The Ancient World

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1 Beginning of Civilization

The first known civilizations in the west developed along the Tigris and Euphrates river system in about 3500 BC in a region known as Mesopotamia. This region, north of the Persian Gulf, is now southeastern Iraq as illustrated in Figure 1. Mesopotamian included the Sumer, Akkadian, Babylonia, and Assyrian empires. The indigenous Sumerians and Babylonians dominated Mesopotamia from 3500 BC to the fall of Babylon in 539 BC. The region was conquered by Alexander the Great in 332 BC and became part of the Hellenistic (Greek) Empire.

Figure 1 Mesopotamia (source: owlcation.com)

The Mesopotamians developed one of the earliest known forms of writing. Called Cuneiform script, it was written on clay tablets using blunt reeds as stylus. Cuneiform writing began as pictographs and gradually evolved into a system of alphabetic signs.

The Egyptian civilization developed along the Nile River, Figure 2, with the Egyptian 1st Dynasty dating back to 3100 BC. The 1st Dynasty marks the beginning of Egyptian history following unification of Upper and Lower Egypt.

Figure 2 Ancient Egypt (source: questgarden.com)

Most of the Egyptian Pyramids were built from 2670 – 2392 BC during the Old Kingdom (the 3rd through the 5th Dynasty) in Lower Egypt. A second period of pyramid building occurred from 1991 – 1759 BC during the Middle Kingdom (the 12th and 13th Dynasty). The Valley of the Kings in Upper Egypt was the principal burial place of the pharaohs and privileged nobles during the Egyptian New Kingdom. The New Kingdom includes the 18th – 20th Dynasties from the 16th through the 11th century BC.

The 30th Dynasty was the last native ruling dynasty of ancient Egypt. The dynasty was overthrown by the Persians in 343 BC who were themselves conquered by Alexander the Great in 332 BC. Following the death of Alexander in 323 BC, Ptolemy Lagides, one of Alexander's generals, declared himself Pharaoh of Egypt and established the Ptolemaic Kingdom. The Ptolemaic Kingdom became a powerful Greek Hellenistic state which included all of Egypt and extended north to Syria. Alexandria was established as the capital city and became a center for Greek culture and trade. Alexandria, which is located along the Mediterranean coast in the Nile delta system, was an ancient Egyptian town that was renamed following Alexander the Great's conquest of Egypt. The powerful Ptolemaic Dynasty lasted for nearly 300 years, ending with the death of Cleopatra VII and the Roman conquest in 30 BC.

Figure 3 Greek Empire (source: Lion Publishing)

2 The First Measurements of Time

The concept of time during the early civilizations was based on natural events that indicated significant changes in the environment. Seasonal winds and rains, the flooding of rivers, the flowering of trees and plants, the breeding cycles of animals and the migration of birds were all very important events to them. The phases of the moon, movement of the sun, and changes in the stellar constellations were early and natural methods of measuring time, particularly for predicting the arrival and duration of particular seasons of the year.

Knowing the approximate time of day became more important as civilizations evolved and social interactions became more complex. For example, knowing whether it was morning or afternoon had significants. This required some means of determining when noon occurred.

The gnomon was probably the first device used for indicating the time of day. It was developed some time prior to 3500 BC. It consisted simply of a vertical stick stuck into the ground. The length of the shadow cast by the stick gave an indication of time of day.

Figure 4 Gnomon – The earliest sundial (source: electronics.howstuffworks.com)

Between 2500 - 2000 BC the Egyptians began building tall tapering four-sided monuments known as obelisks. The obelisk symbolized the god Ra (the god of the Sun, order, kings and the sky) and were often 50 to 60 feet in height. Obelisks were commonly used in ancient Egyptian architecture, frequently placed in pairs at the entrance of temples. The moving shadows formed by an obelisk created a kind of sundial enabling people to divide the day into two parts by indicating when noon occurred. Later, marks were placed around the base of the obelisk to show smaller divisions in time. The length of the shadow at noon was also used to identify the longest and shortest day of the years. The Washington Monument in Washington D.C is a modern day example of a large obelisk.

Figure 5 Ancient Egyptian Obelisk (source: pinterest.com)

Around 1500 B.C., the Egyptians developed a T-shaped sundial consisting of a horizontal stick and crossbar. In the morning the end of the stick with the crossbar was placed facing east, and in the afternoon it was placed facing west. The crossbar cast a shadow on the stick. At noon the shadow was very short, while the shadow was long early in the morning or late in the afternoon. The shadow falling on marks scribed on the stick indicated relative time of day. Numerous sundials of various designs were developed in the centuries that followed. Sundials were used to tell the time of day through 1200 AD when they were gradually replaced in Medieval Europe by mechanical clocks.

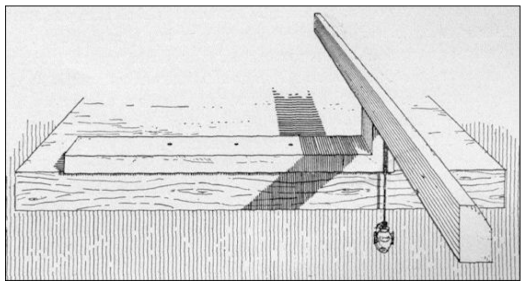

Figure 6 Egyptian T Sundial (source: technologyuk.net)

Figure 7 Greek Sundial (source: Electronics | HowStuffWorks)

Figure 8 Roman Sundial (credit: Mark Goddard)

The Clepsydra or water clock was used in addition to sundials. In its earliest form, a clepsydra consisted of a container filled with water. A small hole near the bottom of the clepsydra allowed water to slowly flow out of the clepsydra at a relatively constant rate. The clepsydra usually had a slanted interior surface to allow for decreasing water pressure as the water drained from the clepsydra. Horizontal lines scribed on the interior surface indicated how much water had flowed out of the clepsydra, and thus how much time had elapsed since the clepsydra was last filled with water. In daily use, the clepsydra was calibrated using a sundial. That is, the clepsydra was filled with water at a particular time of day as indicated by the sundial. The Egyptians and Babylonians were using clepsydras as early as 1400 BC.

Figure 9 Egyptian Clepsydra (source: daviddarling.info)

The design of water clocks continuously evolved over the 2,600 years during which they were extensively used. The Greeks and Romans built complex water clocks using water wheels, gears, and escapements to measure the flow of water out of or into the device, thus achieving more accurate measurements of time (Figure 10). Water clocks continued in use until finally replaced in medieval Europe by the first mechanical clocks in about 1200 AD.

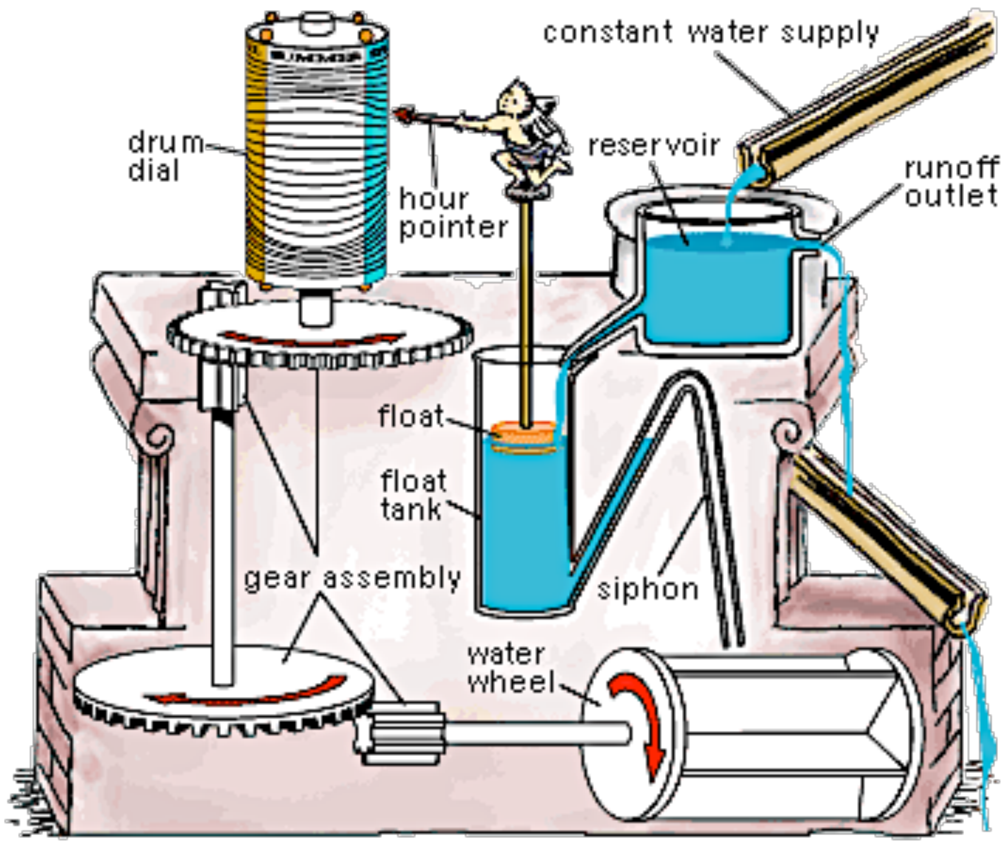

Figure 10 First century AD roman water clock (source: UNRV.com)

By 1100 BC Egyptian astronomers were using a collection of 24 stars evenly spaced across the night sky to measure the passage of time during the night. They were able to subdivide the night into approximately equal segments of time by noting when these specific stars rose and set.

The Egyptians subdivided the day into 12 hours of daylight and 12 hours of night. Specifically, the time between sunrise and sunset was divided into exactly 12 hours. However, sunrise and sunset varies seasonally. Consequently the length of the Egyptian hour also varied seasonally. Sundials were used to divide the period of daylight into 12 hours. The night was divided into approximately 12 equal hours based on the rising and setting of stars. Clepsydra water clocks were also used to measure time during the night.

The hour remained the smallest division of a day until European development of accurate mechanical clocks during the 16th century AD. Prior to the 16th century, minutes and seconds had no meaning to the general public. Minutes and a seconds became relevant only when mechanical clocks with the accuracy to display these units of time were built, that is, clocks with minute and second hands. Until then, minutes and seconds had significants only to astronomers who used these units in their astronomical observations.

Small intervals of time were important throughout history, for example how long a member of the Roman Senate was allowed to speak or a Babylonian landowner was allowed to divert water onto his land. These small intervals of time were typical measured with water clocks and later hour glasses (Figure 11)
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Figure 11 Typical Hourglass (source: shutterstock.com)

3 Babylonian Astronomers and Mathematicians

The Babylonians were outstanding astronomers and mathematicians. The history of both modern day astronomy and mathematics trace back to the early Babylonians. The Babylonians were the first to recognize that astronomical phenomena were periodic. Based on this knowledge, they utilized mathematics to predict when astronomical events would occur.

Babylonian mathematicians utilized a sexaqesimal base 60 numbering system which they inherited from the Sumerians, who had developed it around 2000 B.C. Why they chose 60 as their number base is unknown. The most likely explanation is its divisibility by 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 and 60. The Babylonian numbering system (unlike the Egyptian, Greek, and Roman numbering systems) was a true place-value system similar to our current day base ten system in which a number like 524 = 5x100 + 2x10 + 4x1. The Babylonians were the first to use this advanced type of numbering system. The place-value numbering system allowed the Babylonians to make great advances in the field of mathematics.

From the perspective of the Babylonians, and other early cultures, the Sun revolved around the Earth. It became apparent to the Babylonian astronomers that the Sun also traveled through the background of fixed stars. While they could not directly see the Sun's position against the stars, they inferred its position based on the time specific stars rose and set each night. They also observed that the time a particular star rose changed each night, rising again at the same time approximately 360 days later. (It may be that they observed the time to actually be 365 days but rounded the period back to 360 days for consistency with their sexaqesimal numbering system). In addition, they observed that approximately 12 new moons occurred during the 360 days. The ecliptic is the apparent path which the Sun follows as it travels through the background stars. Each day the Sun appeared to move $\frac{1}{360}\ th$ of the distance around the ecliptic circle.

The Babylonian sexaqesimal numbering system and their astronomical observations were closely related. Old Babylonian inscriptions and tablets indicate that they used a 360 day per year calendar consisting of 12 months with 30 days per month. Notices that 360, 30, and 12 are all multiples or factors of their base 60 numbering system. A 13th month was added every six years to keep the calendar aligned with the seasons. One of the earliest recorded uses of 360 as the total days in a year is found in the Hebrew Bible, Genesis 8–9 in which the Great Flood is described as lasting for 12 months of 30 days each.

It is believed that the Babylonians divided the circle into 360 equal parts (360 degrees) based on the movement of the Sun along the ecliptic. Adhering to the sexaqesimal numbering system, the Greek astronomers later divided a degree into 60 minutes and a minute into 60 seconds.

4 Early Greek Philosophers

4.1 Empedocles

In the fifth century BC the Greek philosopher Empedocles (~ 492 – 432 BC) postulated that everything was composed of four elements: fire, air, earth, and water. He was also one of the first recorded philosophers to speculate that light traveled at a finite speed. He claimed that light was something in motion and therefore must take some time to travel from one place to another. Empedocles further believed that sight was the result of light emitted from our eyes that bounced off objects and back into our eyes permitting us to see an object's size, shape and color. Remarkable as it may seem, this was the perception of vision held by the Greeks and Romans for over a thousand years.

4.2 Plato

Plato (roughly 424 – 348 BC) was the founder of the Academy, the first institution of higher learning in the western world. He is widely considered a key figure in Ancient

Greek history and western philosophy, along with Socrates his teacher and his most famous student Aristotle.

4.3 Aristotle

Aristotle (384 – 322 BC) has exerted a unique influence on almost every form of knowledge in the western world. His views on physical science were considered indisputable well into the 17th century AD.

Aristotle argued that light was due to the presence of something, not a movement as Empedocles suggested. Thus light appeared instantly.

Aristotle strongly believed that knowledge came primarily from sensory experience coupled with inductive and deductive reasoning. He sought to collect all available information. He formed hypotheses based on what he saw, and then applied these hypotheses to further observations. However, Aristotle did not perform experiments to prove his hypotheses. For example, Aristotle taught that the rate at which a body falls is directly proportional to its weight, that is, a heavier body falls faster than a lighter body. Aristotle could have easily proved that this hypotheses was wrong by performing a simple experiment. He could have dropped a stone and a heavy rock at the same time and noted that the rock did not fall any faster than the stone. But he didn't. In general, the concept of experimentation was unknown to the Greek philosophers. They were certainly capable of performing experiments, but it simply did not occur to them.

5 Alexander The Great

One of Aristotle's students was Alexander who became the King of Macedonia (northern present day Greece) in 336 BC at the age of 20 after the assignation of his father. Alexander was a very capable leader and an extremely strong military general who became known as Alexander the Great. In 334 AD Alexander began his conquest of the Persian Empire, a long anticipated invasion planned by his father. Following his liberation of Egypt from Assyria in 332, Alexander instructed that the city of Alexandria be built at the mouth of the Nile River. He conquered Persia in 331 BC and the western part of India in 326 BC creating the extensive Hellenistic Empire shown in Figure 12. In contrast to earlier and later conquering generals, Alexander respected the cultures and gods of the lands that he captured and integrated their cultures into the Hellenistic culture. He even appointed Persians to administer the territories that came under his control. He married a Persian woman and encouraged his generals and soldiers to do the same. However, he was not above accepting the divine status often bestowed on him by those who he conquered, including the status of Pharaoh and son of Zeus. Alexander was an avid supporter of the arts and science. Among other things, he considered himself an explorer contributing greatly to the geographic knowledge of Persia in the course of his conquests. Alexander died an untimely death in 323 BC at the age of 33 from "swamp fever" which may have been malaria.

Figure 12 Greek Empire (source: Lion Publishing)

The Greeks acquired much of their early understanding of astronomy and mathematic from the Babylonians. This knowledge was gained through trade and through Alexander The Great's conquest of Egypt and Persia. Alexander ordered the historical Babylonian astronomical records translated from Cuneiform into Greek with the translations subsequently sent to Greece.

6 The Ptolemaic Kingdom

Following the death of Alexander, Ptolemy Lagides, one of Alexander's Greek generals, declared himself Pharaoh of Egypt and established the Ptolemaic Kingdom. The Ptolemaic Kingdom became a powerful Greek Hellenistic state which included all of Egypt and extended north to Syria. The Ptolemaic Dynasty lasted for nearly 300 years, ending with the Roman invasion of Egypt in 30 BC and the death of Cleopatra VII. Cleopatra, who was not a native Egyptian but Greek in nationality, was the last of the Egyptian Pharaohs.

7 The City of Alexandria

Alexander's plan for controlling his vast empire was to build strategic sea port cities. Alexandria was to be one of those key ports. Construction of the new city in the Nile River delta began shortly after Alexander's liberation of Egypt from Assyria in 332 BC. In accordance with Alexander's wishes, Alexandria was constructed on a lavish scale to be the world center of commerce, culture, and learning. Alexandria was all of that. It quickly grew to become one of the greatest cities in ancient times. Only Rome exceeded Alexandria in size and wealth. The city survived for over 900 years, finally falling to the Arabs in 641 AD.

7.1 The Great Library of Alexandria

The Royal Library and Museum at Alexandria was build on the palace grounds around 295 BC (Figure 13). It became the greatest institution of learning in the ancient world. The library was an architectural marvel of great rooms, fountains, and colonnades encompassing ten large research halls each devoted to a separate subject. The library included an astronomical observatory, botanical gardens, and a zoo. It also had a great dining room where philosophers, mathematicians, and scientists of the time gathered to discuss critical ideas.

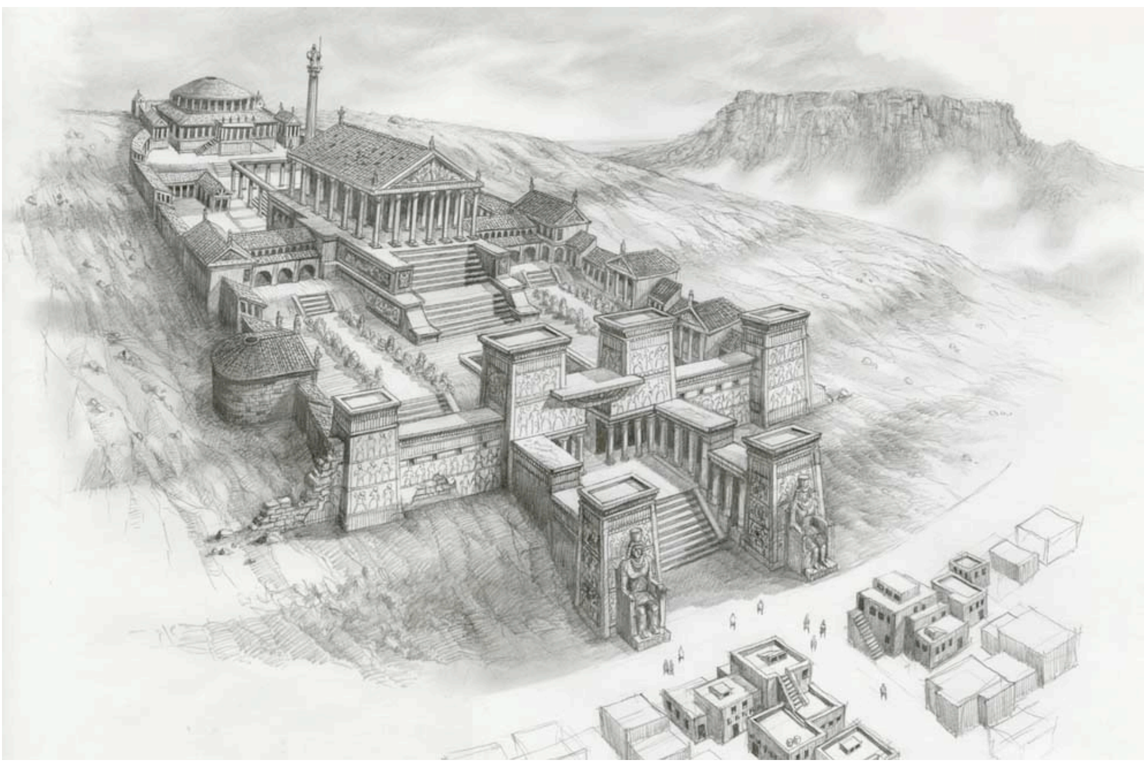

Figure 13 Great Library of Alexandria (source: crystalinks.com)

The heart of the library was its collection of manuscripts aggressively gathered from all over the ancient world. It was the greatest collection of ancient manuscripts ever assembled, numbering perhaps over a half million handwritten papyrus scrolls (Figure 14).

Figure 14 The library's vast collection of manuscripts (source: historyofyesterday.com)

The library had to be expanded some time around 240 BC to house all of the collected manuscripts. The library extension was constructed in a newly build temple located some distance from the Royal Palace.

It was the power and wealth of the Ptolemaic state, coupled with the Greek thirst for knowledge, that allowed the library to thieve, becoming the renowned center for Hellenistic (Greek) learning.

7.2 Burning of the Library

The library was accidently destroyed by fire in 48 BC during the civil war between Cleopatra and her brother Ptolemy XIII following the death of their father. Julius Caesar sided with Cleopatra hoping that she would pay the debt owed to him by her deceased father. In the winter of 48 BC Cleopatra and Caesar, now lovers, were besieged in Alexandria at the Royal Palace by Ptolemy's forces. During the siege Ptolemy's fleet in Alexandrian harbor was set on fire. The fire spread into Alexandria destroying the palace and the library. However, the library extension located at the temple survived. While the temple library was not nearly as extensive as the main library, it never the less was substantial. Cleopatra and Caesar, with reinforcements from Rome, eventually defeated Ptolemy who was later killed. Caesar and Cleopatra had a son named Ptolemy XV.

Cleopatra was in Rome when Caesar was assassinated in 44 BC. Mark Antony became the heir apparent of Caesar's authority following the assassination. Cleopatra and Mark Anthony became involved both militarily and romantically. Cleopatra gave birth to their twins, a boy and girl, in 40 BC. The political situation in Rome was not good. Many were disturbed by the relationship between Anthony and Cleopatra, a situation made worse by the amount of time Anthony spent in Egypt.

In 34 BC at a celebration known as “the Donation of Alexandria” Antony and Cleopatra appeared together seated on golden thrones with Cleopatra’s children sitting beside them. Antony’s actions were seen as an attempt to have his extended family become the rulers of the Roman Empire. The Roman Senate became alarmed, removed Antony from his position of authority, replaced him with Caesar’s grandnephew Octavian, and declared war on Cleopatra. Octavian’s navel forces defeated those of Antony and Cleopatra in 31 BC at the Battle of Actium near Greece. Antony and Cleopatra fled to Egypt. Octavian’s forces followed in pursuit, invading Egypt in 30 BC and defeating Antony. Antony committed suicide on hearing the false report that Cleopatra had been killed. Cleopatra tried to escape across the desert to the Red Sea but was captured by Octavian’s forces and placed under house arrest. Cleopatra committed suicide when she learned that Octavian planned to march her through Rome as the captured Queen of Egypt. Octavian became Emperor Augustus Caesar, the first emperor of the Roman Empire, in 27 BC, a position which he held until his death in 14 AD.

Alexandria became part of the Roman Empire following Cleopatra’s defeat. Alexandria and the temple library continued to prosper as a Roman city and remained the center of learning in the western world for hundreds of years.

Around 391 AD the Roman Christian Emperor Theodosius I, in his zeal to wipe out paganism, destroyed the temples in Alexandria built to honor the Egyptian pagan Gods. The remaining library at Alexandria was destroyed in the process.

8 Greek and Roman Study of Light and Astronomy

During its long existence, many of the best known names in ancient science lived and studied in Alexandria.

8.1 Euclid – Study of Light and Geometry

Euclid (~ 325 – 265 BC) was one of these people living in Alexandria and studying at the great library shortly after the library’s construction . Euclid is best know for his extensive study of geometry and number theory compiled in his multi-volume book *Elements*. Like many in the ancient world, Euclid studied multiple subjects, one of them being the study of light and optics. He documented the results of this work in a book titled *Optica*. In the book Euclid extended Empedocles’ concept that we see by means of light emitted from our eyes, which became known as the emission theory. In addition to promoting the emission theory, Euclid also postulated that light traveled in straight lines and described the phenomena of reflection from polished metal mirrors. From his book it is known that he worked with spherical and parabolic mirrors in addition to plane mirrors. He states in the book that concave mirrors turned toward the sun will cause ignition, presumably of dried grass and leaves on which the Sun’s rays were focused by the mirror.

8.2 Eratosthenes – Circumference of the Earth

Eratosthenes (276 – 194 BC) of Alexandria was one of the early Greek astronomers who made use of the astronomical knowledge gained from the Babylonians. Using this knowledge, Eratosthenes was able to calculated the circumference of the Earth. He was the first to do so. Eratosthenes understood well the position of the Sun during summer solstice in Egypt. It was known that the Sun reflected off the water at the bottom of a deep well in the Egyptian city of Swenet at exactly noon on the day of the summer solstice. This event could only occur at Swenet, and other locations along the Tropic of Cancer, when the Sun was at its zenith (directly overhead). Knowing this, Eratosthenes used a gnomon to measure the Sun's angle of elevation in Alexandria at noon on the summer solstice. The angle that he measured was 1/50th of a circle in a direction south of the zenith. Assuming that the Earth was spherical, and that Alexandria was due north of Swenet, he concluded that the arc distance from Swenet to Alexandria must be 1/50th of the Earth's circumference. He also knew the distance between Swenet and Alexandria based on generations of Egyptian surveying records. Using this information he calculated that the circumference of the Earth was 28,968 miles, an error of about 16.3% .

Eratosthenes is also considered the Father of Geography. Working with information on exploration and travel available to him at the Alexandria Library, he create the first map of the world as it was known at that time. He also developed a system of grids which he placed over his map to estimate the distance from one location to another. This system of grids was the first attempt to create a geographic coordinate system.

8.3 Hipparchus – Greatest Greek Astronomer

Greek astronomer and mathematician Hipparchus (190 – 120 BC) is considered the greatest astronomical observer of ancient Greece. He lived at least part of his life on the Greek island of Rhodes located in the eastern Aegean Sea. Hipparchus quantitatively and accurately modeled the motion of the Sun and Moon, discovered and measured the Earth's precession (the slow change in the orientation of Earth's axis), and compiled the first comprehensive star catalog of the western world, using in part techniques acquired from the Babylonians. In addition, he developed trigonometry, constructed trigonometric tables, and solved problems of spherical trigonometry. Based on this work, he was able to develop a reliable method for predicting solar eclipses. He also expanded on Eratosthenes' coordinate system. Hipparchus normalized the east to west lines of latitude, making them parallel, and devised a system of 360 lines of longitude that ran north to south from pole to pole encompassing the Earth. He insisted that geographic maps must be based only on astronomical measurements of latitudes and longitudes and triangulation for finding unknown distances.

In addition to his other accomplishments, Hipparchus established an hour as 1/24th of a day, eliminating the season variation in the length of an hour as originally defined by the early Egyptians.

8.4 Lucretius - Hypothesized Light and Heat Came From the Sun

Not everyone believed that sight was the result of light emitted from our eyes. A Roman poet and philosopher by the name of Lucretius (~ 99 – 55 BC), was one of those that questioned that theory. In his poem *On the nature of the Universe* he hypothesized that light and heat from the Sun were composed of minute atoms which traveled at great speed from the Sun through the interspace of air to Earth. However, his views were not well accepted and the belief continued to be that sight was the result of light emitted from the eye.

8.5 Lucius Seneca – First Mention of Magnification

Roman philosopher and statesman, Lucius Seneca, better known as Seneca the Younger, (4 – 65 AD) was a tutor and later an advisor to Emperor Nero. In a comment regarding magnification, Seneca wrote “letters, however small and indistinct, are seen enlarged and more clearly through a globe or glass filled with water”. It is said that Emperor Nero watched gladiator fights by holding a green emerald to his eye. While the truth of this claim is questionable, it suggests that polished transparent gems were being used for magnification, a precursor to “seeing stones”.

8.6 Heron of Alexandria – Angle of Incidence Equals Angle of Reflection

Around 60 AD Heron of Alexandria (~ 10 – 75 AD) showed by geometrical methods that light reflected from a flat polished metal mirror takes the shortest possible path from the object (the light source) to the mirror and finally to the observer. Using this result, he concluded that the angle of reflection from the mirror must equal the angle of incidence on the grounds that this would yield the shortest path. He also concluded that the distance from the object to the mirror was equal to the apparent distance of the image behind the mirror. In addition, Heron argued that the speed of light was infinite because stars appeared immediately when opening one’s eyes.

9 Peace and Stability in Roman Empire

From 96 to 180 AD the Roman Empire prospered in an era of exceptional peace and stability. This was due in large part to a string of very capable Emperors who were focused on the well being of the Empire. Regions that one hundred years earlier had been brutally conquered by Roman Armies were now assimilated into the empire. People throughout the empire proudly considered themselves Romans. It was in this period that the Empire grew to its largest geographic extent (Figure 15).

Figure 15 Roman Empire 117 AD (source: Wikipedia)

9.1 Roman Glass Industry

During this time the Roman glass industry underwent rapid technological growth including the introduction of glass blowing techniques. Large scale manufacturing of glass, primarily in Alexandria, resulted in glass becoming a commonly available material. However, the building of flat glass mirrors was difficult and expensive due to the inability to produce flat glass of uniform thickness and the problems of applying hot reflective metal to the glass without cracking it. The clarity of the glass was also a problem due to impurities in the glass. Consequently, highly polished metal mirrors continued to be manufactured.

9.2 Ptolemy – Reflection, Refraction, and Color

It was also during this time that Alexandrian astronomer, mathematician, and geographer Claudius Ptolemy (~ 85 – 165 AD) studied the properties of light including reflection, refraction, and color. Ptolemy continued to promote Empedocles' emission theory (sight is the result of light emitted by the eyes). Ptolemy described a stick appearing to bend when partially immersed in a pool of water, and accurately recorded the angles he observed. He discovered that water and glass have different angles of refraction. He studied reflection by performing experiments with plane, concave and convex mirrors constructed from polished iron. In addition, he explained that magnification occurred when light passed through transparent curved objects.

Most of what we know concerning the work of Eratosthenes, Hipparchus and other early Greek astronomers comes from the treatise "Almagest" written by Claudius Ptolemy around 150 AD. Ptolemy explained and expanded on Hipparchus' work by subdividing each of the 360 degrees of latitude and longitude into smaller segments. Using the sexaqesimal numbering system, each degree was subdivided into 60 parts, each of which was again subdivided into 60 smaller parts. The first division, or first minute, was shorted to simply a "minute." Similarly, the second segmentation, or "second minute," became a second. Whether definition of the minute and second was actually the work of Ptolemy or that of Hipparchus is unclear.

10 Fall of the Roman Empire

In the 90 years following 180 AD there were nearly eighty short-lived emperors who claimed power by right or by usurpation. From 250 to 265 AD a plague raged in many regions of the Roman Empire. For a time as many as 5,000 people a day were dying in Rome. Famine followed the plague coupled with severe price inflation. The purity of the silver imperial coins dropped from nearly 90 to 5%. This was the beginning of the decline and eventual fall of the Roman Empire. The Roman people knew that times were hard but could not conceive of the Roman Empire disintegrating.

The Romans had been trading with the barbarians along the western frontier for a long time. Increasingly Romans neglected their duties of citizenship, including service in the army. Barbarians were hired to do their work for them. The Roman Army increasingly became barbarian solders commanded by barbarian generals hired to fight barbarians crossing the frontiers into the empire. The barbarians flooding across the borders were not interested in over throwing the empire but instead sharing in its prosperity. The fall of the Roman Empire and the birth of Europe occurred gradually from about 400 to 600 BC.

Following the fall of Rome, nearly all western knowledge of ancient Greek astronomy, mathematic, and science (and that derived from the earlier Babylonians and Egyptians) was lost as Europe entered the Dark Ages of Medieval Europe. The illiterate European peasants and their warring kings were far more concerned with day to day survival. They had no comprehension of or interest in the study of science and math. Monks could have preserved the old documents. But other than copying a few works of Aristotle, they where consumed with the very difficult laborious task of producing hand drawn copies of the Christian Bible.

11 Critical Muslim Role

Fortunately, following the collapse of the Roman Empire in the west, the eastern part of the empire survived. It prospered for a thousand years until finally falling to the Turks in 1453 AD. The people living in this region considered themselves to be Romans. From their perspective, that is who they were. Today, the eastern part of the Roman Empire is referred to as the Byzantine Empire to distinguish its politics and culture, as they slowly evolved, from their Roman roots.

In the 7th century AD, the Byzantine Empire lost Syria and Egypt, including Alexandria, to the Arabs as the Islamic Empire expanded out of the Arabian peninsula. The Muslims became fascinated with Greek science, math, and astronomy described in the enormous number of manuscripts discovered in Alexandria and other parts of the conquered territories. Consequently, many of the manuscripts were copied into Arabic.

The Arabic number system, crucial to modern day science and mathematics, was developed during this time replacing the cumbersome and unworkable Roman number system. It is believed that the Arabic number system was influenced by the Hindus in western India with whom the Arabs came in contact.

In addition, the Muslims developed a relatively good understanding of medicine allowing them to build and run the best most advanced hospitals of the time. This period has became known as the Islamic Golden Age.

Figure 16 Islamic Empire around 900 AD (source: www.khanacademy.org)

11.1 Hunayn ibn Ishaq – Ten Treatises on the Eye

Hunayn ibn Ishaq (809 – 873) was the most productive translator of Greek medical and scientific treatises in his day, translating the documents first into Syriac and then into Arabic. In addition he wrote a book titled *Ten Treatises on the Eye* which was influential in western European until the 17th century.

11.2 Abbas ibn Firnas – Color Glass and Magnifying Glass

Abbas ibn Firnas (810 -887) was an inventor, physician, chemist and engineer residing in Spain. His work included manufacturing colorless glass and developing a magnifying glass (a reading stones) for improving vision.

11.3 Ibn Sahl – First to Describe Law of Refraction

Islamic mathematician and physicist Ibn Sahl (~ 940 – 1000) is the first known Muslim scholar to have studied Ptolemy's *Optics* and wrote his own optical treatise around 984. His book was an important precursor to the *Book of Optics* written by al-Haytham some thirty years later. Ibn Sahl studied the optical properties of curved mirrors and thick lenses constructed from transparent material to understand how they bend and focus light. In the process he described a law of refraction mathematically equivalent to Snell's law.

11.4 Al-Haytham – The First to Understand the True Nature of Light

Around 1,000 AD, the Muslim mathematician, astronomer, and physician al-Haytham, (also known as Alhazen) made considerable strides in the understanding of light. al-Haytham is believed to have been born in Persia (now Iraq) around 965 and probably died in Egypt in 1040.

al-Haytham rejected the Greek idea that sight was the result of light emitted by the eye. In his *Book of Optics*, written from 1011 to 1021, al-Haytham maintained that sight was the result of light reflecting off objects and then entering ours eyes. He backed up his claim with a number of very persuasive demonstrations.

He proposed that there were two types of light, primary and secondary light. Primary light came from self-luminous bodies such as "red hot glowing iron". Secondary light was actually the reflection of primary light from a non-luminous object. Both types of light traveled in straight lines.

He believed that sun light consisted of streams of tiny particles also traveling in straight lines. In addition al-Haytham believed that the speed of light was finite arguing that light is substantial matter, the propagation of which requires time, even if this is hidden from our senses. He maintained that the speed of light was variable, traveling at a slower speed through denser material. In his book he described transparent bodies as objects through which light could pass, for example air and water. Opaque objects were objects through which light could not pass, although there were degrees of opaqueness as there were degrees of transparency.

Light could be reflected from smooth objects such as highly polished metal mirrors. When being reflected, light traveled in a straight line to the mirror and also in a straight line after being reflected from the mirror. Furthermore, he made the important observation that the angle of incidence, i.e. the angle between the incident ray of light and the line normal (perpendicular) to the mirror, was in the same plane as the angle of reflection.

He pointed out that magnification could be achieved when light passed through transparent curved objects. He observed that a light ray along the central axis of a thick lens passed through the lens without refraction. However, inclined rays were refracted. The amount of refraction depended on the density of the transparent material. While he made detailed measurements of the angle of incidence and the angle of refraction, he was not able to discover the sine law of refraction. One of the important aspects of his work was his use of observations, experiments, and rational arguments to support his findings. He was an early practitioner of what has become known as the scientific method.

12 Rebirth of Science in Europe

In the 10th and 11th centuries the Muslim city of Cordova, Spain was an important center of scientific learning, primarily in mathematics, astronomy, medicine, and botany. The learning institutions and libraries in Cordova far exceed anything available in the rest of Europe. Toledo, Spain had one of the finest libraries in Islam. It was from Cordova, Toledo and other Muslim cities in Spain that the European scholars, emerging from the dark ages, re-acquired the knowledge that had been lost following the fall of the Roman Empire. Aristotle’s views and the experimental approaches of al-Haytham were introduced to the European scholars via Latin translations of Arabic and Greek texts.

12.1 Robert Grosseteste – One of the First European Scholars

English Bishop, theologian, and scientist Robert Grosseteste (1175 – 1253) was one of the early European scholars. In his treaties De iride (“On the Rainbow”), written between 1220 and 1235, Grosseteste mentions the use of optics to "read the smallest letters at incredible distances".

12.2 Roger Bacon – Early Scientific Method

Franciscan Friar Roger Bacon (1214 – 1292) was one of the earliest European’s to utilize experimentation in the study of science.

Bacon developed a strong interest in mathematics and science while studying and teach at Oxford University in 1247 (at the age of 33). He was strongly influenced by the writings of Grosseteste and embarked on an intense study of languages, mathematics, optics and sciences that would consume him the rest of his life. Bacon read al-Haytham's "Optics" and came to understand the importance of applying mathematics to real world problems. In fact, his most important mathematical contribution was the use of geometry in the study of optics. Bacon planned and carried out systematic observations and experiments with lenses and mirrors in a manner very similar to today's scientific approach. He also promoted the idea of using lenses for magnification to aid natural vision.

Bacon left the University of Oxford in 1251 and entered the Franciscan Friary in Oxford at the age of 37. It is unclear what the reason was for this move. He was a devout Christian who believed that his scientific work would aid in an understanding of the world and God's creation. He spent the rest of his life assigned to various Friary's in England, France, and Italy, not always at his choice. For a while he was imprisoned in Italy, the charge being "suspected novelties" in his teachings. In other works, he expressed views which his superiors disagreed with. However, he was allowed to continue his study of mathematics and science throughout most of his years as a Friar.

13 References

Carroll, Bradley W.; Ostlie, Dale A.; *An Introduction to Modern Astrophysics*; 1996, Addison-Wesley Publishing Company Inc.

Foukal, Peter; *Solar Astrophysics*; 2013 Wiley-VCH Verlag GmbH & Co.

Golub, Leon; Pasachoff, Jay M.; *The Nearest Star The Surprising Science of Our Sun*; 2014 Cambridge University Press

Zettili, Nouredine; *Quantum Mechanics Concepts and Applications*; 2009 John Wiley & Sons, Ltd.

Masi, Marco; *Quantum Physics: an overview of a weird world*; 2018 Marco Masi

Halliday, David; Resnick, Robert; *Physics For Students of Science and Engineering Part I*; 1962 John Wiley & Sons, Inc.

Halliday, David; Resnick, Robert; *Physics For Students of Science and Engineering Part II*; 1962 John Wiley & Sons, Inc.

Klus, Dr. Helen; *How We Came to Know the Cosmos: Light & Matter*; 2017, The Star Garden, UK.

Ling, Samuel J.; Sanny, Jeff; Moefs, William; *University Physics Volume 3*; 2018 Openstax Rice University

Dampier, W. C.; *A History of Science*; 1961 Cambridge University Press

Cajori, Florian; *A History of Physics in its Elementary Branches*; 1917, The Macmillan Company

Williams, Henry Smith; *A History of Science Part 1*; 1904 Kessinger Publishing

Williams, Henry Smith; *A History of Science Part 1*; 1904 Kessinger Publishing

Starr, Chester G.; *A History of the Ancient World*; 1991, Oxford University Press

Davies, Norman; *Europe a History*; 1998, Harper Perennial

Pannekoek, A.; *A History of Astronomy*; 1961, George Allen and Unwin Ltd.

Merzbech, Uta C.; Boyer, Carl B.; *A History of Mathematics*: 2011, John Wiley & Sons, Inc.

Friedman, Herbert; *The Astronomer's Universe Stars, Galaxies, and Cosmos*; 1990, The Commonwealth Fund Book Program

Hogan, Craig J.; *The Little Book of the Big Bang A Cosmic Primer*; 1998 Springer-Verlag New York Inc.

Sagan, Carl; *Cosmos*; 1980 Carl Sagan Productions

Piccioni, Robert L.; *Everyone's guide to Atoms Einstein and the Universe*; 2010 Robert L. Piccioni; Real Science Publishing

J. J. O'Connor and E. F. Robertson; *Light through the ages: Ancient Greece to Maxwell*; MacTutor History of Mathematics, (University of St. Andrews, Scotland) 2002, http://www-history.mcs.st-andrews.ac.uk/HistTopics/Light_1.html

UVA Physics Department; *Newton's Particles Theory of Light-Galileo;* University of Virginia; http://galileo.phys.virginia.edu/classes/609.ral5q.fall04/Lecture:PDF/L20LIGHTII.pdf

Fowler, Michael; UVA Physics Department, *The Speed of Light,* University of Virginia, http://galileoandeinstein.physics.virginia.edu/lectures/spedlite.html
Walbank; Frank W.; Alexander the Great; Encyclopedia Britannica

Setterfield, Barry; *A Brief History of c*; 1987

El-Abbadi, Mostafa; *Library of Alexandria*; Encyclopedia Britannica

Williams, L. Pearce; *History of Science*; Encyclopedia Britannica

Rodrigue, Christine M; *The Geography of Mars: Lab Cassini, Richer, and Picard Experiment, 1672*; Department of Geography California State University, Long Beach, CA.; http://www.csulb.edu/~rodrigue/

Spring, Kenneth R.; Fellers, Thomas J.; Zuckerman, Lawrence D.; Davidson, Michael; *Speed of Light*; Olympus-Life Science, Olympus America Inc.

Abramowitz, Mortimer; Spring, Kenneth R.; Parry-Hill,Matthew; Flynn, Brian O.; Tchourioukanov, Kirill I. Fellers, Thomas J.; Davidson, Michael W.; *The Physics of Light and Color*; Olympus-Life Science, Olympus America Inc. https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/

Urone, Paul Perter; *Image Formation by Mirrors*; LibreTexts

Kovacs, Peter; *History of the reading stones*; Light Microscopes

Herivel, John; *Christiaan Huygens Dutch Scientist And Mathematician*; Feb 14, 2019; Encyclopedia Britannica

Rodriguez, Emily; *Robert Hooke British Scientist*; Feb 27, 2019; Encyclopedia Britannica

Westfall, Richard S; *Sir Isaac Newton English Physicist and Mathematician*; Feb 1, 2019; Encyclopedia Britannica

Tyldesley, Joyce; *Cleopatra*; Encyclopedia Britannica

Toynbee, Arnold Joseph; *Julius Caesar*; Encyclopedia Britannica

El-Abbadi, Mostafa; *Library of Alexandria*; Encyclopedia Britannica

Walbank, Frank W.; *Alexander the Great*; Encyclopedia Britannica

Crowley, Theodore; *Roger Bacon*; Encyclopedia Britannica

Jones, Alexander Raymond; *Ptolemy*; Encyclopedia Britannica

Meinwald, Constance C.; *Plato*; Encyclopedia Britannica

Amadio, Anselm H.; Kenny Anthony J. P.; *Aristotle*; Encyclopedia Britannica

Lorch, Richard;Ibn; *al-Haytham*; Encyclopedia Britannica

Van der Waerden, Bartel Leendert; Taisbak, Christian Marinus; *Euclid*; Encyclopedia Britannica

Editors of Encyclopedia Britannica; *Heron of Alexandria*; Encyclopedia Britannica

Westman, Robert S.; *Johannes Kepler*; Encyclopedia Britannica

Van Helden, Albert; *Galileo*; Encyclopedia Britannica

Wikipedia; *History of optics*

Wikipedia: *History of glass*

Wikipedia; *Glasses*

Wikipedia; *Mirror*

Wikipedia; *al Haytham's Book of Optics*