# Clocks: The Heritage of the Christian Faith



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> When Gibbon indicted the Middle Ages as "the triumph of barbarism and religion," he coupled two great bugbears of the intellectual elite of his day, both widely regarded as hostile to scientific and technical progress.[1]

Following the train of thought popularized by Gibbon, most admirers of modern times vilify the Middle Ages, because of its Christian nature, as the "dark ages" of stupefaction.[2] Consider Professor "Neoteric." See him as he whisks through the university hallways, the pages of his lecture notes fluttering in the air, in a frantic attempt to make his 9:00 AM "Intro to Middle Ages" class. Hardly does Dr. Neoteric realize, as he proceeds to parody Gibbon's medieval maligns, *that he is utilizing three key medieval inventions, without which, he would be voiceless:* (1) the university, (2) the printing press, and (3) the clock.[3] The purpose of this essay is to explore the development and impact of one of these inventions, namely the mechanical clock.

## Ancient Timepieces

According to the British physicist James Clerk Maxwell (1831-1879), "Every science has some instrument of precision, which may be taken as a material type of that science which it has advanced, by enabling observers to express their results as measured quantities. In astronomy we have the divided circle, in chemistry the balance, in heat the thermometer while the whole system of civilized life may be fitly symbolized by a foot rule, a set of weights, and a clock."[4] Beyond a doubt, Maxwell's third key feature of the whole system of civilized life, the weight-driven or mechanical clock, was a medieval invention. Before this, other tools were used to measure time. To measure days, months, years, and seasons, the Sun, Moon, and stars were used (Genesis 1:14-18; cf. Job 38:31-33). For many millennia, these God-created timers were the only clocks people used. To measure hours in a day (i.e., solar time), the sundial was invented (probably by the ancient Egyptians). The shadow of its gnomon indicated the passing of daylight with great precision. Another hour clock, an invention of the either the ancient Egyptians or Chinese (ca. 1500 BC), was the clepsydra or water clock.[5] It worked on the principle of filling or emptying a vessel at a controlled rate. This clock was a common timepiece in early medieval monastic life.[6] To measure the extent of an hour, the hourglass (sand timer) and/or candle[7] were employed. They worked on the same "fill/empty" principle as the clepsydra. These early timekeepers were called *horologium* (Latin meaning "to speak of the hour or season").

As to utility, the sundial and water clock were limited in scope and precision. They were largely used for measuring the duration of *some activity* (e.g., a speech, cooking time, or length of a legal consultation). The sundial only worked if you had enough sunlight (no shadows on a cloudy day). The water clock, an effectual tool for the night, encountered problems in the winter (the water froze). When physical conditions acquiesced, these clocks could only approximate an hourly schedule.

[1] Frances & Joseph Gies, *Cathedral, Forge, and Waterwheel: Technology and Invention in the Middle Ages* (New York: HarperCollins Publishers, 1994), 4. Gibbon is the British historian Edward Gibbon (1737-1794) and his referent to the Middle Ages is in his classic work *Decline and Fall of the Roman Empire* (New York: Modern Library, n.d.), 2:1443.

[2] Unfortunately, too many Christians (especially Protestants) have swallowed Gibbon's indictment "hook, line, and sinker." That Protestants do this is because the history of technology has been neglected due to their theological focus (investigating medieval deviations both in doctrine and in practice). That the academe does this is because the history of technology has been neglected due to their academic focus (imbibing the ancient Greek error that endorses "ivory tower" cogitations and negates manual work and invention).

[3] These intellectual and technological components are preconditions for the enterprise known as modern society. Like the laws of logic to knowledge and the nature of causality to science, they are fundamental to the way the modern world works.

[4] James Clerk Maxwell, *The Theory of Heat* (London: 1872), 75.

[5] Clepsydra means "water stealer." The Italian Galileo Galilei (1564-1642) used this clock along with an inclined plane to time his "falling objects" experiments.

[6] We have evidence of their use as early as 1198 when, in a testimony of a monk name Jocelyn de Brakelond, an abbey fire was quenched by water retrieved from both a well *and a clock*. See James Burke, *Connections* (New York: Little, Brown and Company, 1978), 128 and Arnold Pacey, *The Maze of Ingenuity: Ideas and Idealism in the Development of Technology* (Cambridge: The MIT Press, [1974] 1992), 36.

[7] By inserting a nail into the candle, it was used as an alarm clock. When the candle melted down to the nail, the nail would fall into a metal pan and make a noise.

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## Are You Sleeping, Brother John?

It was only with the rise of civil societies possessing fairly elaborate social institutions that a precise and faithful measurement of time became important. In the Middle Ages, these social institutions became prevalent through a co-ordinated mix of commercial progress and liturgical requirements. With the rise of cities came the rise of artisans (businessmen) and the negotiations that necessitated monetary transactions. Setting a punctual schedule for work and business transactions became crucial. The monasteries followed the order of Benedict (480-543) and experienced re-form in the 12th century through the Cistercians founded by Bernard of Clarivaux (1090-1153).[8] The brothers engaged in designated prayer times by dividing the twenty-four hour day into eight equal parts. Each portion (consisting of three hours) was called an "hour," using the beginning of the period as its indicator. Starting from midnight and using the classical Roman counting, the eight Canonical Hours are: (1) *Matins*, means "morning" – midnight, (2) *Lauds*, means "praise" – 3:00 AM, (3) *Prime*, means "first" – 6:00 AM, (4) *Terce*, means "third" – 9:00 AM, (5) *Sext*, means "sixth" – noon, (6) *Nones*, means "ninth" – 3:00 PM, (7) *Vespers*, means "evening" – 6:00 PM, and (8) *Compline*, means "final" – 9:00 PM.[9] The abbeys especially needed a reliable mechanism (i.e., an alarm clock or ringing bell) to awake the monks for the nightly watches (cf. Psalm 42:8; 63:1-6; 119:55, 62, 147-148). Our word "clock" comes from these monastic alarms (the Latin *clocca* means "bell").

This urgency to not miss Matins has been immortalized for us by the best known of children's songs: *Frère Jacques, Frère Jacques, Dormez-vous? dormez-vous? Sonnez les matines, sonnez les matines, Ding, ding, dong; ding, ding, dong.* Translation: Are you sleeping, are you sleeping, brother John? brother John? Morning bells are ringing, morning bells are ringing; Ding, ding, dong; ding, ding, dong.[10]

## The Mechanics of the Mechanical Clock

As we have noted, the monks developed water clocks to particularly good effect. A slight modification to the alarm mechanism associated with this clock led to the invention of the weight-driven mechanical clock. What is this mechanism? In practice, what was needed was a suitable *driving* mechanism and a suitable *regulating* mechanism. A fal-ling weight was the only natural *driving* force available. Due to the gravitational force of acceleration (a concept ana-lyzed by medieval scholastics), the velocity of the weight needed to be impeded. An innovative braking or *regulating* mechanism was the crying need of the hour. We do not know the name of the person who invented this mechanism but, over a period of time, some inventor (or possibly a group of inventors[11]) combined two pieces of machinery that regulated each other's motion. These medieval engineers invented what we now know to be a *mutual feedback* mecha-nism, a system copied in countless modern instruments.[12] This mechanism works by releasing an equal amount of me-chanical energy at equal, short intervals.[13]

Attached to a wheel are short, horizontal, and uniformly spaced pegs (numbered 1 to 6 in the figure). This wheel is sometimes called a crown wheel because the metal pegs look like a toothed (or king's) crown. This wheel is turned (or driven) by a weight (called the driving weight and labeled W in the figure) at the end of a cord that is wound around an axle. In front of the wheel is a vertical rod (called the *verge*) and attached to it are two small flags or plates

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[8] Bernard's work dynamism led, by the time of his death, to the foundation of 340 Cistercian abbeys all over Europe (each one economically self-sufficient and a center of agricultural innovation, animal management, commerce, and education). Some historians have noted that the Cis-tercian reform and "work ethic" prefigured to some degree the later Puritan reform and "work ethic." See G. G. Coulton, "The high ancestry of Puritanism," in *Ten Medieval Studies* (Cambridge, England: Cambridge University Press, 1930).

[9] At the end of the 14th century, the best selling book in Europe was *Book of Hours*. Wealthy people sometimes commissioned the preparation of a handwritten book to be used in private reading in conjunction with the appropriate canonical hour. Such a book included psalms, other pas-sages of Scripture, anthems, hymns, and prayers, and it usually had full color pictures that are, even today, a rich feast for the eyes. For some samples of this artwork, see *Book of Hours* (San Marino: The Huntington Library, 1976).

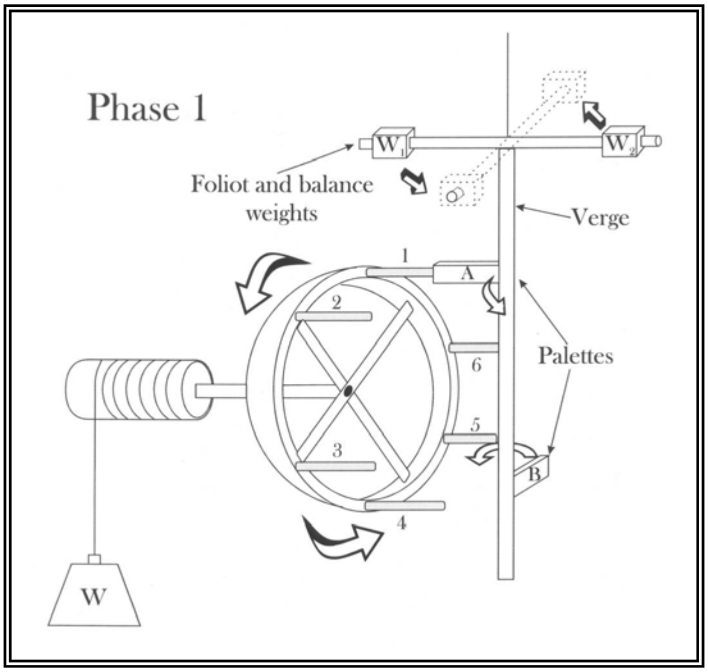
[10] For more information and monks, monasteries, and time, see David S. Landes, *Revolution in Time: Clocks and the Making of the Modern World* (New York: Barnes & Noble, 1983), 53-66.

[11] The design may have resulted from some millwrights who knew about gearing (inherited from the engineers of ancient Greece) and the prob-lems of uniform motion.

[12] Here are some examples. Feedback control appeared as a centrifugal governor, used originally as a convenience for operating the medieval windmill, but as a necessary component of the steam engine (the harbinger of the Industrial Revolution). The aileron enabled controlled flight and ushered in the Age of Aviation. The gyro is a crucial component needed for guidance and control in the Space Age. In electronics, the posi-tive-feedback amplifier increases the gain and acts as a stable oscillator for modulation and demodulation (essential components of radio fre-quency circuits). The negative-feedback amplifier provides the means to build precision amplifiers with low distortion.

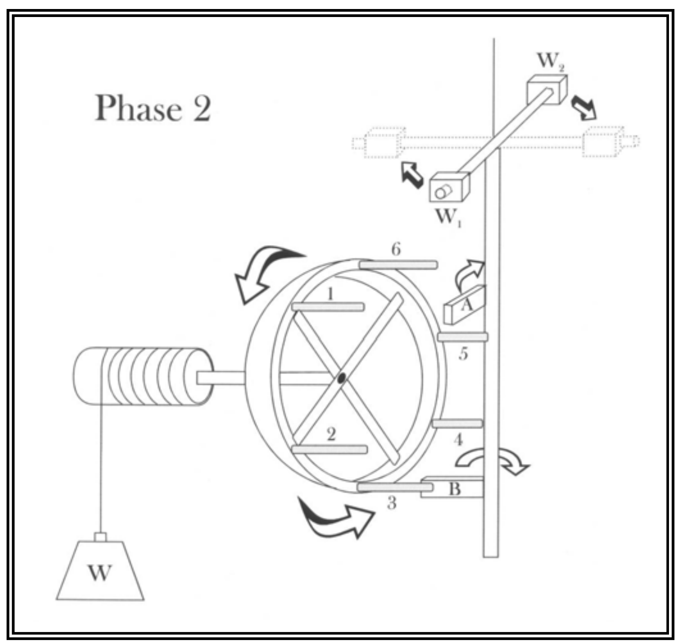
[13] You can build your own 14th century mechanical clock. A Canadian firm (http://members.rogers.com/woodenclock/HourClock.html) sells beautiful wooden clock kits that you can construct and mount in your home.

(palettes) at slightly more than 90° to each other (labeled A and B in the figure).[14] These palettes are placed so that they can "mesh" with the pegs on the wheel. The verge is suspended freely by a rope or cord. A short horizontal rod or crossbar (*foliot*, a French word[15]) is attached to the top of the verge. Two adjustable balance weights are attached to each end of the *foliot* (labeled $W_1$ and $W_2$ in the figure). The crown wheel together with the *verge* and *foliot* incorporate what modern engineers call the escapement.[16]




The falling weight (W) at the end of the chord makes the crown wheel rotate. Peg 1 moves forward and strikes palette A (Phase 1) pushing it out of the way. This action causes the balance weights of the *foliot* to turn as indicated in the figure. This movement of the balance weights turns the verge until palette B strikes peg 3 (Phase 2). As the *foliot* spends its momentum through the opposition (inertia) that peg 3 gives to palette B, the rotation of the crown wheel momentarily stops thus impeding the "free fall" of the driving weight W.

The driving weight W overcomes the inertia of the balance weights and causes peg 3 to push palette B out of the way. This causes the *foliot* to move back to its original position as the driving weight W resumes its "free fall" motion. Peg 5 now moves toward palette A (which is being turned back to its original position by the movement of the *foliot*). When peg 5 strikes palette A, the entire process repeats itself. The *foliot* and balance weights swing to-and-fro and the driving weight W is repeatedly impeded in its fall by being compelled regularly to reverse the motion of the balance weights (this represents the *feedback* action).




By adjusting the *proportion* between the balance weights ($W_1$ and $W_2$) and the driving weight W and the *distance* between the balance weights and the verge, the operator can set the frequency of the oscillatory motion.[17] By these tweaks to the system, the fall of the driving weight can be periodically checked and restarted so that the average, or overall, rate of fall is uniform and the effects of friction essentially erased. To tell time, a sequence of gears attached to the axle drives an arrow-shaped dial across a circular clock face.

## Medieval Ingenuity

The medieval mechanical clock is revelatory of two remarkable ideational and technological innovations both characterized by mental maturity and perspicuity. First, before the mechanical clock appeared, the concept of time had been understood as smoothly flowing (like water, sand, or melting wax). Maintaining a constant

[14] The word "verge" comes from the medieval "verger" who carried a staff with two small flags before a scholastic, legal, or religious dignitary in a procession.

[15] I've been unable to find an etymology of foliot (pronounced "foh-lee-oh"). It was a well-known medieval family name (both in England and in France).

[16] In mechanics, an escapement is a ratchet device that permits motion "in steps" in one direction only.

[17] Moving the foliot weights inward increases the rate, and moving them outward decreases it.

flow, however, was difficult and the solution to this problem was as counterintuitive as it was profound. The escapement caused the driving weight to alternatively speed up and slow down. Each impact of a palette with a peg imparts an impulsive force to the crown wheel causing a *discontinuity* or jump in its velocity. The escapement measured time by packaging it into intervals between impacts. Time, for the first "time" in history, became a *discrete* commodity. Telling time became equivalent to counting the impacts (ticks and tocks) and this counting is a digital process that is measured by an analog dial! The mechanical clock is what engineers call a discrete event system, whose dynamics are continuous between impacts and discontinuous (or discrete) at impacts.[18] Second, this clock makes use of a brilliant, ingenious, and high order mechanical (or kinematic) insight that the motion of the escapement wheel can, by means of *verge* palettes at 90° to each other, be converted into oscillatory (to-and-fro or the famous "tick-tock") motion of the *foliot* balance weights. This device required a mastery of the principles of dynamics accordingly to which the fall of the driving weight is *uniformly* impeded by being made to impart the same quantity of accelerative motion to the balance weights. It had to wait until the Italian Galileo Galilei (1564-1642) and the Englishman Sir Isaac Newton (1642-1727) for a complete scientific and mathematical explanation although medieval scholastics Jean Buridan (1300-1358) and Nicole Oresme (ca. 1323-1382) provided some precocious and anticipatory hints with their theory of impetus. So much for medieval stupefaction!

When did these clocks first appear on the medieval scene? Although very little information is available, the first firm indication is in Burgundy, France (ca. 1275). A key 14th century figure in the early art of clock making is Richard of Wallingford. Clocks driven by falling weights were erected on cathedrals (called turret clocks) in the late 13th century and early 14th century. The earliest extant mechanical clocks are found in the cathedrals at Salisbury, Wiltshire, England (1386), Rouen, France (1389), and Wells, Somerset, England (1392).

## Motivation: More than Mere Utility?

Since the mechanical clock was accurate only to about a quarter of an hour a day (same as the best water-clock accuracy), the question arises is to the real motivation for its invention. Was it utility only, in the name of commerce or liturgy, or something else? According to Arnold Pacey, "The first weight-driven clocks were more probably made for reasons of the intellect or imagination independently of any utilitarian or economic incentive."[19]

The earliest clocks of which full details are available did not just tell mean solar time.[20] They indicated the position in the zodiac of the Sun, Moon, and planets. They were updated astrolabes![21] According to the earliest descriptive details, the faces of these clocks were not marked with hours or used for telling time but were dials familiar to users of the astrolabe.[22] The only difference was that the dials were turning continuously. As Pacey observes, "They represented the fulfilment of an ambition to make powered astronomical models keep pace with the moving planets."[23] Men like Richard of Wallingford were attempting to synchronize a machine with the movement of the starry host, an idea of immense symbolic and spiritual value. When hour numbers were added to the clock face (the first mechanical clocks only had an hour hand), they were set to correspond to the Sun's position as it circles round the Earth (looking at the sky through the geocentric grid). The numbers (either one to twelve or one to twenty-four) are in harmony with

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[18] The mechanical clock *unifies* two *diverse* aspects of experience, the discrete and the continuous, and thus becomes an amazing example of what theologians Cornelius Van Til (1895-1987) and Rousas J. Rushdoony (1916-2001) denote as the "one and the many" principle (in the proximate, man-generated yet God-imaged sense).

[19] Pacey, 37-38.

[20] The mean solar day is the period of time between two successive transits of the mean Sun. It is the standard 24-hour day measured from midnight to midnight and it is now defined as 86,400 seconds (24 hours x 60 minutes/hour x 60 seconds/minute). In contrast, the sidereal (star) day is the period of time for a complete rotation of the Earth in reference to any star and it is equal to 23 hours, 56 minutes, 4.09 seconds (86,164.09 seconds or 997/1,000 of mean solar time). The difference between mean solar time and sidereal time is the reason why stars "break through the horizon" four minutes earlier every succeeding night and why every month of the year the stars pass through exactly the same places in the night sky.

[21] The astrolabe (means "to take the stars") is an astronomical instrument that was used in ancient and medieval times to measure the altitude of the Sun and other celestial bodies (it is now replaced by the sextant). Christian Europe acquired this device from the ancient Greeks through its interface with the Arabic culture in the 11th century.

[22] The oldest clock of which we have detailed knowledge was built by an Italian named Giovanni De'Dondi (ca. 1330-1389). A clock of extraordinary complexity, its seven faces showed the position of seven celestial bodies (Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn); in addition, one rotating dial indicated religious feast days, and another displayed the number of daylight hours in the day. Fashioned by hand with bronze, brass, and copper parts, it took De'Dondi sixteen years to build it, finishing in 1362. The original was destroyed in a 16th century fire but two working replicas were built (based upon De'Dondi's detailed description) in London in 1962.

[23] Pacey, 39.

the twelve regions in the sky that either the Sun crosses by day or the stars by night.[24] The circular nature of the clock reflected the apparent spherical nature of the heavens. *The medieval mechanical clock was a celestial model purposely designed to be an earthly reflection of God's heavenly and harmonious clockwork*.[25]

## Better Precision

Peter Henlein (ca. 1485-1542) invented the balance wheel and clockwork (or coiled-spring drive) in 1510 (he also invented the first portable watch) in Nuremberg, Germany. Henlein nicknamed his portable clocks "Nuremberg Eggs." The problem with these clocks was that the spring needed rewinding. Jacob Zech of Prague invented a fusee (or spiral pulley) in 1525 to offset this difficulty. The Swiss Jost Burgi (1552-1632), a co-inventor with Scotsman John Napier (1550-1617) of logarithms, is credited with having invented the first clock with a minute hand (ca. 1577). In the 17th century Galileo, noting the rhythmic or "heart beat" nature of a swinging pendulum, invented the pendulum clock (using the motion of a pendulum instead of the balance weights). The Dutch physicist and astronomer Christiaan Huygens (1629-1695) actually made the first pendulum timekeeper that made the minute hand practical and precise (his clocks lost less than one minute per day, the first time such accuracy had been achieved). Also, the successive beats of a pendulum made possible a practical second hand (these clocks appeared in the late 17th century and reduced the clock's errors to less than ten seconds a day). In the 17th century, we find the first appearance of glass over the face of a portable watch and English physicist Robert Hooke (1635-1703) introduced the dead beat and a caliper-like "anchor" mechanism. The apotheosis of the mechanical clock came in the 18th century with the invention of the marine chronometer (1761) by the Englishman John Harrison (1693-1776), a carpenter and self-taught clock-maker.[26] Harrison's clock, using a spring and balance wheel escapement, answered the vexing need for determining a ship's longitude at sea, which is a function of time.[27] During its sea trials, it kept time on board a rolling ship to an accuracy of about 1/5 of a second a day.

Although the clock was originally designed to pattern the Sun's march across the sky, the division of the hour into 60 minutes, and the minute into 60 seconds are *inventions of men.*[28] A little thought will inform us that there is a fundamental circularity in the way we measure time; i.e., *the time that is measured by a clock is itself produced by that clock*. Although initially dependent upon the Sun for its calibration, clocks soon became independent of the Sun and the seasons. We hardly give this a second thought, but this has not always been the case. People originally added the phrase "of the clock" (later abbreviated to "o'clock") when denoting the time produced by a clock.

When pendulum clocks with an anchor escapement were invented in the 17th century, the clock became so precise that *it became possible to measure the variation in the Sun's speed* (the speed of the shadow of the sun across the sundial varies slightly from day to day). From then on, instead of sundials calibrating clocks, clocks were used to calibrate sundials and people began to live by "mechanical" time. The habitual "tick-tock" began to invade the consciousness of man by marking the unending passage of time.

## The Impact of the Clock

The mechanical clock provided for a fixed, uniform hour (contra the variable hour based upon longer winter nights and longer summer days).[29] With the invention of the mechanical clock, people began to "time" activities that no one had ever thought of timing before. The mechanical clock shaped the Western World by eventually providing the quantitative precision needed for the birth and growth of modern science.[30] Without a precise and universally ac-

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[24] This allotment by twelve was clearly a derivative of the twelve divisions of the zodiac. The zodiac is a band of the apparent celestial sphere extending about 8° to either side of the ecliptic (the path carved out in the sky by the principal planets, the Moon, and the Sun). This 360° band is divided into twelve equal parts (each 30° wide) called signs and denoted by a specific constellation (e.g., Leo, Virgo). The famous clock tower in Ulm (near the Danube River in southwestern Germany) is characterized by its elaborate decoration depicting the twelve signs of the zodiac.

[25] Likewise, medieval engineers purposely designed the cathedral to model the resurrection age; i.e., the heavenly realities of the New Jerusalem (Revelation 21-22). See Pacey, 43-45.

[26] See Dava Sobel, *Longitude* (New York: Walker and Company), 1995.

[27] One degree (1°) of longitude (east or west) is measured by the difference of four minutes.

[28] In contrast, the seven-day week is the design of the Creator (Genesis 1; Exodus 20:8-11). Note also that the 24-hour day is a reflective pattern of the orderly march of celestial bodies across the sky.

[29] Ancient civilizations had established the custom that twelve daylight hours and twelve night hours would correlate to each dawn-to-dusk and dusk-to-dawn period. Seasonal variations forced variable length hours in this context.

[30] In mathematics, the principles of trigonometry (sinusoidal functions) enabled scientists to understand and make use of the oscillatory motion of timepieces.

cepted time standard (time zones and daily savings time coordinate life and commerce[31]), the administrative, commercial, military, and industrial arrangements of Western Civilization would be impossible.[32] Although we now have sophisticated crystal oscillators[33] and atomic clocks,[34] we still, in the last resort, arrange all of our affairs in the framework and by the measures of time that resulted from the medieval and Christian invention of the weight-driven clock.

On the negative note, the precision of the clock can make our lives somewhat "mechanical," but we must realize that without these timepieces life would be chaos. Whether we like it or not, our modern world is set to the precise punctuality of a clock.[35]

The clock provides the covenant-keeping Christian man with a tool of dominion in terms of his calling to service in Christ's kingdom. It enables him to better obey Ephesians 5:15-16, "See then that you walk circumspectly, not as fools but as wise, redeeming the time, because the days are evil." Redeem means to "buy or purchase." Time in the Greek is *kairos* meaning "season." The Apostle Paul commands the follower of Christ to redeem "seasons of opportunity" and wise use of the timetable, schedule, and clock serves the dominion-oriented man in the redemption of these seasons.[36] In contrast, for the covenant-breaker the "tick-tock" of time, instead of a redeeming opportunity, becomes a remorseless master, a result of the sin's dominion over the law-breaker. The covenant-breaker, as a helpless slave of time, rebels against its tyranny by fleeing from responsibility, history, and ultimately his Maker.

The clock, the heritage of the Christian faith, reminds all men in our modern age that time beats not only to the step of the stars, but also echoes the stroke of eternity. The ticking of each passing second reminds all of us that we are moving toward an engagement and that no escapement can impede this eternal appointment (Amos 4:12; Hebrews 9:27).

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[31] Time zones were incorporated into daily living in the 19th century to coordinate railroad traffic. Each zone was set at a width of fifteen degrees (15°) of longitude, and hence each sector an hour (15 degrees x 4 minutes/degree = 60 minutes) apart from its neighbor.

[32] Apart from acting as timekeepers for just about every aspect of our everyday lives, the use of clocks extends to the automation of factories, time switches in street lighting and other domestic controls, timing in industrial and sporting activities, and for all navigation (including GPS – Global Positioning System) and space travel. The nature of military activities requires timely coordination (e.g., D-day and H-hour). Our desktop computers derive their speed from a highly precise internal clock capable of creating extremely short intervals of time, currently (as of this writing) approaching the 3.06 GHz (gigahertz) range. Hertz is a unit of frequency equal to one "tick" per second. *Giga* is a prefix that denotes one billion ($10^9$).

[33] With the quartz clock, capable of measuring time to the millionth of a second, it became possible to measure the small discrepancy in the Earth's rotation from day to day.

[34] One second is now defined to be 9,192,631,770 Hz, the natural vibration of a caesium-133 atom.

[35] By using an old-fashioned pocket watch instead of the traditional wristwatch, I have discovered that I can remove to some degree the "mechanical" dominion of the clock. I can engage certain activities (e.g., talking to friends, a date with my wife) in a more relaxed manner *without always "peeking" at my wrist!*

[36] Perhaps the best book available that teaches the *noblesse oblige* of redeeming the seasons of life is Stephen R. Covey, *The Seven Habits of Highly Effective People* (New York: A Fireside Book, 1989). Covey, a Mormon, places time management in a creational context, i.e., the seven-day week (although I'm not sure that he self-consciously recognizes this connection). By doing so, his methodology does not succumb to the tyranny of the clock, as some time management schemes tend to do.