Clocks

Time: A history of clocks

History of time

In today’s world, the most widely used numeral system is decimal (base 10), a system that probably originated because it made it easy for humans to count using their fingers. The civilizations that first divided the day into smaller parts, however, used different numeral systems, specifically duodecimal (base 12) and sexagesimal (base 60).

Thanks to documented evidence of the Egyptians’ use of sundials, most historians credit them with being the first civilization to divide the day into smaller parts. The first sundials were simply stakes placed in the ground that indicated time by the length and direction of the resulting shadow. As early as 1500 B.C., the Egyptians had developed a more advanced sundial. A T-shaped bar placed in the ground, this instrument was calibrated to divide the interval between sunrise and sunset into 12 parts. This division reflected Egypt’s use of the duodecimal system—the importance of the number 12 is typically attributed either to the fact that it equals the number of lunar cycles in a year or the number of finger joints on each hand (three in each of the four fingers, excluding the thumb), making it possible to count to 12 with the thumb. The next-generation sundial likely formed the first representation of what we now call the hour. Although the hours within a given day were approximately equal, their lengths varied during the year, with summer hours being much longer than winter hours.

Without artificial light, humans of this time period regarded sunlit and dark periods as two opposing realms rather than as part of the same day. Without the aid of sundials, dividing the dark interval between sunset and sunrise was more complex than dividing the sunlit period. During the era when sundials were first used, however, Egyptian astronomers also first observed a set of 36 stars that divided the circle of the heavens into equal parts. The passage of night could be marked by the appearance of 18 of these stars, three of which were assigned to each of the two twilight periods when the stars were difficult to view. The period of total darkness was marked by the remaining 12 stars, again resulting in 12 divisions of night (another nod to the duodecimal system). During the New Kingdom (1550 to 1070 B.C.), this measuring system was simplified to use a set of 24 stars, 12 of which marked the passage of the night. The clepsydra, or water clock, was also used to record time during the night, and was perhaps the most accurate timekeeping device of the ancient world. The timepiece—a specimen of which, found at the Temple of Ammon in Karnak, dated back to 1400 B.C.—was a vessel with slanted interior surfaces to allow for decreasing water pressure, inscribed with scales that marked the division of the night into 12 parts during various months.

Once both the light and dark hours were divided into 12 parts, the concept of a 24-hour day was in place. The concept of fixed-length hours, however, did not originate until the Hellenistic period, when Greek astronomers began using such a system for their theoretical calculations. Hipparchus, whose work primarily took place between 147 and 127 B.C., proposed dividing the day into 24 equinoctial hours, based on the 12 hours of daylight and 12 hours of darkness observed on equinox days. Despite this suggestion, laypeople continued to use seasonally varying hours for many centuries. (Hours of fixed length became commonplace only after mechanical clocks first appeared in Europe during the 14th century.)
Hipparchus and other Greek astronomers employed astronomical techniques that were previously developed by the Babylonians, who resided in Mesopotamia. The Babylonians made astronomical calculations in the sexagesimal (base 60) system they inherited from the Sumerians, who developed it around 2000 B.C. Although it is unknown why 60 was chosen, it is notably convenient for expressing fractions, since 60 is the smallest number divisible by the first six counting numbers as well as by 10, 12, 15, 20 and 30.

The Greek astronomer Eratosthenes (who lived circa 276 to 194 B.C.) used a sexagesimal system to divide a circle into 60 parts in order to devise an early geographic system of latitude, with the horizontal lines running through well-known places on the earth at the time. A century later, Hipparchus normalized the lines of latitude, making them parallel and obedient to the earth's geometry. He also devised a system of longitude lines that encompassed 360 degrees and that ran north to south, from pole to pole. In his treatise Almagest (circa A.D. 150), Claudius Ptolemy explained and expanded on Hipparchus' work by subdividing each of the 360 degrees of latitude and longitude into smaller segments. Each degree was divided into 60 parts, each of which was again subdivided into 60 smaller parts. The first division, partes minutae primae, or first minute, became known simply as the "minute." The second segmentation, partes minutae secundae, or "second minute," became known as the second.

Minutes and seconds, however, were not used for everyday timekeeping until many centuries after the Almagest. Clock displays divided the hour into halves, thirds, quarters and sometimes even 12 parts, but never by 60. In fact, the hour was not commonly understood to be the duration of 60 minutes. It was not practical for the general public to consider minutes until the first mechanical clocks that displayed minutes appeared near the end of the 16th century. Even today, many clocks and wristwatches have a resolution of only one minute and do not display seconds.

Thanks to the ancient civilizations that defined and preserved the divisions of time, modern society still conceives of a day of 24 hours, an hour of 60 minutes and a minute of 60 seconds. Advances in the science of timekeeping, however, have changed how these units are defined. Seconds were once derived by dividing astronomical events into smaller parts, with the International System of Units (SI) at one time defining the second as a fraction of the mean solar day and later relating it to the tropical year. This changed in 1967, when the second was redefined as the duration of 9,192,631,770 energy transitions of the cesium atom. This recharacterization ushered in the era of atomic timekeeping and Coordinated Universal Time (UTC).

The use of time and clocks

Time. A potentially endless dimension known by all, yet understood by none. It is described as the fourth dimension, a measure of ordering events from the past, through the present and into the future.
Ever since the dawn of man, time has been important to mankind. This makes sense, otherwise there would not be a dawn for man that would be noticed. From sunrise till sundown: knowing when to get up, when noon is and at what time to start a fire to keep the night lit. Time is one of the few natural concepts known by all humans, in various units of measuring the time elapsed. A clock finds its place in time by being one of the oldest human inventions, created by the need to consistently measure time intervals shorter than the natural units; the day, the lunar month and the solar year.

The earliest form of somewhat accurate clocks were most likely gnomons, followed by sundials. A gnomon is the ‘stick’ part of a sundial that casts a shadow which aligns to the sundials’ different hour lines. To know how much time had passed between one moment and another, hourglasses, water clocks and candle clocks have also been in use since ancient times. These all have to be calibrated in advance to know how much time it would take from start to finish, as these clocks can not tell one what time of day it was, is or will be.

Now, let us do something that is seemingly impossible in our linear vision of time: fast forwarding. Luckily, this is only a thought experiment so we can go from the ancient times of gnomons, sundials and hour glasses to the present time. We find ourselves in the 21st century, a time in which the world is seemingly dominated by our obsession of time. We live in a time where we wish to always know what time it is, in a time where time equals money and power, and in a time in which we simply wish we had more time. But, what is the use of time and clocks with it?

Consider time as a linear event. This implies that, as mentioned in the beginning of this section, that time is a measure of ordering events from the past, through the present and into the future, and once the moment passes it becomes part of the past. Time in such a fashion is used nowadays for multiple purposes. First and foremost, to know what time of day it is. This is also the use of clocks to a large extent. Knowing the time enables, for example, multiple people to arrange a meeting at a certain time at which every participant will be present. To get to this meeting, one might have to catch a train that leaves at a certain point. To get to the train before it leaves, the potential participant will have to leave his house before a specific time.

Time however is not only used to know the specific moment of the day, it is also used to express distance and speed.

When you’re traveling to a location, say for example the bus stop near your house, you usually don’t talk about a certain amount of meters that you have to travel. Instead, the bus stop is located at roughly a five minute walk. Or, when taking an airplane from Helsinki to New York, it’s an eight hour trip. Hardly anyone thinks about the 6620 kilometers that are travelled during this trip.

Why we think in this way, might be because the time it takes to travel a certain distance is relative to the speed at which it is travelled. If we were to travel from Helsinki to New York at the same speed at which we went to the bus stop, it would take roughly 55 days at an average of 5 km/h - not including the necessary stops and rests.
It is to no surprise then that time is one of the seven fundamental physical quantities in the International System of Units and in the International System of Quantities. Time is used to define, amongst things, velocity and acceleration. The flight from Helsinki to New York will average out at about 830 kilometers per hour. In order to measure this, or any, velocity, being able to measure the amount of time it took to travel a certain distance is crucial.

## Types of clocks

Time can be measured in many ways and there are many types of clocks to measure time. The most of the clocks indicate the time of the day. Measuring cycle is typically 12 or 24 hours, which the clock divide smaller parts.

Clocks can be classified by the type of time display, as well as by the method of timekeeping. Typical classifications are by mechanism, by function or by style.

## Principles of clock types

**Water Clock.** A water clock is any timepiece in which time is measured by the regulated flow of liquid into or out from a vessel where the amount is then measured.

**Candle clock.** A candle clock is a thin candle with consistently spaced markings, that when burned, indicate the passage of periods of time.

**Incense clock.** The clocks' bodies are effectively specialized censers that hold incense sticks or powdered incense that have been manufactured and calibrated to a known rate of combustion, used to measure minutes, hours, or days.

**Sundial.** A sundial is a device that tells the time of day by the position of the Sun. The sun casts a shadow from its style onto a surface marked with lines indicating the hours of the day. The style is the time-telling edge of the gnomon.

**Astronomical clock.** An astronomical clock is a clock with special mechanisms and dials to display astronomical information, such as the relative positions of the sun, moon, zodiacal constellations, and sometimes major planets.

**Hourglass.** An hourglass measures the passage of a few minutes or an hour of time. It has two connected vertical glass bulbs allowing a regulated trickle of material from the top to the bottom. Once the top bulb is empty, it can be inverted to begin timing again.
Mechanical clock (e.g. pendulum clock, pocket watch, equation clock, Marine chronometer, wristwatch). A mechanical clock uses a mechanical mechanism to measure the passage of time, as opposed to modern watches which function electronically. It is driven by a spring (called a mainspring) which must be wound periodically. Its force is transmitted through a series of gears to power the balance wheel, a weighted wheel which oscillates back and forth at a constant rate. A device called an escapement releases the watch’s wheels to move forward a small amount with each swing of the balance wheel, moving the watch’s hands forward at a constant rate.

Electric clock. An electric clock is a clock that is powered by electricity, as opposed to a mechanical clock which is powered by a hanging weight or a mainspring. The term is often applied to the electrically powered mechanical clocks that were used before quartz clocks replaced them in the 1980s.

Quartz clock. A quartz clock is a clock that uses an electronic oscillator that is regulated by a quartz crystal to keep time.

Atomic clock. An atomic clock is a clock device that uses an electronic transition frequency in the microwave, optical, or ultraviolet region of the electromagnetic spectrum of atoms as a frequency standard for its timekeeping element.

How clocks work

A clock needs a power source, that provides power to keep the clock going. The timekeeping element in every modern clock is a harmonic oscillator, a physical object (resonator) that vibrates or oscillates repetitively at a precisely constant frequency. A clock has usually some kind of controller, which has the dual function of keeping the oscillator running by giving it 'pushes' to replace the energy lost to friction, and converting its vibrations into a series of pulses that serve to measure the time. Also there are counter chain, which counts the pulses and adds them up to get traditional time units of seconds, minutes, hours, etc. It usually has a provision for setting the clock by manually entering the correct time into the counter. Lastly there has to be an indicator, that displays the count of seconds, minutes, hours, etc. in a human readable form.

Accuracy

Why are some clocks more accurate than others?
An accurate clock is a clock that is in synchrony with the standard clock. When the time measurements of the clock agree with the measurements made using the standard clock, we say the clock is accurate or properly calibrated or synchronized with the standard clock or simply correct. A perfectly accurate clock shows that it is time t just when the standard clock shows that it is time t, for all t. Accuracy is different from precision. If a clock read exactly three minutes slow compared to the standard clock, then it's very precise, but it's inaccurate by three minutes.

One issue is whether the standard clock itself is accurate. Realists will say that the standard clock is our best guess as to what time it really is, and we can make incorrect choices for our standard clock. Anti-realists will say that the standard clock cannot, by definition, be inaccurate, so any choice of a standard clock will yield a standard clock that is accurate.

A clock is accurate, if firstly it's action is precise, and secondly it's action is more close in synchrony with the standard clock. The more constantly the clock ticks, the more precise it is, and the more close in synchrony with the standard clock the clock is, the more accurate it is.

How does energy interact with matter in clocks?

How does light (electromagnetic radiation) interact with matter in clocks?

Without researching, we can first of all say that one type of interaction that EM waves have with clocks is reflection. As with any type of matter, light must reflect off of it to make it visible. Depending on the wavelength of the radiation, different effects can occur. These effects also depend on the type of clock.

For mechanical clocks, the following would apply. If one were to put a clock in a microwave, the molecules of which the clock is made will start to oscillate with the waves. This increase in motion of the molecules will manifest in an increased temperature of the clock (or any type of matter). If the wavelength is lowered to the wavelengths of visible light, the waves will be reflected and the clock is visible. Lower the wavelength even more to, for example, x-ray wavelengths, and one could somewhat see through the clock, depending on the matter-composition.

An atomic clock is a different situation altogether. This type of clock uses the molecular energy transition frequency of a specific wavelength to keep track of time. If this process would be subject to an external source of radiation, the process could be disrupted, resulting in an incorrect display of time.

What does the research say?
For most physical type of clocks, the same principles apply that also apply to most of the existing matter. Because matter largely consists of nothing, any given photon has a finite probability completely passing through an atom. This probability depends on numerous factors, such as the photon’s energy and the medium’s composition and thickness. If an atom has a higher atomic value, implying a larger nucleus, the photon has a larger probability of encountering this atomic particle. When this happens, the photon transfers energy to the particle. This energy may be reflected back, scattered in a different direction, or transmitted forward into the material.

Reflection and transmission of electromagnetic radiation occur because the waves transfer energy to the electrons of the material, causing them to vibrate. If the material is transparent, such as glass, then the vibrations are passed on to neighbouring atoms through the bulk of the material and reemitted at the other side of the material. If the material is not transparent, the electrons vibrate for a short period of time and then reemit the energy as a reflected wave. (3.1)

X-rays and -rays also transfer their energy to matter, however due to their higher energy levels they do more than merely making the electrons vibrate. Instead, they eject or excite electrons. This increase in electron energy is then transferred to nearby electrons. With each interaction, the direction of energy may be changed. If the radiation has had enough energy upon entry of the material, it may eventually make it through the material, even if it wasn’t transparent. This is the starting principle of how x-ray photographs are made.

Reference list

3.1