ANTIQUARIAN HOROLOGY

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An illustration of a medieval water-clock from a moralised Bible (Ms. Bodl. 270b fo. 183v) dating from the late 13th century. It illustrates the miracle of the turning back of time in the dial of Ahaz, the latter being a sundial. See the important article by Eduard Farré-Olivé in this issue.

NUMBER FOUR VOLUME EIGHTEEN WINTER 1989

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A MEDIEVAL CATALAN CLEPSYDRA AND CARILLON

by Eduard Farré-Olivé

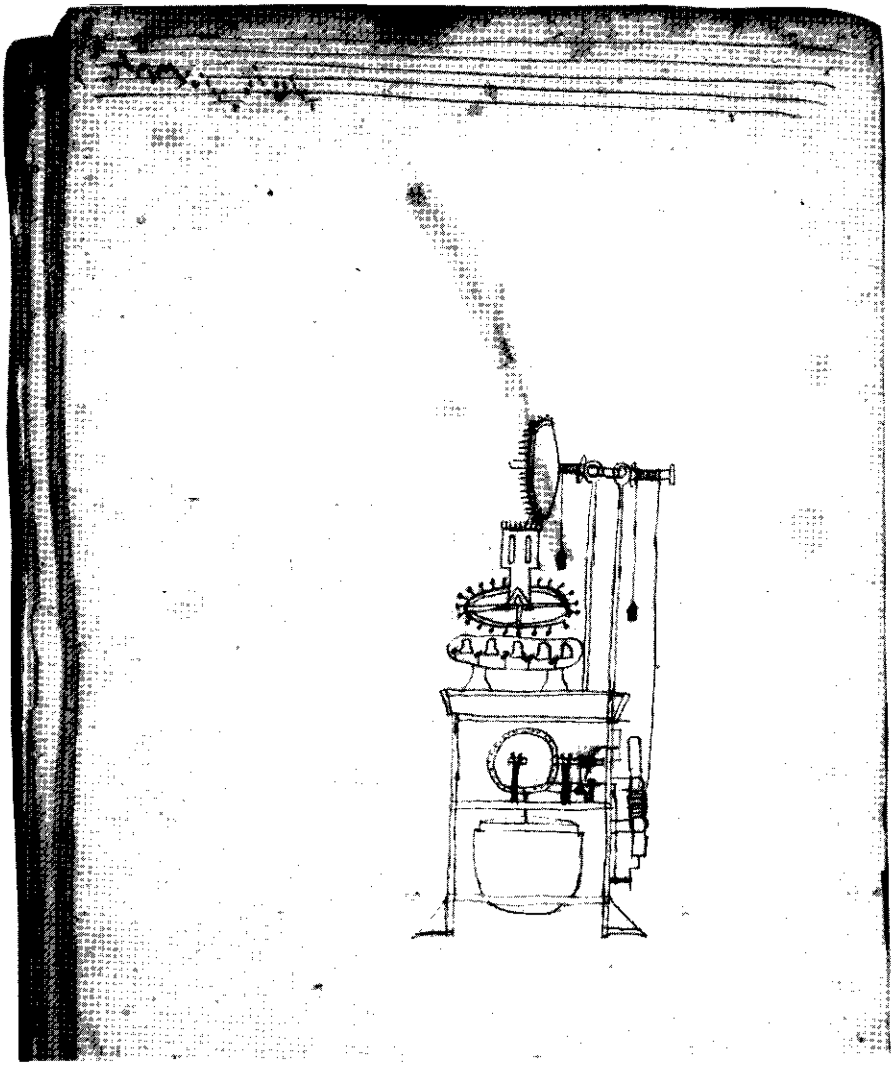


Fig 1. The diagram and musical score drawn on the verso of the last folio of the manuscript *Constituciones Cathalonie de tempore de regis Petri I ad regem Jacobum II*, preserved in the Arxiv de la Corona d'Aragó Barcelona.

A SHORT time ago, Dr. Joan Vernet, noted Arabist and specialist on the history of science, asked me to examine a drawing found in a medieval Catalan manuscript. The drawing had recently been discovered by the Deputy-Director, Dr. Rafael Conde, on a document held in the Arxiv de la Corona d'Aragó,[1] Barcelona. Both of these specialists had formed the impression that the device depicted might be a representation of some form of medieval time measurer.

The drawing, see Fig. 1, which I propose to discuss[2] in detail, is placed on the verso of the last folio of a legislative compilation drawn up in the reign of King Jaume II of Catalonia (1291-1327). the title of the manuscript is Constituciones Cathalonie de tempore de regis Petri I ad regem Jacobum II (A. C. A. Cancelleria, caixes de legislació, no. 2, II).

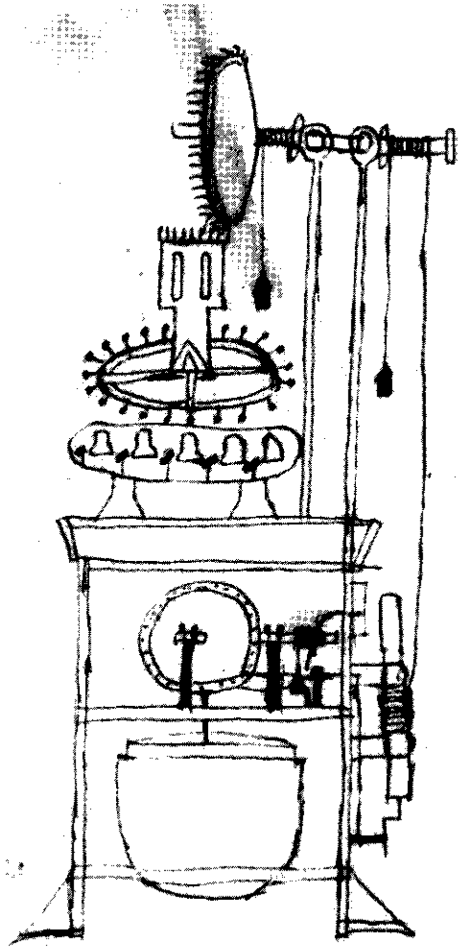


Fig 2. An enlarged view of the drawing in which two well differentiated sections are seen. The uppermost part is a carillon, the lower is a time-measuring device which initiates the playing of the carillon at a chosen time.

The drawing is unconnected with the contents of the manuscript and could therefore be a later addition. In order therefore to arrive at an approximate date for the drawing it is necessary to analyse the details presented, in particular that of the musical score shown at the top of Fig. 1, shown on an enlarged scale in Fig. 3.

During the reign of King Jaume II, Europe witnessed the transition of time measurement from the clepsydra, with its many centuries of history, to a new form of time-measuring device using weights and a mechanical escapement whose originator is quite unkown to us today. This great change commenced at the beginning of the last quarter of the thirteenth century, about the same time as the completion of the famous *Libros del Saber de Astronomia* in 1276, prepared at the instigation of the Castillian King Alfonso X[3]. Together with the reference of Robert Anglicus in 1271[4], about the necessity of achieving a regular movement to be able to reproduce the daily movement of the sun accurately and the character of the compilation of the known astronomical knowledge of the time incorporated in the Alphonsine Book, most historians of horology believe that the new weight-driven mechanical clock had not been realised up to that time.

The universal use of the word 'horologium', irrespective of the actual type of time-measuring device referred to, does not help identify particular examples, whilst illustrations in manuscripts are very scarce and often lack the necessary details for a proper understanding of the structure and function of the represented device. Quite often the artist lacked sufficient understanding of the device to show the correct form and did not produce the perspective views which we are so accustomed to seeing today. The drawing under discussion here, however, is much clearer than most of the contemporary illustrations remaining to us.

Before commencing on a detailed analysis of the diagram it is necessary to point out that it combines an elevation view with some details distorted in order to clarify certain components which would otherwise be hidden; a method often employed in medieval drawings. It is not a fault in the perspective on the part of the artist. For example, the roller near the base is shown vertically when it should be placed horizontally and the arbor of the lowest wheel within the frame has its arbor drawn to one side in order to be able to show the details. If the roller had been drawn in its proper position the view would have shown a circle with a line sticking out from its centre and the arrangement would be ambiguous for understanding the correct form. Furthermore, the diagram presents the principles without giving precise details of the construction, although the artist took care to give correct views. For example, he erased the parts of the lower container which are hidden by the metal bar although the original ink line has become obvious after the centuries. Other niceties on the artist's part will become apparent in the course of the discussion.

The Upper Mechanism

It will be convenient to commence by studying the pair of contrate wheels at the top of the structure, Fig 2. The arbor of the large wheel rotates in two bearings at the tops of the vertical supports. On the right the arbor is employed as a drum on which ten turns of rope are wound. One end of the rope carries a weight, the other descends to a roller placed at the base and is wound upon that. This lower roller is prevented from turning by a detent acting upon the crank fixed to the roller. When released, the roller turns in the two bearings fixed to the lower frame and the driving weight turns the upper contrate wheel clockwise as viewed.

On the left hand side of the pair of bearings is another rope which is wound round the arbor in the opposite sense and supports a weight of comparable size. 'Cheeks' are fitted on the arbor to guide and keep the ropes in the correct positions. The size of the driving weight on the right is not to scale since it is far too small to turn the mechanism as shown. The weight on the left cannot be for rewinding for it is necessary to turn the roller in order to rewind the rope upon it and raise the driving weight again; perhaps the function of the counterweight is to control the upper mechanism in some way. No arrangement is shown to allow rewinding without turning the upper contrate wheel, an essential requirement in practice.

The view of the upper contrate wheel appears strange because there are no crossings, possibly the wheel has a rim fastened to a disc. In spite of the appearance the wheel is intended to be mounted at right angles to its arbor, this latter being continued to the far side for some reason.

The Carillon Drive

It is not easy to explain the significance of the structure upon which the lower contrate wheel is placed. Apparently the large wheel below carrying ball-headed pins on its circumference is directly driven by it. Nothing is shown of how the speed of this mechanism is controlled, nor any indication of how the pins actuate the hammers placed by the bells below. The arrangement merely gives a general indication of the principles involved, without the precise details necessary for making a practical model, although it must be remembered that medieval craftsmen did not usually work from drawings.

Twenty-one pins can be counted on the periphery of the carillon wheel, two further pins may be assumed to be behind the structure, although 24 pins could be construed. However it will be seen later that

Fig 3. Above: The medieval motation of the musical score for the carillon. Middle: Redrawn to clarify the medieval notation. Below: Transposed into modern pitch and notation.

the number of pins is dictated by the requirements of the musical sequence to be played upon the bells of the carillon.

Bells

The five bells shown below the pin-wheel constitute part of a carillon, of which another five bells are hidden from sight, the whole set being arranged in a circle. These are intended to render the musical score placed above the diagram itself. Again we are presented with a structure conveying the main ideas without concrete, practical details. However the artist has drawn the bells in graded sizes excepting that on the extreme right and he has shown the hammers to strike the bells. The assembly carrying the bells is supported on two short pillars.

The Musical Score

The finding of a representation of a European medieval clepsydra is an outstanding discovery, whilst the musical score associated with it is possibly unique. Figure 3, shows the medieval notation on the manuscript, below is the score to display it more clearly and finally it is shown transposed into a modern representation. This is shown in the key of C, in the fourth line, bearing in mind that there can be no exact counterpart since the temperaments of medieval and modern concert pitch scales are different.

The main sequence starts on the note C and descends to lower G, ie. a complete octave plus three notes, of which lower B is not used. There is a total of 38 notes in all, requiring ten different bells and the number of pins to cause these to sound depends on the mechanical arrangement used. The mark on the left hand side of the musical score, shown on the folio, is not a note but a hole in the folio.

In the examination of the musical score I have had the good fortune to be helped by two leading authorities on medieval Catalan music, Mª Carme Gómez and Joaquim Garrigosa. They state that the musical notation shown, with a semi-breve as a time unit, was in use from the thirteenth century until about 1430, thus the musical score could be from 1291, at the beginning of the reign of King Jaume II, until the year 1430; approximately the maximum period of time. Mª Carme Gómez informed me that she had never before seen a medieval musical, vocal score having such a descendant scale. It was then normal to end the music on the same note as the first, hence it seems to indicate that the score was not intended for the human voice but was written especially to be played by a mechanical device. I am grateful to Mr Charles Aked for drawing my attention to the fact that descending scales are always used with clocks. It gives a better effect to the listener, possibly because the higher toned bells do not ring for as long as the lower ones, which could mask the higher tones if played first.

With music played on bells it is not possible to alter the duration of the sounded notes, one can only alter the interval between the notes. Although the first note (*longa* in Latin = modern breve) is indicated as being four times the duration of the following notes (archaic notation, *rhombic* = modern semi-breve), it merely means that the bell was struck and allowed to sound for one musical bar before the next bell sounded. All the following notes are one-quarter of the duration and, of course, four beats to the bar. The only other variation possible is that of the lift of the hammer striking the bell, enabling a softer or louder sound to be obtained. As indicated previously, the artist knew sufficient about bell music to show the bells in different sizes for the playing of the different notes.

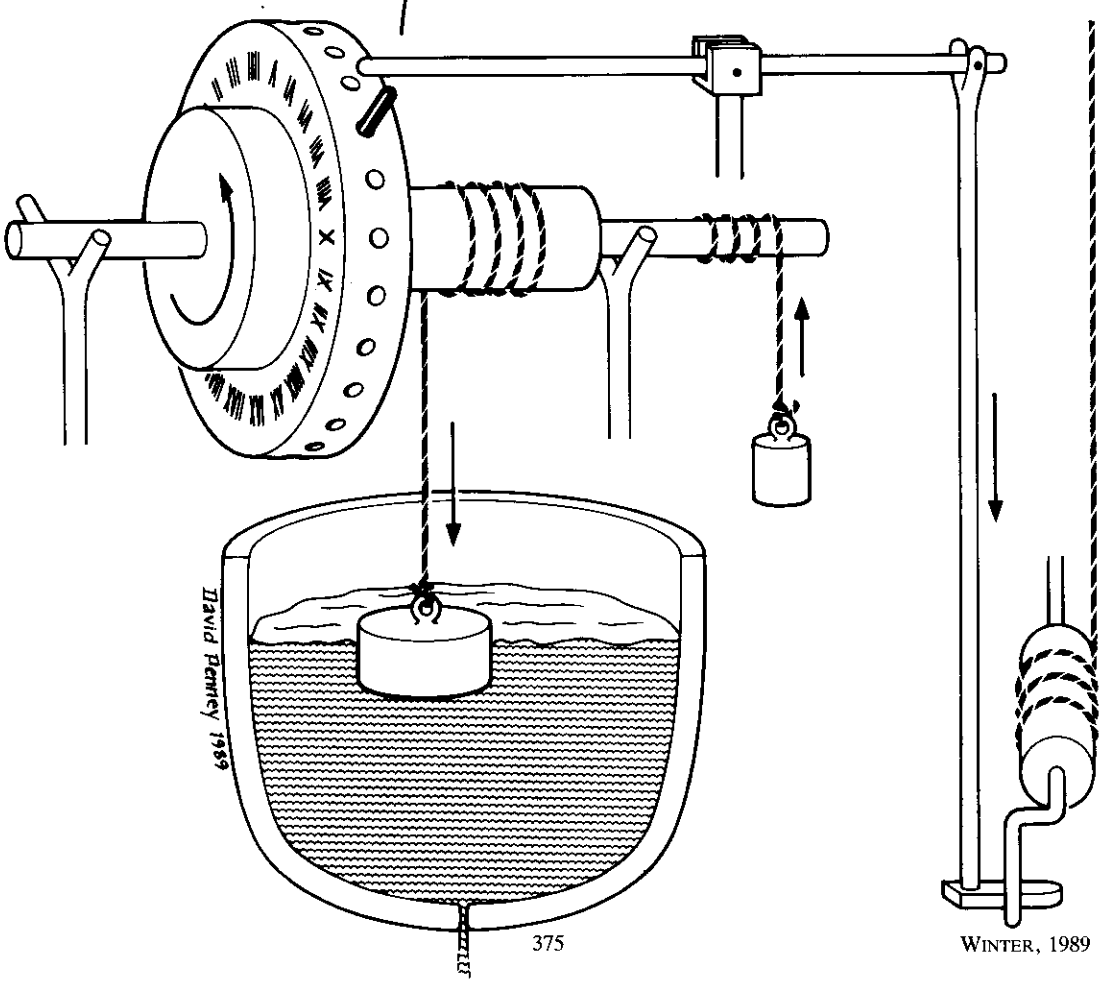
The examination up to now indicates that the upper part is a carillon which will play when the crank on the lower roller is released and the driving weight can turn the mechanism shown. The exact mode of functioning of the mechanism is not indicated as the artist has made the assumption that this is familiar to the person consulting the diagram, just as Richard of Wallingford and Giovanni de' Dondi in the descriptions of their astronomical clocks nowhere mention how the actual timekeeper is made. They say only that if the reader does not know how to make a common clock, he need not read further; the inference being that the description that is given would be too complicated for his understanding.

Lower Frame

We can turn our attention to the lowest part of the structure. What appears to be a confusion of details can be resolved into a large wheel mounted on an horizontal arbor turning in two forked bearings. The arbor is extended beyond the furthest forked bearing to allow a rope carrying a counterpoise to be coiled round it. From behind the lowest part of the wheel descends another rope which passes into the large cauldron shaped vessel below. From the view given it would seem that the rope passes to the left-hand side of the arbor and its motion is balanced by the counterweight, see Fig 4. However it would operate more in keeping with the other features, outlined later, if the rope actually passed to the right-hand side of the arbor. The purpose of the counterweight appears to be to turn the arbor to balance the changing conditions transmitted through the rope from the container below.

Fig 4. A possible reconstruction of the time-measurement section of the device shown in the drawing of the manuscript. An outflow clepsydra turns a wheel the rim of which is provided with holes for the insertion of pin(s) to set the required time for releasing the carillon. The inserted pin moves a lever at the set time and allows the driving weight to turn the upper mechanism to commence playing the musical programme.

On the rim of the wheel 29 dots can be counted which are not regularly spaced out. These are holes intended to hold pins as required for the purpose of releasing the mechanism for playing the music. If the comtemporary demand for a wheel turning exactly once in twenty-four hours had been met[4], these pins would be at intervals of one hour. The dots could only be a reference point to count down a certain interval of time before the carillon was released; nearer to a count down clock and far from an alarm clock. The irregular spacing of the holes shows that equal angular displacement for each hour was not expected from the device below for measuring the time. From which we can conclude that there is no mechanical escapement involved and in the large vessel below is an arrangement for water to flow out of a vessel which is not shaped to give a uniform rate of flow (the flow of water from any vessel with a hole in the bottom is greatest when full, steadily reducing in rate until the head of water is so reduced that the



flow is only a small fraction of the initial flow). Translating the resulting change of water level into angular motion means that the final hours are greatly reduced in spacing, just as shown. It is possible to shape the outflow vessel so that the water level change is virtually uniform from start to finish, as was done in Ancient Egypt, Greece, Rome and China. In the drawing the number of dots, on what we might consider as the time wheel, should have been exactly 24; the discrepancy may be put down to artistic license, as already seen between the bells represented and those actually needed.

A further complication is deciding upon which system of hours the mechanism was based, at the time of the drawing. Because temporal hours require arrangements to be made to be able to regulate the water flow day by day, a different set of hours are required by night. However the drawing gives no indication of any means of varying the flow, so in view of the contemporary search for a wheel turning once in 24 hours to match the motion of the sun, it could be assumed at the time the drawing was made, (Fourteenth or fifteenth century) a translation to equal hours had already been made.

The wheel could also be arranged for turning once every twelve hours with pins spaced at half-hourly intervals, which would reduce the quantity of water required. A flow of only 50 millilitres per second amounts to 43.2 litres in 24 hours; 43.2 kilogrammes or about 95 pounds. This is a considerable weight when the water has to be changed daily. The rate of flow is governed by the smallest practical orifice which can be used, if it is too small the orifice is easily blocked by particles in the water, especially as the rate diminishes. The drawing of the water vessel is not clear because there is no inlet or outlet pipe for the water shown. The projection above the rim may be a large float or an inner container, closely fitted in the outer. If the drawing shows one container fitting closely inside another, whether the water flows in or out of the inner container, the internal space of the outer container must be divided into two equal volumes. This enables the water to be displaced from one to the other if there is no water fed into or drained out of the system, ie it is self-contained, which is strongly suggested by the drawing to be the system adopted.

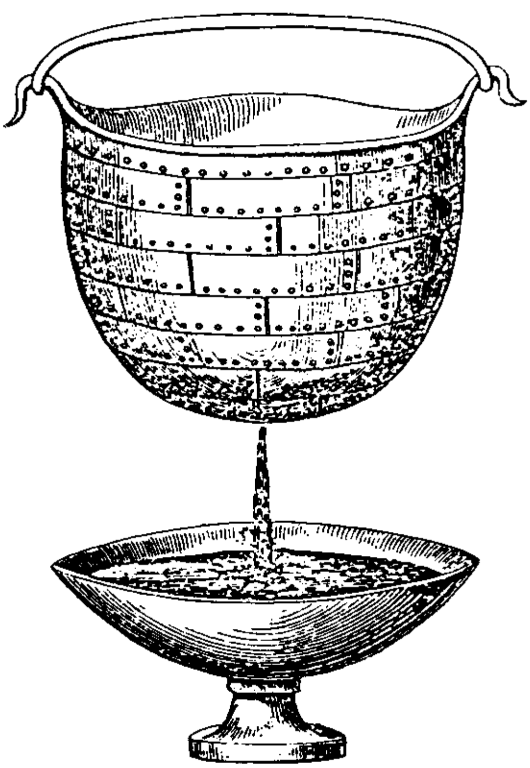


Fig 5. Hemispherical bowl illustrated in the 'Libro del Reloj de Agua' from the *Libros del Saber de Astronomia* compiled by King Alfonso X. The author, Rabiçag, used this vessel to measure the quantity of water discharged each hour; the amount discharged each hour varying with the changing level in the vessel.

In this case the inner container must be free to move vertically up and down if it is an inflow type of clepsydra, but may be fixed in the upper position if it is an out-flow type of clepsydra. In view of the further difficulties presented with the inner container moving up and down without the water level inside it changing, the evidence is that it is an outflow type. It is possible to have an inflow type with constant flow by using a weighted bowl; the difference in water level between the outside and inside is kept constant by the volume required to give flotation to the loading of the weight, but at the start of the timing period the bowl is very unstable and tends to fall over unless constrained, until the inflow of water brings the centre of gravity of the bowl below the water level outside. This, of course, could be the reason for the closely fitting vessels; however the resulting scale of hours would be precisely uniform and as we have already seen, such is not the case. The arrangement is obviously capable of several alternative interpretations. The clepsydra seems most likely to be an outflow type with a large float to transmit the changing level to the wheel above by a rope wrapped round a drum on the arbor of the wheel.

A vessel 40 cm across and 20 cm deep suspended inside a container slightly over 40 cm in depth, would be more than sufficient to deal with the quantity of water quoted earlier. If the flow, or period of time was halved, the inner vessel would be only 30 cm across and 15 cm deep, rather like a very deep washing bowl. These sizes are quite practical to make and use. A drum diameter of approximately 6 or 5 cm respectively would give the necessary one turn of the wheel in the period of time selected. The quantities given here are only to illustrate the possible working conditions.

In *Antiquarian Horology,* Vol 1, No 5, pages 54-58 & 63, there is a very full account of the medieval monastic water-clock illustrated in an illumination of a moralised Bible, (Ms Bodl, 270b fo. 183v); by Charles B. Drover, see cover picture. This Bible is of the late thirteenth century. The bowl of this water-clock is placed under the lower part in a similar way, however it was not possible to evaluate the mode of its operation from the representation. The resemblance goes further than the form of the bowl since there is a wheel with several holes in it above the bowl, in addition to a set of five bells mounted just above the wheel. A rope drops vertically and appears to be related to the wheel, bowl and bells. On the upper left is a curious wheel, perhaps performing the office of an aerodynamic brake, but which some researchers maintain is an allegorical representation of the Sun.

Fig 6. The well-known miniature from the fifteenth century manuscript known as *L'Horloge de Sapience,* (Clock of Wisdom), folio 13 verso, Bibliotheque Royale de Belgique. The basic features are similar to those in Fig 1.

Other Medieval Representations

In the *Libros del Saber de Astronomia* of the thirteenth century[3] there is an illustration of a cauldron having a hole in the bottom from which water flows into another vessel in order to measure the amount of water discharged in one hour, hour by hour, Fig 5.

There is also much similarity between the elements of the newly discovered drawing and that illustrated in the famous manuscript of the fifteenth century known as the *L'Horologe de Sapience* (folio 13v) preserved in the Bibliothéque Royale de Belgique [5] and shown in Fig 6. On the right of the illustration is an early carillon machine with a contrate wheel driving another to actuate the bells suspended above it. The arrangement is very similar to the Catalan carillon but inverted and there is a similar lack of precise detail in the mechanical features and apparent distortion of the perspective. The line diagram prepared by the late Colonel A. Simoni gives an impression of how the carillon could have appeared and operated, Fig 7.

These examples demonstrate that there is a common foundation with the example under discussion but it is recommended that the reader refer to the articles in order to gain a more detailed and informed view.

The Carillon Release

It will be apparent from the discussion of the clepsydra itself that there will be very little force available to actuate any release mechanism, in fact it will depend upon the force applied by the weight of the float less the weight of the counterpoise on the arbor of the time wheel, less the friction of the arbor in the fork bearings and taking into account the relative diameters at which the two ropes act. There appears to be a pivoted lever acted upon by a pin set in the time wheel and this is further connected by a wire or string to the stop, preventing the crank on the roller from moving. As shown, the wheel must turn clockwise if the lever is going to be acted upon for a relatively short time only, the engagement and disengagement being produced by a relatively small angular rotation. In the reverse direction the detent lever would be acted upon for a long time which would completely upset the timekeeping and make the exact time of release variable.

There is also another line under the lever and a rectangle near the top of the roller from which a line is drawn to the arbor of the wheel and which projects beyond. The available force from the clepsydra arbor could never free the crank directly, as it is represented, since this has the driving weight

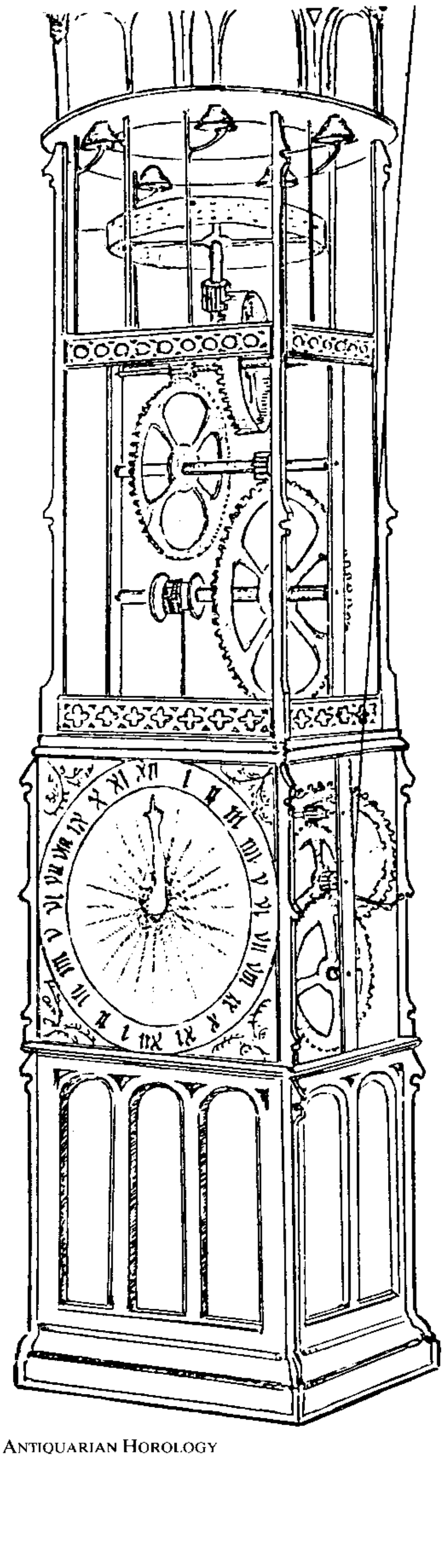


Fig 7. The proposed reconstruction of the monumental clock and carillon illustrated in the miniature of *L'Horloge de Sapience*, by the late Colonel Antonio Simoni in 1965.

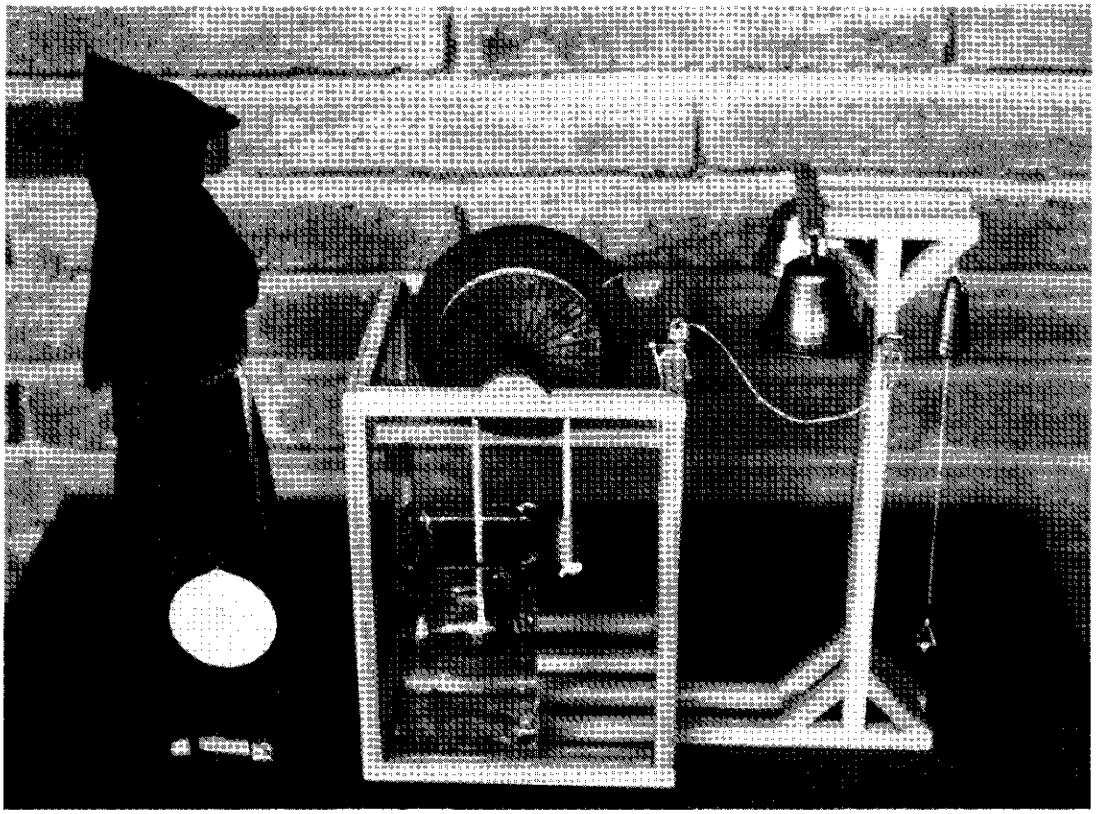


Fig 8. A personal interpretation of the water-clock alarm described in a fragment of manuscript 225 from the Monastery of Ripoll. Although the description of the time setting and triggering of the alarm is not absolutely clear, it has a close resemblance to the present device.

acting directly on it. It is almost impossible to unravel the exact arrangement from the meagre details shown, but it is clear that the whole is intended to release the crank at an appointed time. This is previously selected by inserting a release pin in the appropriate hole in the periphery of the time wheel, upon which the music is played on the carillon of bells, possibly for a duration of half a minute, or multiples thereof if allowed to repeat, at the selected time. This could be used as an alarm, or as a diversion for a party of assembled guests, or at some gathering of people.

The outline of this system using pins to programme the initiating of an alarm at a given time is very similar to that described in the manuscript (Ms 225) of the eleventh century preserved in the A.C.A. from the Monastery of Ripoll, also in Catalonia near the Pyrenees. This was discussed in some detail by Francis Maddison et al [6] in *Antiquarian Horology,* Vol 3, No 12, pages 348-353. Figure 8, shows a model of this water-clock constructed by the author in his School of Watchmaking. The details of the striking parts in the manuscript are the most uncertain, but it is believed to be similar in its use of a wheel, into the periphery of which are inserted pins to program the sounding of the bells, if not actually identical. The rectangle drawn on the outside of the frame near the top of the roller may be part of the release system in the present water-clock but the discussion on its possible action would be mere speculation in the absence of more precise details. The line drawn from the rectangle to pass behind the arbor of the time wheel seems to suggest a connecting mechanism of some kind.

Conclusions

From the discussion given here the arrangement shown in the diagram is a water-clock in the lower part with a carillon mechanism above, the whole being designed to allow the clepsydra to trigger the musical sequence at any desired interval of time within the range of the period measured. The features indicate a European development owing little to the earlier Arabic tradition of water-clocks. The features would seem to indicate the use of an outflow clepsydra calibrated for measuring equal hours.

Although the drawing might well have been done after the invention of the weight driven clock, within the limits indicated earlier of 1291-1430, it does not detract from its importance. The old water-clocks and the new weight clocks could well have existed side-by-side for a period of time during the initial period of the introduction of weight driven time-measurement, because the water-clock time-measurer would be far less costly to construct than any type of early weight clock. Furthermore there is considerable evidence that the keepers of water-clocks well understood how to regulate them for the purpose of temporal hours where this was required, whereas the alteration of the rate of a weight clock to perform the same timekeeping task would not have been at all easy. Nor would the new clocks have been greatly superior in accuracy until their characteristics became familiar to their keepers.

Lynn White stated [7] that the Ms 270b preserved in the Bodleian Library had the only illustration of a medieval Western water-clock extant. Now it is necessary to take note of the drawing conserved in the Arxiv de la Corona d'Aragó thanks to the discovery of Dr Rafael Conde and Dr Joan Vernet; as well as the most complete description of a water-clock in the Ms 225 from Ripoll, also preserved in the A.C.A. If the newly-found illustration is not as beautiful as that in the Bodleian Library it more than makes up for this in the clarity of the mechanical details provided and it gives us a glimpse into the erudition of those far-off days.

This discovery of a diagram of a Catalonian clepsydra with carillon and its notation of music can therefore be ranked as a most important addition to the history of the water-clock in Europe.

Acknowledgements:

In addition to the acknowledgements made in the text, the author wishes to express his gratitude to Mr Ramon Beseran, head of the horological school in Barcelona, to Mr Charles K Aked for his revision of the text, to Dr A. A. Mills of Leicester University for his constructive remarks about the operation of the medieval water clock and carillon described here, and to David Penney for his reconstructional drawing based on my sketch, Fig 4.

NOTES

1. The Arxiv de la Corona d'Aragó (A.C.A.) in Barcelona is the main repository of the documents of the medieval Catalan kingdom which achieved its political independence c. AD 988 when the Count of Barcelona seceded from the French kingdom, followed by confederation with the neighbouring kingdom of Aragon in AD 1137. The Count of Barcelona acquired the title of King of Aragon from this date until the end of the Catalan dynasty and union with the crown of Castille in AD 1410, followed by a complete loss of autonomy under the Bourbon dynasty (1714), when the documentation in the archives ends. For an outline of the history of Catalonia in English see 'Catalonia, Spain's Country within a Country', *National Geographic* Vol 165, No 1, January 1984, pages 95-127. For the French reader, *La Catalogne* in the series 'Que sais-je?', No 2426, Paris 1988, is an excellent outline.

   The horological contents of the Arxiv de la Corona d'Aragó are now well known as a result of the article by Jeanne Vielliard, 'Catalan Clocks and Clockmakers to the end of the Middle Ages', published in *Annales de la Faculté des Lettres de Bordeaux,* Bulletin Hispanique, Tome LXIII, No's 3-4, July-December 1961. This was translated by Charles K Aked and appeared in *Antiquarian Horology,* Vol 10, No 6, Spring 1978, pages 722-727. Also from this rich source is the article based on Ms 225 from the monastery of Ripoll, see note 6. There is also the magnificent work of Dr C. F. C. Beeson, *Perpignan 1356 — The Making of a Clock and Bell for the King's Castle,* published as Monograph No 23 in 1982 by the Antiquarian Horological Society.
2. First shown at a lecture given at the University of Barcelona on 11 October 1988, attended by Dr Joan Vernet i Ginés, Dr Juli Samsó, Director of the Millás Vallicrosa Institute for the History of Arabic Science, Dr Rafael Casals i Bohigas, specialist in Arabian horological devices, Dr Enric Freixa i Pedrals, President of the Royal Academy of Sciences and Arts, and Ramon Beseran i Claret, head of the horological school in the institute Verge de la Mercé, Barcelona.
3. *Libros del Saber de Astronomia del Rey Alfonso X El Sabio,* edited by Manuel Rico y Sinobas, five volumes. Madrid, 1863.
4. Lynn Thorndike, 'Invention of the Mechanical Clock about 1271 A.D.', *Speculum,* XVI, 1941, pp 242-243.
5. Henri Michel, 'L'Horloge de Sapience et l'Histoire de l'Horlogerie', *Physis,* 2, 1960, pp 291-298; and Antoni Simoni, 'Un Orologio a Cembalo in una Miniatura Quattrocentesca', *La Clessidra,* 11, 1965, pp 40-42.
6. Francis Madison, B. Scott, and A. Kent, 'An Early Medieval Water Clock', *Antiquarian Horology,* Vol 3, No 12, 1962, pp 348-353.
7. Lynn White, *Medieval Technology and Social Change,* Oxford, 1962, page 129 of the French translation, Paris 1969.