ENGLISH HOROLOGICAL LITERATURE

by Herbert A. Gold (CA)

This article is from a talk presented at the 1985 NAWCC Seminar held in Portland, Oregon.

I collect books. I primarily collect books about clocks and watches and related matters. We can study clocks and watches from the past and draw many conclusions, but nothing tells it "like it was" as the words in the books written at the time "it was." Books are the only horological artifacts that can actually "speak" to us. Except of course, the talking clock. I'd like to share what I have read, enjoyed, and feel is worthwhile. While not meant as a definitive bibliography, the horological literature to be discussed covers the time period principally between 1675 and 1753.

The first author I would like to discuss was truly one of the greatest men of science: Christiaan Huygens. Huygens was born in the Netherlands in 1629 and died in 1695 at the age of 66. His father was a wealthy, well known Dutch diplomat and poet.

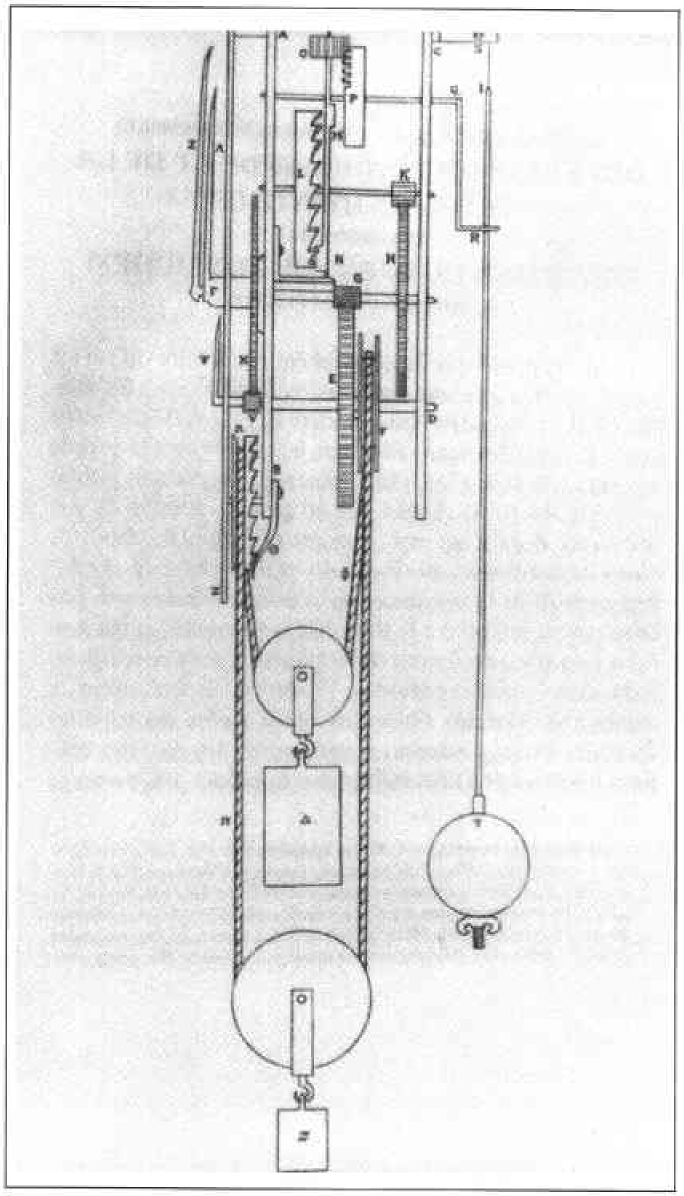
Huygens is credited with the invention of the micrometer; he was the first to study polarized light; to develop the wave theory of light; and to coin the term "ether" for the medium that light travelled through. He built the most powerful telescope of the time, 10 ft. long, with lenses ground and polished to his own design. With his telescope, Huygens discovered the true shape of Saturn's ring and a then-unknown satellite of Saturn. He enumerated the laws governing the impact of elastic bodies, and he discovered the laws of centrifugal force for uniform circular motion. Huygens also wrote that the planets were inhabited. But then, no one is perfect. Despite all his substantial contributions to science, Huygens felt overshadowed throughout his life by Isaac Newton, with whom he was a fierce competitor.

In 1598, the King of Spain offered a fantastic reward for a method to determine longitude at sea. In the same year, and probably of more importance to Huygens, the States-General of the Netherlands offered a reward of 10,000 florins to anyone who could fulfill the same need.

While Huygens does not seem to have been financially motivated, he was very interested in furthering his growing, and soon to be substantial, reputation. We know that the discovery of a means to determine longitude was of very great interest to him. His studies of the physics of moving bodies, and his command of mathematics led to his investigations of the pendulum. As a result of these studies, he applied for, and received, a patent for a pendulum-driven clock in 1657. He was only 28 years old at the time.

The patent was limited in its protection to only one province of the Netherlands and was challenged almost everywhere. Samples were made by the clockmaker Salomon Coster, to whom Huygens assigned the rights, and some of these clocks are extant. Very soon Huygens became aware of the many other claims to his invention. His patent, fame, and integrity were not enough to still the critics, and challenges arose everywhere. So with the idea of quieting the hubbub he published *Horologium,* in 1658, the year after the patent.

Horologium is a very rare book. It has 15 pages, one plate, and is 7½ inches high. The text is in the scientific language of the day, Latin. There is a copy in the library at the University of Leiden. I have not seen any on the market. *Horologium* is the first published work to treat the pendulum clock exclusively. It is dedicated, "To their Lordships the Most Illustrious and Most Powerful Governors of Holland and West Friesland." Huygens' plaintive state of mind is revealed in the dedication from E. L. Edwardes' translation of the Latin:



The drawing that is reputed to be the first graphical representation of a pendulum driven clock.

". . . former honesty and inventiveness are accounted to return occasionally on earth. Assuredly, since these virtues are no longer found amongst the greater part of mankind, but on the contrary, widespread imposture and disparagement obtain in all things, I indeed easily foresaw that a like fate would befall my invention as soon as it had begun to be generally known, nor did my misgivings deceive me. For see now, in our own country such conduct is surpassed by the audacity and impudence of certain people, who not deterred by your patent, have slightly modified my invention, and then, if you please, have dared to display it as altogether new, and even more praiseworthy than mine. And those who have seen these things happening in my presence and before my very eyes have warned me repeatedly that I can expect nothing better from abroad. It is certain that elsewhere also will arise men, unjustly envious and eager for fame, who will seize upon this invention of mine and will endeavor to persuade the whole world, if not themselves, that it was not due to my talents; but rather to their own, or those of their own people, by whom the device had been produced for a long time previously."

The clock described below is one much improved over the patent. Huygens says he was inspired by Galileo's use of pendulum motion to count units of time. Astronomers would manually impel a weight suspended on a light chain and count the individual vibrations. While the method was obviously crude, Huygens says that with patience, they were able to make more accurate observations of eclipses, the sun's diameter, and calculate distances to stars. Then he says something interesting, ". . . other [things] more subtle, will be examined; for example, they will measure the true equality of the days from meridian to meridian, those presuming to deny which being, up to the present, refuted by reason rather than by the certainty of experience." He was referring to the fact that the cause of the difference between mean solar time, that is, clock time and apparent solar time or sun dial time, was not widely understood at that time. Huygens also says that this invention will be great for determining longitude. "But this matter will occupy me or others later. . . ." And so, of course, it did.

Included is the famous drawing that has been reproduced almost as often as the Mona Lisa, the first graphical representation we have of a pendulum driven clock. The main features are the pinion and crown wheel (with teeth on only a fraction of its circumference). This was his scheme to reduce the pendulum arc. He realized that a pendulum swinging in a small arc was more isochronous than one swinging in a large arc. Isochronism, in its meaning here, is the property of a pendulum to take the same amount of time to swing in a large arc or a small arc. That is, if the arc is larger, the pendulum will move faster, in a small arc, it will move slower, thereby covering either distance in the same amount of time. However, he hoped to use his discovery aboard ship to determine longitude, but clocks with small arcs tended to be stopped by the ship's motion. Therefore, he continued his search for isochronism with large arcs.

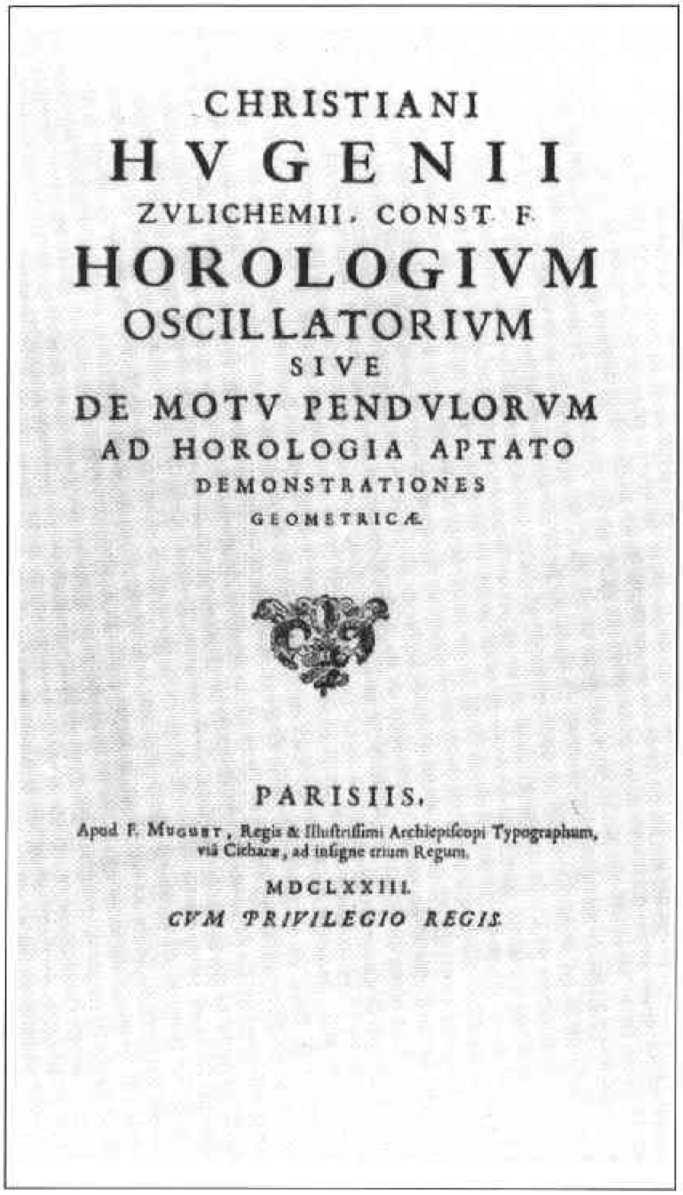
It sounds like a tag line for a soap opera: "Can there be true isochronism with everyone swinging in large arcs?" The pendulum controls the verge and receives its impulse through the fork and crutch. It has a regulating nut. There is a sweep seconds hand concentric with the hour hand, and a separate small minutes chapter—a somewhat unusual arrangement. The pendulum is about 12 inches long and beats ½ seconds. Huygens shows the first known example of maintaining power, the ability to keep power applied to the going train while the clock is being wound.

Following publication there was much controversy over who should get credit for applying the pendulum, Huygens or Galileo. Galileo had written a letter in 1637 suggesting that a pendulum rod be connected to a train of wheels to count the vibrations. But he left the details of execution to a "skilled craftsman." This is an early example of my geometry class nemesis, "The proof is left to the student." But Huygen's big contribution was the elastic suspension of the pendulum and coupling the pendulum to the verge with a crutch. His problem was a poor choice of escapement for the pendulum. The arc in a verge escapement was really too wide for true isochronism. The extra contrate wheel was an attempt to compensate, but Galileo had already shown a "pin wheel" escapement that would have been a much better choice. Even though the anchor escapement eventually blew the verge away, Huygens stuck to the verge to the bitter end. But even with all the controversy, he was clearly the first to reduce to practice a clock regulated by a pendulum and nothing should rob him of that glory. It was a dog-eat-dog world out there in 1658, but Huygens persevered.

In 1673, in Paris, he published his most famous work, *Horologium Oscillatorium.* The title page shows the following: "Christiaan Huygens of Zulichem, son of Constantin. The Pendulum Clock, or Geometrical Demonstrations of the Motion of Pendulums applied to Clocks." There are about 170 pages with one plate. It is 12½ inches high by eight inches wide. Granville Baillie, in his wonderful book on horological books, says this work is the most important item in a horological bibliography. Begun in 1660 as an amplified version of *Horologium,* Huygens worked on it on and off for 12 years. It was sent for printing in 1672. He was living in Paris at the time where he was a founding member of the French Academy of Science. The book's introduction raised many eyebrows as he dedicated the book to Louis XIV. This was not unreasonable on the face of it, since Louis was paying Huygens' rent. The problem was, that France was at war with the Dutch. The text is in five parts. In Part 1 is a description of another famous figure: a clock with cycloidal cheeks and maintaining power. The pendulum is suspended in such a fashion, that when it swings, the center of oscillation follows the curve of a cycloid. The cycloid is a particular geometrical curve. Huygens describes the form of the cycloidal curve, its properties, and how to generate it. There is also an Equation of Time table, with instructions for its use, that was originally published in 1655. Huygens may well have been the first to publish such a table.

Finally, he gives a description of his marine clocks and the results of their trials at sea—a less than sensational entry.

In Part 2, there are theorems on falling bodies and properties of the cycloid. Huygens proves the proposition that a pendulum swinging in a cycloidal arc is isochronous. That is, the time of oscillation is independent of the amplitude of the swing. The pursuit of that theoretical proposition kept clockmakers busy for the next 250 years. In


CHRISTIANI
HVGENII
ZVLICHEMII, CONST. F.
HOROLOGIVM
OSCILLATORIVM
SIVE
DE MOTV PENDVLORVM
AD HOROLOGIA APTATO
DEMONSTRATIONES
GEOMETRICÆ.

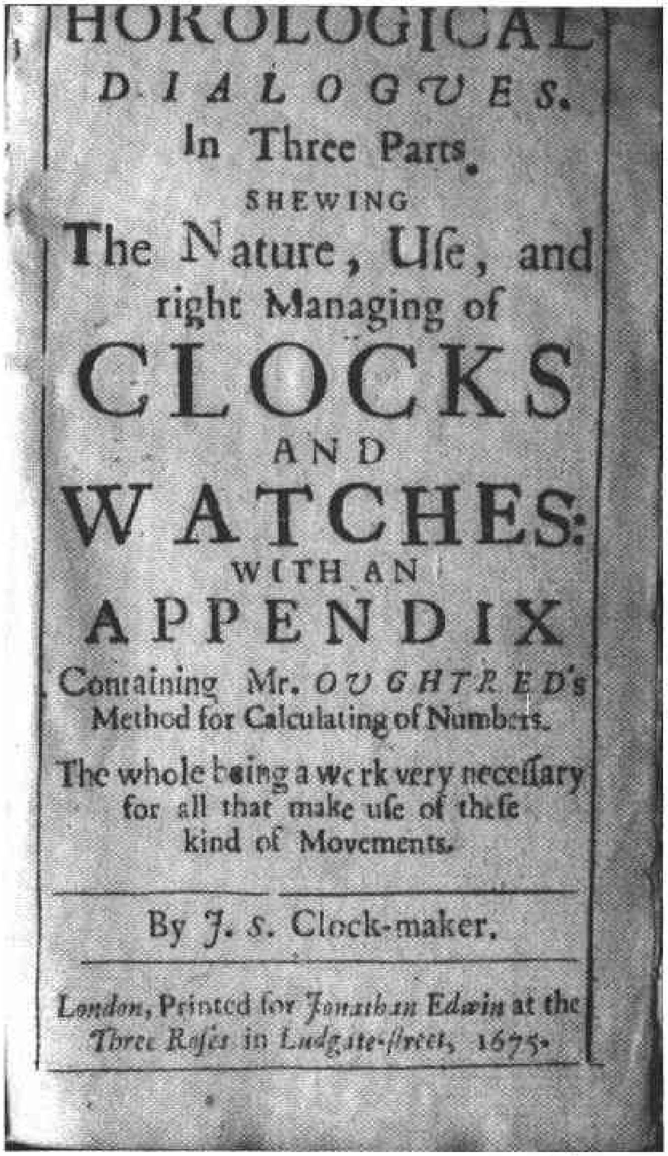
PARISIIS,
Apud F. Muguet, Regis & Illustrissimi Archiepiscopi Typographum, via Citharæ, ad insigne trium Regum.
MDCLXXIII.
CVM PRIVILEGIO REGIS.

The title page of Christian Huygens' Horologium Oscillatorium.

Part 3, there are more geometrical machinations. He shows mathematically that a pendulum suspended between cycloidal cheeks will swing in a cycloidal arc. In Part 4, there are theorems on the center of oscillation of bodies.

Part 5 has a description of an isochronous conical pendulum, that is, a pendulum that swings in a circle. It was a device of interest to astronomers as it provided a stepless motion suitable for driving telescopes. This principle has been used in astronomical observatories well into the 20th century. He points out here that the best way to avoid rotational friction in a vertical arbor, in a train of wheels, is to let the arbor rest on a flat diamond. This is considered the earliest mention of the use of an endstone. This book is a collectible piece, although a very expensive one.

Now we move to England. In 1660, the monarchy was


HOROLOGICAL
DIALOGUES.
In Three Parts.
SHEWING
The Nature, Use, and
right Managing of
CLOCKS
AND
WATCHES:
WITH AN
APPENDIX
Containing Mr. OUGHTRED's
Method for Calculating of Numbers.
The whole being a work very necessary
for all that make use of these
kind of Movements.

By J. S. Clock-maker.

London, Printed for Jonathan Edwin at the
Three Roses in Ludgate-street, 1675.

John Smith's Horological Dialogues, *Note the "J. S. Clockmaker" signature.*

restored with Charles II on the throne. In 1665, the Great (bubonic) Plague, wiped out 100,000 souls or about ⅕ of the population. A year later the Great London Fire took St. Paul's and 80 other churches, the Royal Exchange and 13,000 houses. Fortunately, there was no recorded loss of life. It was, however, a bonanza for the architect, Christopher Wren, who was hired to rebuild many of the buildings.

By 1675, pendulums had been swinging for about seven years. Robert Hooke, wearing his architect's hat, began building Bedlam Hospital, for, "the relief and cure of persons distracted." He probably had Huygens and his many other fancied rivals in mind. Greenwich Observatory was established this year, and John Smith published his first book. This is not the famous John Smith whose name turns up on motel registers throughout the ages, but John Smith the clockmaker.

Smith, originally a Lancastershire tool maker, became a member of the Clockmakers' Company in 1674. In addition to his horological activities, he wrote on barometers, painting, and on the plentiful use of cold water as a preservative of good health. He worked in London and died sometime before 1730. Apparently a vocal Unitarian, he got into a heated theological discussion with a Rev. Francis Gregory who advised him, "to go back to the noise of his hammers and the use of his pincers." Smith wrote three little books on clocks and watches, publishing his first book in 1675. *Horological Dialogues* is considered to be the first English language book on clocks and watches. It is a small book of about 132 pages, 5½ inches high by three inches wide. It is written in the form of a Socratic dialogue, between "C-h-i-v.," the questioner and "Articus," the respondent. I was unsuccessful in finding any historical, literary, or mythological meanings for the choice of these names.

The following is the introduction:

> "To the reader. Clocks being things in themselves so useful and excellent, that no production of art whatsoever doth surpass them (especially those well made) yet are extraordinarily subject to give dissatisfaction to those that own them, which happeneth from two causes; the one from the workman's unskillfulness and unfaithfulness in making them, and the other is from the owner's unskillfulness in keeping and managing them. To remove the latter of these causes hath engaged me to endeavor (in the following tract) to reveal (to those that are ignorant) some of those secrets that are necessary to be known by those that would rightly manage them: in doing which, I have been as plain as possible, considering the brevity of it, and I doubt not but it will give sufficient light to any understanding man whatsoever, and though it come forth into the world but in a plain country dress, yet I can assure you it hath a good design, and will deliver those things that are of use and profit to all that have occasion to make use of it, from whom I hope to gain a friendly acceptance, which if I find sufficient encouragement, then this shall not be the last of my endeavors to serve you."

And so it was not. John Smith wrote two more books which I shall mention later.

Smith begins *Horological Dialogues* by classifying clocks into several categories: "By Driving Power: weight or spring/By Regulator: Ballance (foliot) or pendulum." Then he made further subdivisions into: "Repeating, chiming and alarum and By Going: 16 hours, 30 hours, 8 days, 5 weeks, 3 months, 6 months and 1 year." He gives a pretty good description of the working mechanism of a clock covering the going train and the count wheel striking train. Smith tells the reader what to look for in a well-made clock: Well finished metal work, brass wheels, steel pinions and brass plates. He says you should buy a clock where "the teeth of the wheel be cut down by an ingine for there is no man can cut them down by hand so true and equal as an ingine doth." This is an interesting comment since Robert Hooke had only invented the wheel-cutting engine three years earlier in 1672. I guess good news travelled fast.

Then Smith tells how to choose a good clockmaker: "Choose him not by [his] testimony of his own labours." Smith goes on to say, "Resolve to give a price valuable to the work you purchase. . . . He that sells a clock for a small price cheats either himself or his customer, for if he sells good work at a low rate, he cheats himself; but if he sells bad work at a low value then he cheats his customer . . ." On the subject of getting repairs, he expressed the view, held down through the ages by family physicians, which was, bring the clock to the workman and not vice versa: "for 'tis impossible for a workman when he is from his tools to perform his business so exquisitely as otherwise he might . . ." Probably good advice, even today, at least for the clockmaker.

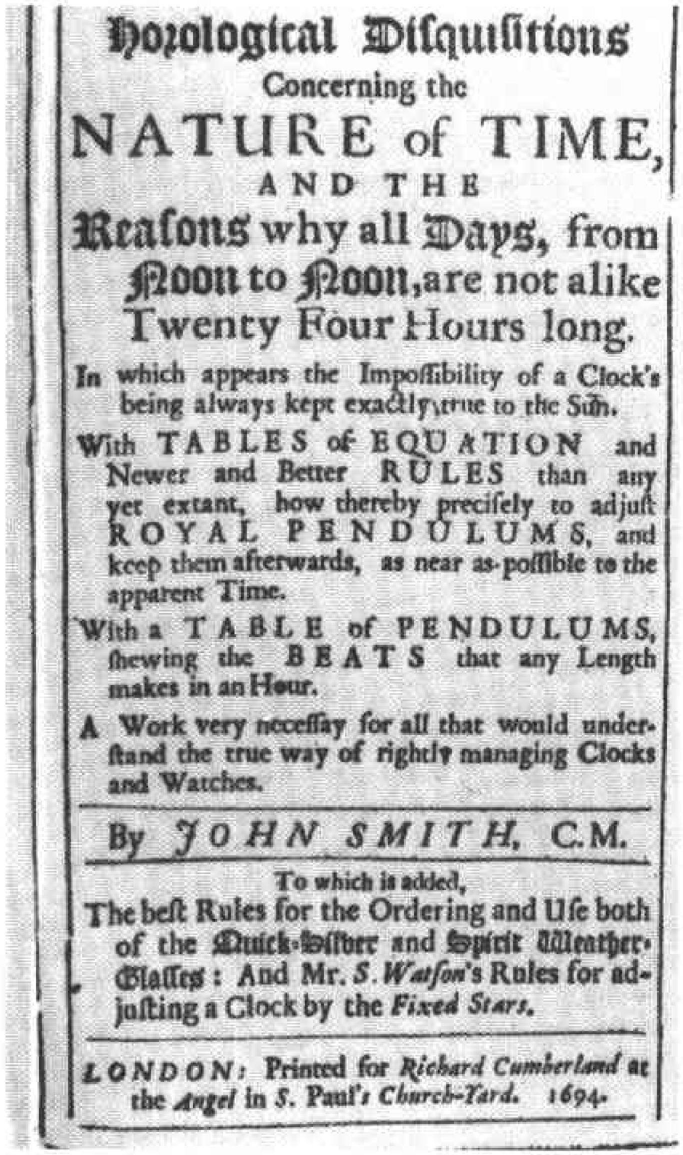
Because the advent of the pendulum had made clocks so much more accurate, the notion that a clock can be a reliable measurer of time was now prevalent. To test this premise, clocks were measured most conveniently against sun dials. Also, dials were the only convenient way to set a clock or watch to time. Smith gives a good discussion on the unequality of time, why clock time (mean solar time) and the sun dial will not directly agree. There is no Equation of Time table but there is a fairly sophisticated explanation of refraction, that is, the distortion of the apparent position and size of an observed heavenly body due to the earth's atmosphere. He gives corrections and optimum times for taking observations for various times of the year.

In the quest for accurate comparison to sun dial time, I was amused by his admonition,

> ". . . set your watch continually by one sun-dial, because 'tis seldom known that two sun-dials go true together; so that, if you set it sometimes by one, and sometimes by another, you will never know when your watch or clock goeth right. Also observe further to set it always to one hour on the same dial; because many times the hour lines give not true time alike. . . ."

On the regulation of watches he observes, ". . . it being equally as unpossible to make a watch go always true as to have light and darkness both in the same place at the same time." But Smith goes on to say that this problem of watch regulation describes balance, that is, foliot watches and not "pendulum watches that are drawn by springs."

Smith writes that an "ancient writer," presumably Galileo, says that a pendulum will vibrate in equal time irrespective of its displacement. Smith disputes this claim and cites an experiment with a 7-foot pendulum that beats 41 per minute with a 4-inch displacement and 37 per minute with a 180-degree displacement. It is obvious that he was unfamiliar with Huygens' work of 1673. That is understandable since England had declared war on the Dutch in 1672, not of course, because of anything Huygens had done.


Horological Disquisitions Concerning the NATURE of TIME, AND THE Reasons why all Days, from Noon to Noon, are not alike Twenty Four Hours long.

In which appears the Impossibility of a Clock's being always kept exactly true to the Sun.

With TABLES of EQUATION and Newer and Better RULES than any yet extant, how thereby precisely to adjust ROYAL PENDULUMS, and keep them afterwards, as near as possible to the apparent Time.

With a TABLE of PENDULUMS, shewing the BEATS that any Length makes in an Hour.

A Work very necessay for all that would understand the true way of rightly managing Clocks and Watches.

By JOHN SMITH, C.M.

To which is added,

The best Rules for the Ordering and Use both of the Quick-Silver and Spirit Weather-Glasses: And Mr. S. Watson's Rules for adjusting a Clock by the Fixed Stars.

LONDON: Printed for Richard Cumberland at the Angel in S. Paul's Church-Yard. 1694.

Smith's Horological Disquisitions, *published 1694.*

In an appendix is a separate work by the famous English mathematician, William Oughtred. Oughtred is credited with the invention of the slide rule, the trigonometric abbreviations we use today, and the signs for multiplication and proportion. His work in this book is called "Of Movements or Automata." Oughtred covers the calculation of wheel work for watches. He discusses motions to show the age of the moon, day of the year, the sun's rising and setting and its location in the ecliptic, and "the hour of full tide at any port." It is probably the first publication of this very important material.

I'm sure John Smith was a fine craftsman. The same cannot be said of Jonathan Edwin Smith's printer, at the

Three Roses in Ludgate Street. The text has many typographical errors, inverted type, crooked lines, and type face substitutions. Some examples are: two different "P"s are used in the in the word "pendulum," the word spacing on line 6 is a bit rough, and if there is a word for typographic onomatopoeia, then the phrase, "a certain motion" should get it. This is a fairly rare book, but still a few turn up now and again. A facsimile edition is available for about $10.

John Smith's next book, *Of The Inequality of Natural Time,* was published in London in 1686. Since Smith's last book, Huygens discovered the polarization of light, Newton explained the moon's gravitational effect on the tides, and London had a postal service, rudimentary street lighting, and bank checks. A small volume, 6¼ inches by 3¾ inches, with 42 pages of text and one very nice folding table, the book is devoted to the Equation of Time and how to rate clocks. The data in the table comes from Huygens' work published in the *Philosophical Transactions,* the famous journal of the Royal Society.

Smith talks about, "those long and curious pendulums of 40 inches that fetch not above three inches compass, they are so exact, that being once adjusted they shall always keep the same time, if their motion continue. . . ." The word "curious," at that time, had the meaning, ingenious, skillful or clever. The anchor escapement and the Royal pendulum were definitely operating in 1686. Who actually invented them is still a matter of dispute. The printing of this volume is a much better job. There are very few typos, and it is nicely laid out. It is a fairly rare book with only about eight known in existence.

John Smith's last book was *Horological Disquisitions.* The first edition was published in 1694, and there was a second edition in 1708. This is another small book, 7 inches × 4½ inches, 92 pages of text, and one folding plate. "Disquisition" means a treatise or discourse in which a subject is investigated and discussed, or the results of an investigation are set forth at some length.

The first table is the same as the one in the last book. The second table, however, is rather novel. Ten days are identified and called "rectifying days." On these days you set your clock fast or slow according to the table. Then throughout the year, the clock will be within 3′45″ (that is $\frac{1}{16}$ hr) of apparent solar time throughout the year. He credits William Clement with the invention of the movement combining a long (40″) pendulum with a narrow arc. He names this the "Royal" pendulum, but makes no mention of the details of the escapement, which we must assume is an anchor.

Again, this time at greater length, he discusses the difference between mean and apparent solar time. He credits Huygens with being the first to publish equation tables. He also gives credit to John Flamsteed, the Astronomer Royal, "whose tables are used by Mr. Tompion;" William Molyneux, an Irish patriot and gentleman scientist; Dr. William Salmon who published an almanac in 1694; and Samuel Watson, an eminent horologist and "the curious contriver of that rare celestial orbitery now in the present Queen Mary's possession."

Watson's clock is an astronomical marvel that is running today in the Royal Collection. Watson made it on the order of Charles II who had the poor taste to die before it was finished. In 1690, Watson came up with a scheme to raffle it off by selling £1000 worth of lottery tickets. Queen Mary came to his rescue and apparently bought all the tickets. She was probably also a sucker for Girl Scout cookies.

Smith gives us a table showing how a rating nut under a pendulum bob may be engraved with divisions according to the pitch of the screw, so that a movement of one division of the screw adjusts the rate 1/sec per day. He suggests the use of an index plate located behind the pendulum bob to calibrate the arc when the clock is newly cleaned and oiled. When the arc diminishes, you know it's time for a cleaning. The index plate may also be used when rating the clock over a long period of time. If the arc does not stay constant over the rating period, all bets are off.

Smith credits Robert Hooke with the invention of the balance spring for watches. He gives no sign, however, of being aware of anything that might have happened abroad, such as Huygens claiming the same invention. He gives several tables of pendulum length versus beats per hour, for pendulums running from one inch to 30 feet.

There is a section on managing mercury barometers, or "baroscopes" as he sometimes calls them. It covers set up, filling, and interpretation of the barometer's reading. There are several pages of hints from nature to help one in forecasting the weather. For example: "Crows, if they caw or cry early in the morning, with a loud and clear voice, it shews that the day will be fair." Or how about, "Swarms of little gnats and flies, sporting themselves together, in the evening, is a certain token that the day following will be fair."

Just as the book was going to press, there was a short section contributed by Smith's good friend, the aforementioned Samuel Watson. It covers a simple technique and device for observing a star transit. There is a table of the difference between sidereal, star time, and mean solar time that will allow one to rate a clock. This was the method that John Harrison used to rate his clocks and was probably in widespread use at the time.

This is a fairly rare book, I haven't seen too many of them offered lately. However, a very inexpensive facsimile edition is available.

By 1696, William and Mary were on the throne of England. Louis XIV was still ruling France. Tompion, Graham, and Quare were at work in London. Sully and Le Roy were working in France. Since Smith's last book, the Bank of England was founded, Huygens died, and the aromatic herb peppermint was first described.

At this time a very famous horological book was published, famous in that it is very often quoted to support one view or another in many horological disputes. There is also much material in it that was published for the first time. It was written by William Derham, D.D., F.R.S. Born in 1657, Derham died in 1735 at the age of 88. He was an Essex clergyman and a Canon of Windsor, and chaplain to George I. He published over 17 papers on various scientific subjects in the *Philosophical Transactions.* Derham was the very picture of the 17th century ecclesiastic-scientist.

In Derham's biography in *Rees Cyclopedia,* published in 1819, two of his books are singled out for mention, *Physico-Theology* and *Astro-Theology,* each being a demonstration of the being and attributes of God from "His Works of Creation" and "a Survey of the Heavens." The biographer goes on to say of them, "These volumes are too well known to require from us any particular account of their contents. Few books can be put into the hands of young persons with greater advantage." This is high praise indeed from an authoritative source.

In 1696, Derham wrote his very famous horological work, *The Artificial Clock-Maker.* The term "artificial" means contrived and brought about by constructive human skill as a clock or watch. An artificer was one who had these skills. It was the first attempt, in an English book, to give practical help to clockmakers and to record the history of horology. It has the first horological bibliography. It went to five English editions, two French editions, and one German. It is larger than the Smith books, but still a fairly small volume, six to seven inches high by four to 4½ wide, depending upon the edition, running from 132 pages in the 1st edition to 140 pages in the 3rd, 4th and 5th.

Why does an eminent man of the cloth write a book on horology? I quote from his preface:

> "Many there are, whose fault or calamity it is, to have time lying upon their hands; and for want of innocent, do betake themselves to hurtful pleasures. This is the too common misfortune of some gentlemen. Among some of the looser sort of which, if this book shall find acceptance, it may be a means to compose their rambling spirits; and by an innocent guile, initiate them in other studies, of greater use to themselves, their family, and country. However, it may hinder their commission of many sins, which are the effects of idleness."

Dr. Derham acknowledges help from "Dr. H. and Mr. T." Dr. H. is certainly Robert Hooke, and since there was no "A-Team" in 1696, Mr. T. was undoubtedly Thomas Tompion.

In the first chapter is a glossary of terms compiled with the help of the famous clock and watchmaker, Langley Bradley. As an aside, Bradley was the maker of the great clock in St. Paul's Cathedral, rebuilt after the Great Fire and the foremost public clock in London until Grimthorpe's so-called Big Ben was built in Westminster. Fraud was alleged in the construction of Bradley's clock as it was said to be perpetually out of order. This was due to the wind blowing the hands around and occasionally right off the clock. Bradley also was a Master of the Clockmakers' Company.

With few exceptions, the terms Derham defines are in use today. In some of the exceptions, he calls the barrel a "spring box." The fuzee stop is called a "gar-de-gut," a curious mixture of French and English. How about "the flying pinion" for a fly? He talks about "The Art of Calculation," which he defines as, ". . . those automata do by little interstices, or strokes, measure out longer portions of time." At that time the word interstices meant small intervals of time. Derham continues, "Thus the strokes of the balance of a watch, do measure out minutes, hours, days, etc." "Now to scatter those strokes amongst wheels and pinions, and to proportionate them, so as to measure time regularly, is the design of Calculation."

There is a very clear explanation of the theory of wheelwork and a practical example of designing a watch, with a seconds hand, no less. Here we have the George Daniels of the 17th century. And as far as I know, Derham never actually built anything. He covers striking and chiming trains in similar detail. The only system he discusses is based on the count wheel or locking plate. No mention is made of Edward Barlow's rack striking system, even though it was applied by Tompion in 1675. Perhaps because Barlow was a competing clergyman? He does, however, mention Barlow later, in connection with repeating clocks.

Derham claims to be the first to explain the details of designing a chiming train. Examples are shown in the book of translating a tune into pins on the chime barrel. It can be seen how the location of the pins on the barrel correspond to the notes. This section may have caused his readers some grief. For in my edition, at the end of the section on chiming trains he says, "If any thing going before appears gibberish, I can't help it, unless I should here teach the skill of Musick too." Then follows a short section on wheelwork to show astronomical indications such as moon's age, the tides, and motions of the planets.

Derham's section on pendulums recognizes the influence of temperature on the going rate, but ascribes it to thickening and thinning of the oil, rather than the expansion or contraction of the length of the pendulum rod. It would be 30 years before the work of George Graham and John Harrison on temperature compensating pendulums would be known.

He says there is some support for the use of Huygens' cycloidal cheeks, particularly by Sir Jonas Moore. Moore was an eminent mathematician, Surveyor-General of Ordnance, patron of Flamsteed (the first Astronomer Royal) and one of the driving forces behind the establishment of Greenwich Observatory. Tompion is known to have made clocks to his order for Greenwich. However, Derham was unconvinced of the value of cheeks. He says, ". . . and this way is much ceased, since the Crown wheel method (to which it is chiefly proper) is swallowed up by the Royal Pendulums." Poor Huygens loses again.

Following is a history of clocks and watches. Derham covers biblical mention of "dials," clepsydra (water clocks), and early Greek and Roman references. This material represents the first published bibliography of horological material that we have. He gives Huygens priority over Galileo in the controversy over the application of the pendulum to clockwork. William Clement is his choice over Robert Hooke in the claim for invention of the Royal Pendulum. Curiously, there is again, no actual mention of the anchor escapement.

Derham reports that some folks were so impressed with the idea of the constancy of the pendulum, that Sir Christopher Wren, the great architect, proposed the "horary foot" as a universal standard measurement of length based on the length of a seconds pendulum. The word "horary" means "of the hour." He gives credit to Robert Hooke for the invention of the spiral balance spring, the basis of what were called pendulum watches. Derham gives 1658 as the year of invention based on an inscription in a watch made by Tompion for Charles II.

Derham recognizes Huygens' claim to the spiral spring, but says he thinks Huygens got wind of Hooke's work through Henry Oldenburg, the powerful 2nd Secretary of the Royal Society. This is a dispute that has been the subject of much published debate. It should be remembered that the English and Dutch were bitter commercial competitors at that time and often settled their disputes with cannons. The competition between Edward Barlow and Daniel Quare for priority on the invention of repeating work for watches is discussed in detail. He describes James II's preference for Quare's work because of its simpler operation.

There is a section describing a device designed by Olaus Romer. Olaus Romer was mathematician to Louis XIV and a clever astronomer. He was the first to show that light had a finite velocity. Previously, it was supposed, that light moved instantaneously from one point to another. Romer designed an instrument to show the relative motions of the moons of Jupiter. He shared this work with Flamsteed, who gave Derham permission to publish it. The device described is much like an orrery, and Derham illustrates the details of construction. Derham suggests, "This instrument may be of good use to such as make Observations of the Eclipses of Jupiter's Satellites either by Sea or Land . . ." Note that these observations of Jupiter's satellites were proposed as a method of determining longitude. It was a technique thought to have much promise and was pursued by many. Of course, trying to observe the satellites of Jupiter from the rolling and pitching deck of a ship on the high seas left much to be desired.

In Derham's chapter on the Equation of Time he credits, ". . . that great Astronomer Mr Flamsteed, who was the first Man that fully demonstrated and cleared this Inequality of Natural Days, and brought it to a certainty, although others, even Ptolemy himself had a partial Notion of it." Apparently he disagrees with John Smith who gave Huygens priority in this matter. Priority is certainly not clear. Will Andrewes, formerly of The Time Museum, has told me of seeing tables that were printed in the 15th century. Derham then gives four tables with the equation, one for the bisextille or leap year and one for each of the years following.

For my last book I'd like to talk about my favorite kind of book, what I call the harangue. In the 18th century, if you felt strongly about something, you wrote a pamphlet. Then someone would write a reply that refuted what was said. You would get a friend to answer in another pamphlet, and so on. The person who thought he had the last word would put all the arguments together and publish a book. In our own Colonial history, pamphlets played a big part in stirring up the populace, particularly those by Tom Paine in fomenting the Revolution.

Publishing one's grievances was an accepted practice. In the horological area examples abound. We have: Langley Bradley's defense against accusations of fraud in building the clock for St. Paul's; John Harrison's battle with Nevil Maskelyne, the Astronomer Royal, the Commissioners of Longitude and Parliament; Thomas Mudge Jr.'s defense of his father against that same Astronomer Royal; and Thomas Earnshaw's moaning and groaning, even though Maskelyne liked his work.

But I am going to discuss John Ellicott's problems. Ellicott was an 18th century horologist who many rank with Graham, Mudge, Earnshaw, Arnold, and Harrison. His grandfather came to London from Cornwall and was a founder of the bank of England. His father was a warden of the Clockmakers' Company. Ellicott is said to have been of a cheerful disposition and took his recreation in whist and archery. He was a fellow of the Royal Society and was Clockmaker to the King. His clocks and watches were of the highest quality. The raconteur and man of letters, Horace Walpole, wrote in 1759 about a watch by Ellicott that cost 150 guineas. Paul Chamberlain, in his book, *It's About Time,* relates a strange anecdote about Ellicott.

> "A most curious thing occurred in his family. His wife appeared to have died and notices were sent out to that effect. The Quaker Dr. Fothergill stopped to make a friendly call and on examination of the body stated that Mrs. Ellicott was not dead but in a trance. In eighteen days she came out of the trance and lived for many years."

In 1753 Ellicott published *A Description of Two Methods.* It is a small volume of about 67 pages. It is moderately rare, but it appears on the market from time to time. The first part of the book is the paper he read in June of 1752 before the Royal Society and was published in the *Philosophical Transactions.* It covers his famous temperature compensated pendulum. Ellicott says in the introduction to the book, ". . . in this paper I have confined myself entirely to facts relating to my own invention, without concerning myself in the least with what had been done by others on the same subject." Those others, of course being John Harrison and George Graham. He continues, "I make no doubt, but that, upon a fair and candid perusal, it will not be found to deserve any of those cavils which have been raised against it." We shall see about that.

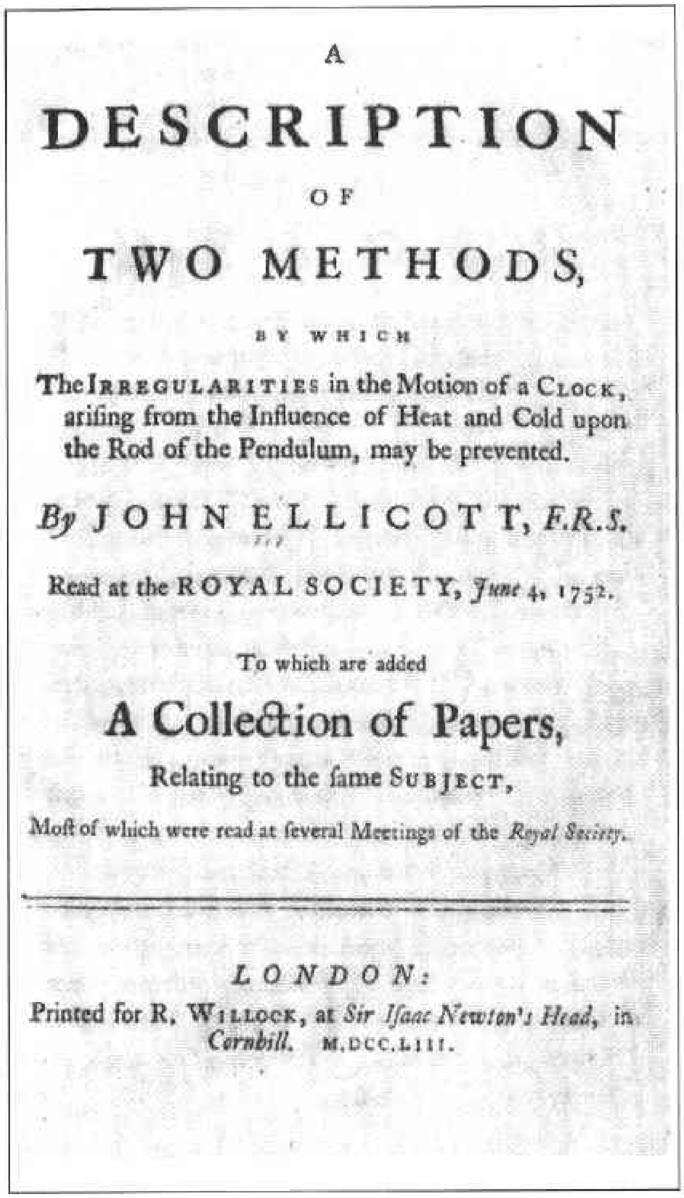
Let's examine the device that is the subject of this controversy. The principle of compensation is based on the difference in the rate of expansion of brass and iron. Brass expands about 50% more than iron for the same increase in temperature. The principle of the mechanism is rather straightforward. The pendulum rod is iron and supports the bob. A brass bar is firmly fastened to the top of the pendulum rod and its end is free to move. If the temperature rises the iron rod expands. But the brass rod expands more and presses down on the levers. The ends of the levers move up, lifting the bob through the screws. The center of oscillation is restored to where it was before the temperature rose. It's a neat scheme.

Also shown is a geometrical construction showing how to determine the ratios of the lever arms. In an illustration, he adds two indices to aid in the adjustment. The top index is fastened as close to the center of oscillation as possible. The bottom index is fastened to the bottom of the iron pendulum rod. When the screws are properly located on the lever arms, as the bottom index moves up and down with the expansion and contraction of the pendulum rod, the upper index at the center of oscillation should remain fixed.

Ellicott describes heating and cooling the pendulum and observing the index at the end of the pendulum rod move smoothly down and up while the center of oscillation remained rock steady. The scheme worked and there are examples around today. Paul Chamberlain in his book, *It's About Time,* says he owned one, and that the compensation was a magnificent piece of craftsmanship. He estimated that it took an artisan approximately 1000 hours to build it. My friend, Peter Booz, in Los Angeles, has one and confirms the outstanding craftsmanship and complexity. You can see why it wasn't at once a commercial hit.

Ellicott makes clear that he got the idea of using the differential expansion of metals from the paper George Graham read before the society in 1726. Graham, at that time, described his experiments with the expansion of metals that led to his "quicksilver" pendulum. A clock was made using Ellicott's compensated pendulum and was satisfactorily tested over a period of two years by Mr. Reverend Nathaniel Bliss. Bliss, then a professor at Oxford, later became Astronomer Royal. We'll hear more about him in a bit. Ellicott delivered his paper in June, and one would think that would be the end of it. But it wasn't.

In November, James Short, a Fellow of the Society, wrote a letter to the Society. He says the purpose of his letter is to supply a history of temperature compensation using the differential expansion of metals as applied to pendulums. This was not an unreasonable project. In his



A

DESCRIPTION

OF

TWO METHODS,

BY WHICH

The IRREGULARITIES in the Motion of a CLOCK, ariſing from the Influence of Heat and Cold upon the Rod of the Pendulum, may be prevented.

By JOHN ELLICOTT, *F.R.S.*

Read at the ROYAL SOCIETY, *June* 4, 1752.

To which are added

A Collection of Papers,

Relating to the ſame SUBJECT,

Moſt of which were read at ſeveral Meetings of the *Royal Society.*

LONDON:

Printed for R. WILLOCK, at *Sir Iſaac Newton's Head*, in *Cornhill.* M.DCC.LIII.

John Elliott's Description of Two Methods, *a discussion of the effects of temperature on pendulum compensation.*

letter, Short says that clearly George Graham is the undisputed originator of almost any ideas that have to do with temperature compensation of pendulums. Graham, he says, built a pendulum with levers, but discarded the idea because, ". . . he found that the clock was liable to sudden starts and jerks in its motion . . ." Short mentions John Harrison who, with his grid-iron approach, made great contributions to compensation, in parallel with, but independent of, Graham's work.

Then he says, "I have been informed that one Mr. Frotheringham, a quaker, of Lincolnshire, caused a pendulum to be made consisting of two bars, one of brass and the other of steel, fastened together by screws, with levers to raise or let down the bob, and that these levers were placed above the bob; this clock I have seen, and was told by the maker, Mr. John Berridge, [that] it was made in 1738 or 1739."