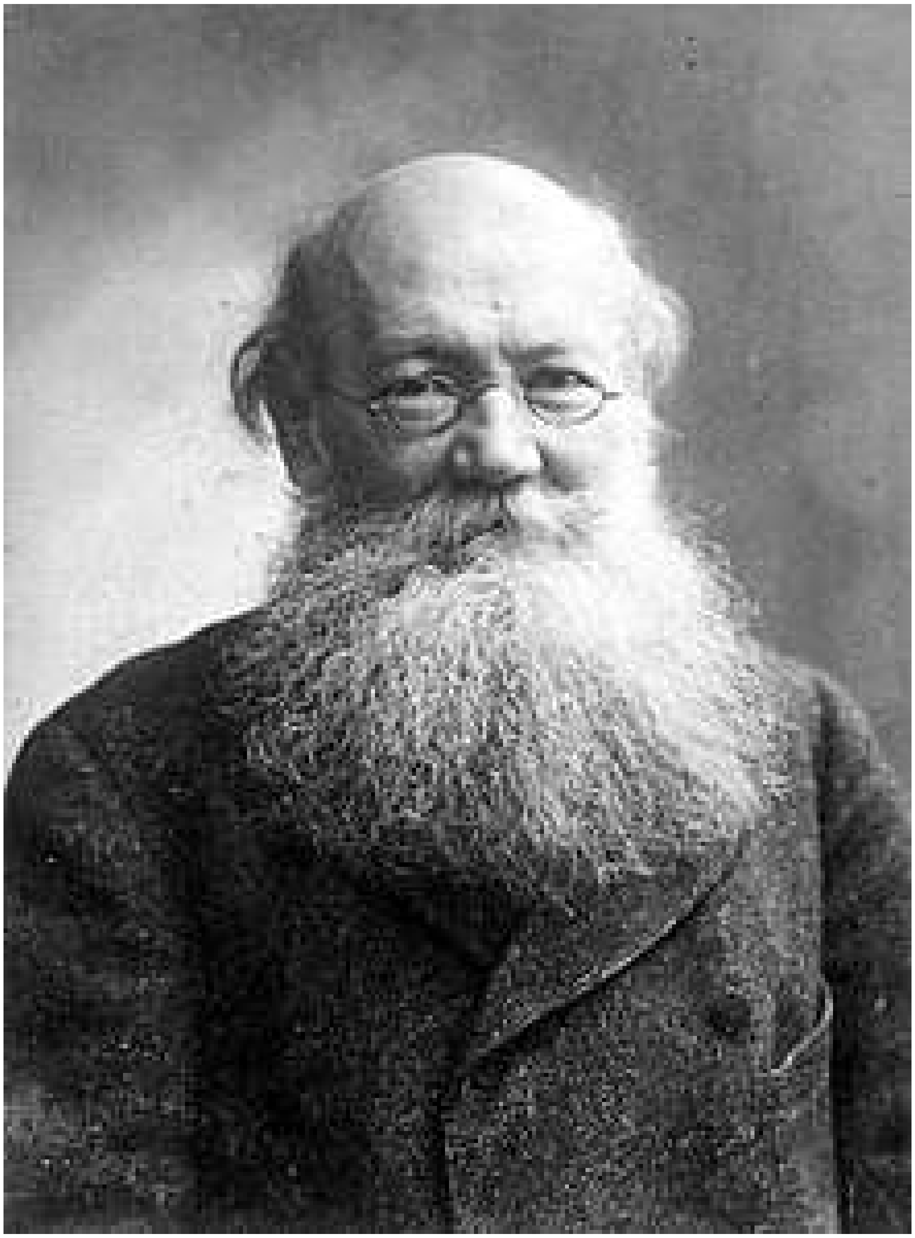


Figure 12.8: **Prince Peter Kropotkin (1842-1921) was the author of the book *Mutual Aid: A Factor in Evolution.* Later, the work of Lynn Margolis convinced biologists of the importance of symbiosis in evolution, a topic that both Darwin and Kropotkin had pioneered.**

Cooperation between cells; multicellular organisms

Multicellular organisms evolved from cooperative communities of eukaryotic cells. Some insights into how this happened can be gained from examples which are just on the borderline between the multicellular organisms and single-celled ones. The cooperative behavior of a genus of unicellular eukaryotes called slime molds is particularly interesting because it gives us a glimpse of how multicellular organisms may have originated. The name of the slime molds is misleading, since they are not fungi, but are similar to amoebae. Under ordinary circumstances, the individual cells wander about independently searching for food, which they draw into their interiors and digest. However, when food is scarce, they send out a chemical signal of distress. (Researchers have analyzed the molecule which expresses slime mold unhappiness, and they have found it to be cyclic adenosine monophosphate.) At this signal, the cells congregate and the mass of cells begins to crawl, leaving a slimy trail. At it crawls, the community of cells gradually develops into a tall stalk, surmounted by a sphere - the "fruiting body". Inside the sphere, spores are produced by a sexual process. If a small animal, for example a mouse, passes by, the spores may adhere to its coat; and in this way they may be transported to another part of the forest where food is more plentiful. Thus slime molds represent a sort of missing link between unicellular and multicellular or organisms. Normally the cells behave as individualists, wandering about independently, but when challenged by a shortage of food, the slime mold cells join together into an entity which closely resembles a multicellular organism. The cells even seem to exhibit altruism, since those forming the stalk have little chance of survival, and yet they are willing to perform their duty, holding up the sphere at the top so that the spores will survive and carry the genes of the community into the future.

Multicellular organisms often live in a symbiotic relationship with other species. For example, in both animals and humans, bacteria are essential for the digestion of food. Fungi on the roots of plants aid their absorption of water and nutrients. Communities of bacteria and other organisms living in the soil are essential for the recycling of nutrients. Insects are essential to many plants for pollination.

Cooperation in groups of animals and human groups

The social behavior of groups of animals, flocks of birds and communities of social insects involves cooperation as well as rudimentary forms of language. Various forms of language, including chemical signals, postures and vocal signals, are important tools for orchestrating cooperative behavior.

The highly developed language of humans made possible an entirely new form of evolution. In cultural evolution (as opposed to genetic evolution), information is passed between generations not in the form of a genetic code, but in the form of linguistic symbols. With the invention of writing, and later the invention of printing, the speed of human cultural evolution greatly increased. Cooperation is central to this new form of evolution. Cultural advances can be shared by all humans.

Figure 12.9: **Slime mold Trichia varia. Sponges and slime molds are on the borderline between single celled organisms and multicellular ones. The single cells of these species can live independently, but they can also function as members of a cooperating colony.**

Figure 12.10: **A termite mound made by the cathedral termite. The almost perfectly altruistic behavior of the social insects towards members of their own hive is a consequence of their special method of reproduction, which insures that all the members of the hive are more closely related to each other than they would be to a potential offspring. A hive of bees can be regarded as a superorganism, with the individuals playing roles that are analogous to the roles played by individual cells in a multicellular organism. The degree of cooperation in human society is so great that it too can to some extent be regarded as a superorganism.**

Trading in primitive societies

Although primitive societies engaged in frequent wars, they also cooperated through trade. Peter Watson, an English historian of ideas, believes that long-distance trade took place as early as 150,000 before the present. There is evidence that extensive trade in obsidian and flint took place during the stone age. Evidence for wide ranging prehistoric obsidian and flint trading networks has been found in North America. Ancient burial sites in Southeast Asia show that there too, prehistoric trading took place across very large distances. Analysis of jade jewelry from the Philippines, Thailand, Malaysia and Viet Nam shows that the jade originated in Taiwan.

The invention of writing was prompted by the necessities of trade. In prehistoric Mesopotamia, clay tokens marked with simple symbols were used for accounting as early as 8,000 BC. Often these tokens were kept in clay jars, and symbols on the outside of the jars indicated the contents. About 3,500 BC, the use of such tokens and markings led to the development of pictographic writing in Mesopotamia, and this was soon followed by the cuneiform script, still using soft clay as a medium. The clay tablets were later dried and baked to ensure permanency. The invention of writing led to a great acceleration of human cultural evolution. Since ideas could now be exchanged and preserved with great ease through writing, new advances in technique could be shared by an ever larger cooperating community of humans. Our species became more and more successful as its genius for cooperation developed.

Gracilization and decreasing sexual dimorphism

Early ancestors of modern humans had a relatively heavy (robust) bone structure in relation to their height. This robust bone structure seems to have been favored by frequent combat. During their evolution, modern humans became less robust and more gracile. In other words, their skeletons became lighter in relation to their height. Simultaneously the height and weight of males became less different from the height and weight of females. These trends are generally interpreted as indicating that combat became less important as present-day humans evolved.

Ethics and growth of the social unit

Early religions tended to be centered on particular tribes, and the ethics associated with them were usually tribal in nature. However, the more cosmopolitan societies that began to form after the Neolithic agricultural revolution required a more universal code of ethics. It is interesting to notice that many of the great ethical teachers of human history, for example Moses, Socrates, Plato, Aristotle, Lao Tzu, Confucius, Buddha, and Jesus, lived at the time when the change to larger social units was taking place. Tribalism was no longer appropriate. A wider ethic was needed.

Today the size of the social unit is again being enlarged, this time enlarged to include the entire world. Narrow loyalties have become inappropriate and there is an urgent need for a new ethic - a global ethic. Loyalty to one's nation needs to be supplemented by a higher loyalty to humanity as a whole.

Interdependence in modern human society

All of the great upward steps in the evolution of life on earth have involved cooperation: Prokaryotes, the first living cells, can be thought of as cooperative communities of autocatylists; large, complex eukaryote cells are now believed to have evolved as cooperative communities of prokaryotes; multicellular organisms are cooperative communities of eukaryotes; multicellular organisms cooperate to form societies; and different species cooperate to form ecosystems. Indeed, James Lovelock has pointed out that the earth as a whole is a complex interacting system that can be regarded as a huge organism.

The enormous success of humans as a species is due to their genius for cooperation. The success of humans is a success of cultural evolution, a new form of evolution in which information is passed between generations, not in the form of DNA sequences but in the form of speech, writing, printing and finally electronic signals. Cultural evolution is built on cooperation, and has reached great heights of success as the cooperating community has become larger and larger, ultimately including the entire world.

Without large-scale cooperation, modern science would never have evolved. It developed as a consequence of the invention of printing, which allowed painfully gained detailed knowledge to be widely shared. Science derives its great power from concentration. Attention and resources are brought to bear on a limited problem until all aspects of it are understood. It would make no sense to proceed in this way if knowledge were not permanent, and if the results of scientific research were not widely shared. But today the printed word and the electronic word spread the results of research freely to the entire world. The whole human community is the repository of shared knowledge.

The achievements of modern society are achievements of cooperation. We can fly, but no one builds an airplane alone. We can cure diseases, but only through the cooperative efforts of researchers, doctors and medicinal firms. We can photograph and understand distant galaxies, but the ability to do so is built on the efforts of many cooperating individuals.

An isolated sponge cell can survive, but an isolated human could hardly do so. Like an isolated bee, a human would quickly die without the support of the community. The comfort and well-being that we experience depends on far-away friendly hands and minds, since trade is global, and the exchange of ideas is also global.

Finally, we should be conscious of our cooperative relationships with other species. We could not live without the bacteria that help us to digest our food. We could not live without the complex communities of organisms in the soil that convert dead plant matter into fertile topsoil. We could not live without plants at the base of the food chain, but plants require pollination, and pollination frequently requires insects. An intricate cooperative network of inter-species relationships is necessary for human life, and indeed necessary for all life. Competition plays a role in evolution, but the role of cooperation is greater.

Two sides of human nature

Looking at human nature, both from the standpoint of evolution and from that of everyday experience, we see the two faces of Janus; one face shines radiantly; the other is dark and menacing. Two souls occupy the human breast, one warm and friendly, the other murderous. Humans have developed a genius for cooperation, the basis for culture and civilization; but they are also capable of genocide; they were capable of massacres during the Crusades, capable of genocidal wars against the Amerinds, capable of the Holocaust, of Hiroshima, of the killing-fields of Cambodia, of Rwanda, and of Darfur

As an example of the two sides of human nature, we can think of Scandinavia. The Vikings were once feared throughout Europe. The Book of Common Prayer in England contains the phrase "Protect us from the fury of the Northmen!". Today the same people are so peaceful and law-abiding that they can be taken as an example for how we would like a future world to look. Human nature has the possibility for both kinds of behavior depending on the circumstances. This being so, there are strong reasons to enlist the help of education and religion to make the bright side of human nature win over the dark side. Today, the mass media are an important component of education, and thus the mass media have a great responsibility for encouraging the cooperative and constructive side of human nature rather than the dark and destructive side. In the next chapter we will explore the question of how the media can better fulfill this responsibility.

Mahatma Gandhi's message for us today

Gandhi believed that human nature is essentially good, and that it is our task to find and encourage whatever is good in the character of others. During the period when he practiced as a lawyer, Gandhi's aim was "to unite parties riven asunder," and this was also his aim as a politician. In order for reconciliation to be possible in politics, it is necessary to avoid escalation of conflicts. Therefore Gandhi used non-violent methods, relying only on the force of truth. "It is my firm conviction," he wrote, "that nothing can be built on violence."

To the insidious argument that "the end justifies the means," Gandhi answered firmly: "They say 'means are after all means'. I would say 'means are after all everything'. As the means, so the end. Indeed the Creator has given us control (and that very limited) over means, none over end. ... The means may be likened to a seed, and the end to a tree; and there is the same inviolable connection between the means and the end as there is between the seed and the tree. Means and end are convertible terms in my philosophy of life." In other words, a dirty method produces a dirty result; killing produces more killing; hate leads to more hate. But there are positive feedback loops as well as negative ones. A kind act produces a kind response; a generous gesture is returned; hospitality results in reflected hospitality. Hindus and Buddhists call this principle "the law of karma".

Gandhi believed that the use of violent means must inevitably contaminate the end achieved. Because Gandhi's methods were based on love, understanding, forgiveness and reconciliation, the non-violent revolution which he led left very little enmity in its wake.

When India finally achieved its independence from England, the two countries parted company without excessive bitterness. India retained many of the good ideas which the English had brought - for example the tradition of parliamentary democracy - and the two countries continued to have close cultural and economic ties.

Gandhi's insight can be applied to the argument that the nuclear bombings that destroyed Hiroshima and Nagasaki helped to end World War II and were therefore justified. In fact, these terrible events lead to a nuclear arms race that still casts an extremely dark shadow over the future of human civilization. In this case, as in many others, the end achieved was contaminated by the evil methods used to achieve it.

Today, as in Gandhi's lifetime, we need a revolution. We urgently need to end the institution of war. We need to restore democracy in our own countries when it has been replaced by oligarchy. To save the future, we must act promptly to prevent catastrophic climate change, thermonuclear war and a large-scale global famine. But this revolution must be a non-violent one, like Gandhi's revolutions in South Africa and India.

We must stop using material possessions for social competition

Mahatma Gandhi was assassinated by a Hindu extremist on January 30, 1948. After his death, someone collected and photographed all his worldly goods. These consisted of a pair of glasses, a pair of sandals and a white homespun loincloth. That was all. Here, as in the Swadeshi movement, we see Gandhi as a pioneer of economics. He deliberately reduced his possessions to an absolute minimum in order to demonstrate that there is no connection between personal merit and material goods. Like Veblen, Mahatma Gandhi told us that we must stop using material goods as a means of social competition. We must start to judge people not by what they have, but by what they are.

12.2 We stand on each other's shoulders

Cultural evolution depends on the non-genetic storage, transmission, diffusion and utilization of information. The development of human speech, the invention of writing, the development of paper and printing, and finally, in modern times, mass media, computers and the Internet: all these have been crucial steps in society's explosive accumulation of information and knowledge. Human cultural evolution proceeds at a constantly-accelerating speed, so great in fact that it threatens to shake society to pieces.

In many respects, our cultural evolution can be regarded as an enormous success. However, at the start of the 21st century, most thoughtful observers agree that civilization is entering a period of crisis. As all curves move exponentially upward, population, production, consumption, rates of scientific discovery, and so on, one can observe signs of increasing environmental stress, while the continued existence and spread of nuclear weapons threaten civilization with destruction. Thus, while the explosive growth of knowledge has brought many benefits, the problem of achieving a stable, peaceful and sustainable world remains serious, challenging and unsolved.

Our modern civilization has been built up by means of a worldwide exchange of ideas and inventions. It is built on the achievements of many ancient cultures. China, Japan, India, Mesopotamia, Egypt, Greece, the Islamic world, Christian Europe, and the Jewish intellectual traditions, all have contributed. Potatoes, corn, squash, vanilla, chocolate, chili peppers, and quinine are gifts from the American Indians.

The sharing of scientific and technological knowledge is essential to modern civilization. The great power of science is derived from an enormous concentration of attention and resources on the understanding of a tiny fragment of nature. It would make no sense to proceed in this way if knowledge were not permanent, and if it were not shared by the entire world.

Science is not competitive. It is cooperative. It is a great monument built by many thousands of hands, each adding a stone to the cairn. This is true not only of scientific knowledge but also of every aspect of our culture, history, art and literature, as well as the skills that produce everyday objects upon which our lives depend. Civilization is cooperative. It is not competitive.

Our cultural heritage is not only immensely valuable; it is also so great that no individual comprehends all of it. We are all specialists, who understand only a tiny fragment of the enormous edifice. No scientist understands all of science. Perhaps Leonardo da Vinci could come close in his day, but today it is impossible. Nor do the vast majority people who use cell phones, personal computers and television sets every day understand in detail how they work. Our health is preserved by medicines, which are made by processes that most of us do not understand, and we travel to work in automobiles and buses that we would be completely unable to construct.

The fragility of modern society

As our civilization has become more and more complex, it has become increasingly vulnerable to disasters. We see this whenever there are power cuts or transportation failures due to severe storms. If electricity should fail for a very long period of time, our complex society would cease to function. The population of the world is now so large that it is completely dependent on the high efficiency of modern agriculture. We are also very dependent on the stability of our economic system.

The fragility of modern society is particularly worrying, because, with a little thought, we can predict several future threats which will stress our civilization very severely. We will need much wisdom and solidarity to get safely through the difficulties that now loom ahead of us.

We can already see the the problem of famine in vulnerable parts of the world. Climate change will make this problem more severe by bringing aridity to parts of the world that are now large producers of grain, for example the Middle West of the United States. Climate change has caused the melting of glaciers in the Himalayas and the Andes. When these glaciers are completely melted, China, India and several countries in South America will be deprived of their summer water supply. Water for irrigation will also become increasingly problematic because of falling water tables. Rising sea levels will drown many rice-growing areas in South-East Asia. Finally, modern agriculture is very dependent on fossil fuels for the production of fertilizer and for driving farm machinery. In the future, high-yield agriculture will be dealt a severe blow by the rising price of fossil fuels.

Economic collapse is another threat that we will have to face in the future. Our present fractional reserve banking system is dependent on economic growth. But perpetual growth of industry on a finite planet is a logical impossibility. Thus we are faced with a period of stress, where reform of our growth-based economic system and great changes of lifestyle will both become necessary.

How will we get through the difficult period ahead? I believe that solutions to the difficult problems of the future are possible, but only if we face the problems honestly and make the adjustments which they demand. Above all, we must maintain our human solidarity.

The great and complex edifice of human civilization is far too precious to be risked in a thermonuclear war. It has been built by all humans, working together. And by working together, we must now ensure that it is handed on intact to our children and grandchildren.

12.3 The collective human consciousness

No man is an island entire of itself; every man is a piece of the continent, a part of the main, John Donne (1572-1631)

If I have seen further it is by standing on ye shoulders of Giants, Isaac Newton (1643-1727)

One needs an exceptional stupidity even to question the urgency we are under to establish some effective World Pax, before gathering disaster overwhelms us. The problem of reshaping human affairs on a world-scale, this World problem, is drawing together an ever-increasing multitude of minds. H.G. Wells (1866-1946)

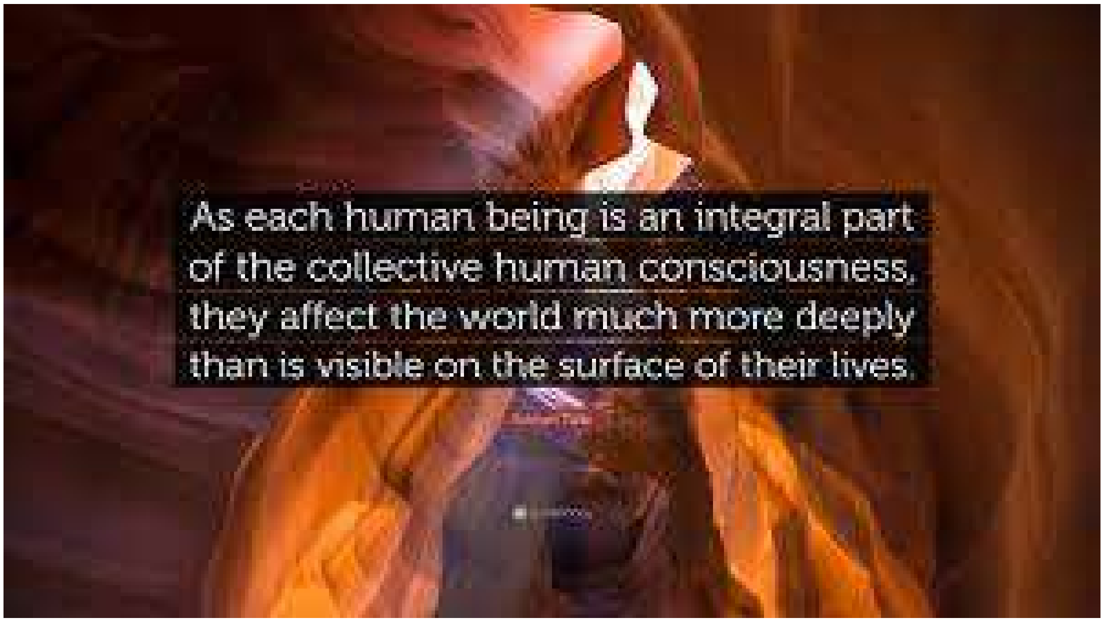
The Open Access Movement has fought valiantly to ensure that scientists do not sign their copyrights away but instead ensure their work is published on the Internet, under terms that allow anyone to access it., Aaron Schwartz (1986-2013)

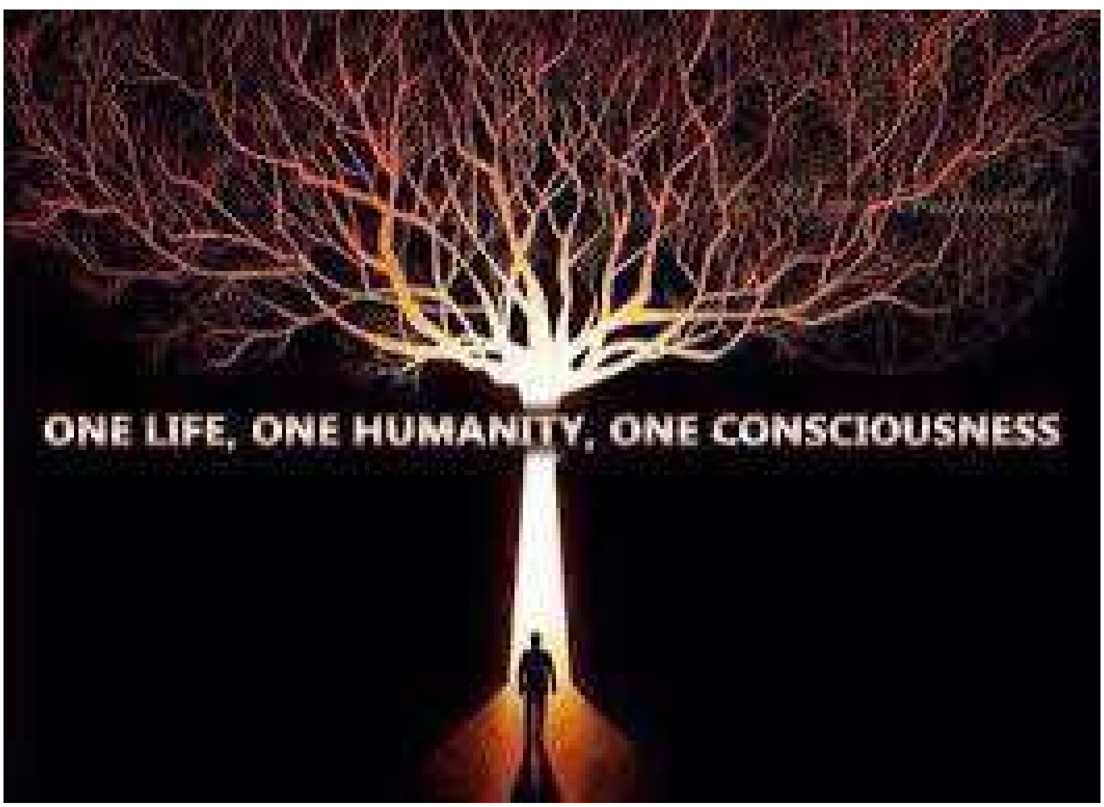
Sharp qualitative discontinuities have occurred several times before during the earth's 4-billion year evolutionary history: A dramatic change occurred when autocatalytic systems first became surrounded by a cell membrane. Another sharp transition occurred when photosynthesis evolved, and a third when the enormously more complex eukaryotic cells developed from the prokaryotes. The evolution of multicellular organisms also represents a sharp qualitative change. Undoubtedly the change from molecular information transfer to cultural information transfer is an even more dramatic shift to a higher mode of evolution than the four sudden evolutionary gear-shifts just mentioned. Human cultural evolution began only an instant ago on the time-scale of genetic evolution. Already it has completely changed the planet. We have no idea where it will lead.

The whole is greater than the sum of its parts. Human society is a superorganism, far greater than any individual in history or in the present. The human superorganism has a supermind, a collective consciousness far greater than the consciousness of individuals. Each individual contributes a stone to the cairn of civilization, but our astonishing understanding of the universe is a collective achievement.

Science derives its great power from the concentration of enormous resources on a tiny fragment of reality. It would make no sense to proceed in this way if knowledge were not permanent and if information were not shared globally. But scientists of all nations pool their knowledge at international conferences and through international publications. Scientists stand on each other's shoulders. Their shared knowledge is far greater than the fragments that each contributes.

Other aspects of culture are also cooperative and global. For example, Japanese woodblock printers influenced the French Impressionists. The nonviolent tradition of Shelly, Thoreau, Tolstoy, Gandhi, Martin Luther King and Nelson Mandela is international. Culture is cooperative. It is not competitive. Global cultural cooperation can lead us to a sustainable and peaceful society. Our almost miraculous modern communications media, if properly used, can give us a stable, prosperous and cooperative future society.


As each human being is an integral part
of the collective human consciousness,
they affect the world much more deeply
than is visible on the surface of their lives.


ONE LIFE, ONE HUMANITY, ONE CONSCIOUSNESS

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