DEVELOPMENT OF

THE MEASUREMENT OF TIME

The birth of the measurement of time

For thousands of years, Man has subscribed to the law of time dictated by the periodicity of the different natural and astronomic phenomena influencing their direct environment.
However, the need to daily space-time incited Man to create better and better measuring instruments.

Created over 10,000 years ago, the gnomon (fig. 1) was most certainly the oldest time measuring instrument.
It was used in Egypt 3,000 years before our time and the Chinese used it in 2,400 B.C. It is comprised of a vertical element whose shadow cast over the sun varies depending on its position in relation to the sun.

More well developed than the gnomon, the sundial can be horizontal (figure 2) or vertical (fig 2'). It also works with the complicity of the sun. After the Egyptians, the Greeks and the Romans used the sundial. The sundial continued to be used until the Middle Ages and the Renaissance.

Other instruments had the benefit of being able to be used to measure time when there was no sun:

- the clepsydra (fig. 3), comprised of a calibrated funnel indicating the hours of the day as the water drips away,
- the time candle (fig. 4),
- the hourglass (fig. 5).

Fig. 1

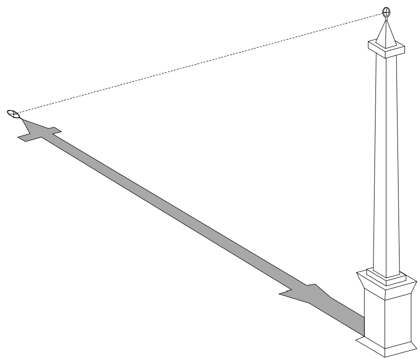


Fig. 2

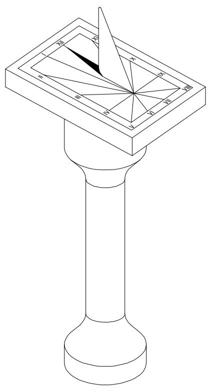


Fig. 2'

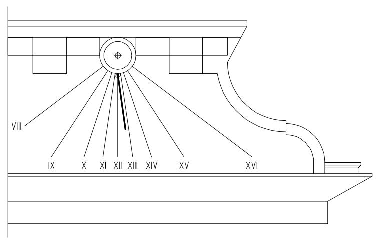


Fig. 3

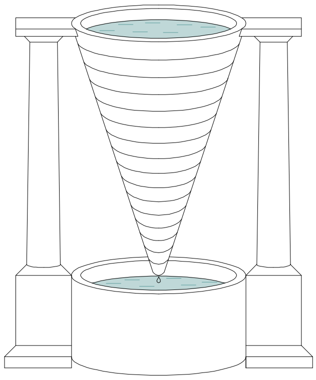


Fig. 4

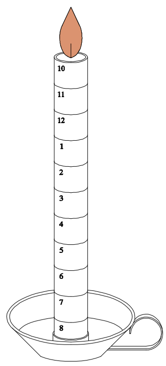
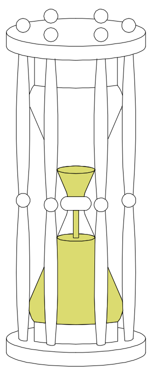


Fig. 5



Ref.: *Ecole Technique de la Vallée de Joux*

Hand + moon = 60

By observing the sky and the first visible planets – Mercury, Venus, Mars, Jupiter and Saturn – Sumerian astrologist-astronomers created the lunar months. For simple calculations they used their fingers.

The sky divided the year into the 12 lunar phases. This is why we count time in so many diurnal and nocturnal hours, divided into 60 minutes each one counting 60 seconds.

But why 60?

We owe this system to the Sumerians[1]*, who created it 2500 year ago. This people, settled between the Tigris and the Euphrates, were the first to divide the day into 12 hours each equivalent to 2 of our modern hours. This system was not adopted in Europe until the end of the 13th century with the introduction of the clock!*

Sumerian mathematics and astronomical science was developed enough to leave the universal 10 base of 10 fingers to adopt (invent) the sexagesimal system based on 60.

As the Sumerians lived under a completely theocratic system, they attributed the sexagesimal system to a mystic-cosmic origin: by multiplying the number of the five known planets – Mercury, Venus, Mars, Jupiter and Saturn – by the twelve lunar months: 5 x 12 = 60. The attentive observation of the sky enabled the Sumerian astrologist-astronomers and priests to observe that the lunar months were not completely equal. They varied between 29 days and 6 hours and 29 days and 20 hours. The Sumerians did not have a precise enough time measuring instrument, but by counting months at 29 days, alternatively with months of 30 days to give a total of 354 days per year, they observed an annual deficit of 11 days that they compensated for with an extra month every three years, in order to stay in time with the seasons. They established the average year at 360 days and divided the flat and round earth into 360 degrees subdivided into 60 minutes and 60 seconds. Which is still in use today for our arc and angle calculations as well as for determining geographic points.

For the Sumerians, like for any pensive race, the hand remained the first "calculator". Today, hands, fingers and phalanx are still used to count figures and numbers by various Asian communities and European traders.

The Sumerians used the 12 phalanxes of the four fingers of their right hand, without the thumb. Dozens were counted on the five fingers of the left hand, 12, 24, 36, 48, 60.

Sixty, divisible by the first 6 numbers, also met the calculation needs of traders as well as builders and astronomers by establishing the link between the hand and the sky.

And it was again in Babylon where, during the 2nd millennium B.C., mathematical science with the position numbering, which assigns a value of one unit, a tenth, a hundredth, a thousandth, etc. to a figure, according to the position that it occupies in the number. For example, 555: 5 hundredths, 5 tenths and 5 units.

It was not until three thousand years later that the European Middle Age (13th century) adopts, with the Indo-Arabic figures, the position numbering at the same time as zero, invented in India and promoted by Muslims and their evil culture as it was decreed as devil like by the Church of the Crusades…

Gil Baillod / Montres Passion (April 2004)

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[1] People that settled in the valley of the Euphrates

Figures

The figures that we use, *the Arabic numerals,* were introduced to Europe in the 10th century by Pope Sylvester II. Their exact origin is not known. Their name is used simply because it is the Arabs who gave us our written decimal number system.
The Hebrews, the Greeks and the Romans used letters to represent their numbers. *Roman numerals* are still used for certain specific uses:

I = 1,
V = 5,
X = 10,
L = 50,
C = 100,
D = 500,
M = 1000.

These letters are combined as follows: any letter placed to the right of another of equal or greater value is added to this other letter; when placed to the left of a letter of a greater value it is subtracted from the other letter.

Mechanical instruments

In the 13th century Man began building **the first mechanical clocks** which are powered by **a weight**.

In the 15th century, **the spring** made its appearance. It enabled the construction of portable instruments.

In 1657, Huygens[2] became the first to design and build a time piece whose precision was given by **a pendulum**. This became known as the **escapement** system.

In 1673, Huygens also invented **the spiral** which, connected to **a balance**, would go on to become the regulator for all mechanical clocks.

Around 1950, **the tuning fork** for short time, then **the quartz** and **the atom** became the regulators enabling research on precision to be moved forward.

Ref.: *Ecole Technique de la Vallée de Joux*

[2] Christiaan Huygens: Dutch physicist, mathematician and astronomer 1629-1695

The Revolution in the Measurement of Time (1793 – 1805)

The Revolution measures its time

Conquering time

The rationality of the new calendar (system developed by man to logically count the days, weeks, months and years, while staying in line with the main directly observable astronomical phenomena, concerning mainly the position of the sun in space and, possibly that of the moon) *drew on two principles; "matching the republican year with the celestial movements" and also "measuring time through more exact and more symmetrical calculations" while applying the decimal system as far as possible. Thus, "reason wants us to follow nature rather than slavishly drag ourselves over the mistakes made by our predecessors", "in the future, the year shall start at midnight, the day of the true equinox of autumn for the Paris observatory". The year is comprised of* ***12 months*** *of* ***30 days*** *each instead of being shared "in unequal months of 28, 30, 31 days". The last five days of the year form a special "corpus". Every four years we shall add a day at the end of the year, from the third year of the Republic, "as far as is necessary in order for the republican year to fall into line with the celestial movements".*

The months are divided into three equal parts, each of ***10 days****, instead of weeks that "don't exactly divide the month, the year or the lunar months". The implantation of the decimal system is also advanced even further. The old division in hours and minutes was irrational and "made calculations difficult". From this point forward, the day shall be divided into* ***10 hours****, each hour in* ***tenths****, and each tenth in* ***hundredths****.*

As such, the year shall be comprised of :

- ***12 months and 5 days****,*
- ***36 and a half decades****,*
- ***365 days****,*
- ***3,650 hours****,*
- ***36,500 tenths of an hour****, and*
- ***365,000 hundredths of an hour****.*

According to Bronislaw Baczko, Professor at the University of Geneva/Revolution in the measurement of time

Republican hour

Adoption of a decimal division of the day

At the session on 5th October 1793, the national Convention adopted a new division of the day proposed by Gilbert Romme[3], 20th September, as part of the calendar reformation

The day, midnight to midnight, is divided into ten parts, each part in ten others, and so on and so forth, until the smallest measureable part of the duration. This article shall only be compulsory for public acts from the first month of the third year of the Republic.

The definitive decree of the national Convention on the divisions of time and their inventory, dated 24th November 1793, specifies under article eleven:

The hundredth part of the hour shall be called the decimal minute; the hundredth part of the minute shall be called the decimal second.

Two major reasons dictated the choice of a decimal hour system: a concern on rationality and a desire for uniformity. While the reformation of the calendar arose in a passionate context which expresses, above all, the hatred of the Old Regime and anticlericalism, the reformation of the hour appeared to be the result of a thought process within the scientific community that had been looked at over several years.

Forty years earlier, the author of the article Decimal of the encyclopaedic dictionary of Diderot[4] et d'Alembert[5] wanted all divisions, for example division of the pound, the penny, the fathom, the day, the hour, the minute, etc. to be divided ***10*** *by* ***10****; this division would make calculations much easier and more convenient, and would be far preferable to the arbitrary division of the pound into 20, the penny into 12 deniers, a day into 24 hours, an hour into 60 minutes, a minute into 60 seconds.*

The inconvenience of the sexagesimal division in the calculations is also highlighted by academics, forming the Commission of weights and measurements, in the report that Jean-Charles Borda[6] presented to the Convention, in November 1792. The commissioners believed that the decimal system should have been extended to all the measuring instruments used in astronomy and geography. They cited the promising example of a decimal astronomic clock, made by Louis Berthoud[7] for the experiments on the length of the pendulum and the advantages of the instruments of Lenoir[8], with a decimal graduation, including Méchain[9] and Delambre[10] used for measuring the land arc between Barcelona and Dunkirk. According to them, the use of decimal numbering made such work quicker and more accurate.

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[3] Charles Gilbert Romme: French politician 1750 – 1795, creater of the revolutionary calender.
[4] Denis Diderot: French author 1713-1784.
[5] Jean Le Rond d'Alembert: French philosopher and mathematician 1717-1783; his precocious mathematic genius led to being elected to the French Academy of Science at just 23 years of age (1741).
[6] Charles de Borda: French sailor, physicist and mathematician 1733-1799; involved, among other projects, in the measurement of the Meridian arc for establishing the metric system.
[7] Louis Berthoud: Swiss watch maker 1754-1813; nephew of Ferdinand Berthoud.
[8] Etienne Lenoir: French engineer 1744-1832; in 1784 he made the "repeating circle", invented by Charles de Borda, the provisory measurement standard in 1793 and the definitive standard in 1799.
[9] Pierre Méchain: French astronomer 1744-1804
[10] Jean-Baptiste Joseph Delambre: French astronomer 1749-1822

By presenting the project of the new measurement of the day, Gilbert Romme – whose inclinations and training were those of a mathematician – includes comments from experts at the Academy in his reasoning. He underlined that French astronomers made some changes to the division of their instruments, that tended to make operations quicker and more accurate; this improvement would be completed once time signed up to the general and simple rule of dividing everything by ten. He stated that several observation clocks were made where the day is divided into tenths and, driven by enthusiasm, he stated that they measured up to the hundred thousandth of the day which equated to the gap in the heart rate of a healthy man of average size or a soldier's double step.

These arguments, used to argue in favour of the decimalisation of the hour, are publically exposed in the Instruction on the first era of the Republic for providing information to the public:

The division of the hour into sixty minutes, of the minute into sixty seconds, is inconvenient for calculations, no longer corresponds to the new division of astronomy instruments, which are so useful for sailing and geography; the decimal division gives the work more clarity while also making it easier and more accurate.

The desire to standardise the measurement system is also decisive in the choice of new units of time. By establishing them, the Convention completed the law adopted, on 1st August 1793, on the decimal division of weights as well as length, surface and weight measurements.

In favour of the establishment of the decimal hour, the experts applied it in the vendémiaire month (22nd September to 21st October), *without waiting for the frimaire decree* (21st November to 20th December). *As such, Antoine-Laurent de Lavoisier[11], in a convocation letter to the members of the Commission for weights and measurements, for 13th October (22 vendémiaire) expressed himself in terms of the new regulations: we remind you, dear citizen, that the Commission for weights and measurements shall meet, from now on, on the 2nd, 5th and 8th of each decade, at 7 decimal hours exactly (4 hours 48 minutes in the afternoon in the old style).*

Such enthusiasm was not required from all citizens. Measuring the disruption to routines and the significance of the transformations on the timekeeping that it involved, the elected representatives only made decimal time compulsory from 22nd September 1794 (1st vendémiaire, year III). In order to facilitate its introduction into daily life, instructions were published aimed at informing the public and clock makers.

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[11] Antoine-Laurent de Lavoisier: French chemist 1743-1794; deputy representative for the State in 1789, appointed in 1790 as a member of the Commission for the establishment of the new measurement and weight system.

Instructions given to clock makers

Printed in a large number in order to propagate the reform, the almanacs included comparison tables between the new and the old hours. The most complete contained comparison tables, for each month, between the times of sunrise and sunset as well as times for moon rise and set.

The decree came with two conversion tables. One for reducing the old hours, minutes and seconds into decimal hours, minutes and seconds and the other for carrying out the conversion the other way. Decimal thirds (hundredths) are introduced: one old second equating to one second and 16 decimal thirds; one old minute equating to 69 seconds and 44 decimal thirds. The tradition 24 hour day, comprised of 1,440 minutes and 86,400 seconds, equates to a decimal day of 10 hours, comprised of 1,000 minutes or 100,000 seconds.

In addition to the almanacs, the manuals aimed at bringing the use of the decimal system into general use for weights and measurements also contained the new units of time compared with the old ones and how to use them.

Examples often explained the use of the tables. As clear as they were, the comparison tables did not offer the advantage of a clock dial where the correspondence of hours can be read straight away. The huge work of the reform involved clock makers.

As soon as the decree was promulgated, the representatives were aware that the success of the decimalisation of time largely depended on the artisans who, through their clocks and their pendulums, had the power to introduce the system into the daily lives of the French people. Two pages of recommendations were sent to them in the Instructions on the 1st era of the Republic. They were asked to find the most simple, the most cursory, the most exact and the most economic means to divide the day from midnight to midnight into sections of 10, 10,000 or 100,000.

The advice from the Instruction related in particular to the composition of the dials and the operation of hands.

To gradually familiarise the public with the decimal hour, the Public Instruction Committee proposed sharing the dial in two parts, where one would relate to the division into 12 hours and the other the division into 5 hours: a single hand would indicate both divisions at the same time. This idea dreamt up by Gilbert Romme, president of the Committee, has the advantage of presenting a clear and simple comparison of the hours.

The simplicity and economic saving were the main qualities championed by the work of the clock makers. For the most ordinary uses, clocks with one hand were recommended. The old movements had to be kept and adapted to the new system by making as few changes as possible.

For clocks, the committee suggested removing the minute hand, making the dial bigger, allowing the old division to remain and on the boundary to show the ten decimal hours in two concentric turns so that they corresponded to the duodecimal hours.

Metrology's beginnings in Switzerland

The exchange of assets requiring very different reference values for the measurement and weight as well as many measurement units made an early appearance in Switzerland and the rest of the world. Initially, they varied from town to town. Worse still, the same name for different quantities was used depending on where you were.

With the increase in commercial relations in the 18th century and the scientific and technical progress, people ended up becoming more and more clearly aware of the difficulties and the confusion over the measurement units. This resulted in the first attempt, in 1801, to also introduce the **metric system** to Switzerland, a system that has been in existence in France since 1795.
Initially, this measurement system did not have much success in our country. It was too far removed from what we were used to, which is why it failed. Nevertheless, it opened up a few perspectives for the future.

In 1835, twelve cantons signed an agreement by which they agreed to use the **metric system** and the **decimal scale** while also keeping, as far as possible, the traditional terminology of pounds and feet.

In 1851, the Confederation, drawing on the 1848 Constitution, declared:

- **the metric system** and **the decimal scale** compulsory throughout Switzerland,
- in 1868, that it was introducing by law **this metric system** alongside the pre-existing measurements.

The unification of the metrology still left to be desired due to this bilateralism on the part of the cantons, in 1875 Switzerland decided to abolish the agreement and use only **the metric system**.
At the same time, Switzerland was a founding member of the International Metre Convention aimed at putting in place internationally recognised units of measurement.

International System of Units

The signing of the Metre Convention had standardised, at an international level, the reference units for length, surface area, volume and weight. However, throughout the rapid technical progress at the end of the 19th century, it was even more evident that the numerous units of measurement already in existence in other domains of physics were also seeking standardisation.

This need arose from the observation that in nature "everything holds" and that the number of units resulting from the isolated study of natural phenomena was superfluous. As such, for example, it had been established that power represented the same physical scale in electricity, thermodynamics and mechanics and that one sole unit would suffer. Yet, at this time, three different units of measurement that were difficult to relate to one another were used:

- the watt in the first of these disciplines,
- calorie per hour in the second and
- horsepower in the last.

The efforts made to establish a standard and *consistent* unit system lead, in 1901, to that proposed by the Italian engineer Giorgi, which drew on base units: metre, kilogram, second and ohm.

Through further development, it became the MKSA (metre – kilogram – second – ampere), internationally acknowledged in 1948, and from which the addition of three other base units arose, the **International System of Units (SI**) adopted in 1960 by the 11th general conference on weight and measurement.

The structure of the International System of Units

The SI is designed in a rigorous scientific manner. It is based on seven base units through which all physical values can be measured.

The number seven is not just a coincidence: it is determined by which of the physical scales in the system are considered to be independent. Given that the number of scales that we want to use in physics exceeds seven the number of equations of determination (equations of definition and natural laws), we need seven units to make the physical scales measureable. We call them base units.

The seven base units are:

- the metre (length),
- the kilogram (weight),
- the second (time),
- the ampere (the intensity of the electric current),
- the Kelvin (thermodynamic temperature),
- the mole (amount of substance),
- the candela (luminous intensity).

The second is defined as being the duration of 9'192'631'770 periods of the radiation corresponding to the transition between the two hyper-thin layers of the fundamental state of the atom of cesium 133.

Although, according to current knowledge, any measurable physical scale can be covered by a combination of the seven base units, particular names are given to some combinations used for physical scales that are commonly used. For example, the <force>, whose unit is defined as the square kilogram divided by seconds squared ($kg\cdot m/s^2$), but which can also be referred to under the name <newton>. Alongside the base units, these derived units, form the SI units. **An important characteristic of these derived units is their coherence: they are all formed by a combination of base units, in which the single numerical factor 1 appears. This puts an end to the highly complicated conversion calculations which, until quite recently still in use, are less common.**

We shall cite as an example the old kilopond force unit which had to be multiplied by a factor of 9.80665 to convert it into $kg\cdot m/s^2$.

Ref : *Legal units of measurement in Switzerland*
International System of Units (SI)
Federal Office of Metrology / 1986

The decimal division of the measurement of time

The hour and the minute are units of time from the International System of Units (SI). However, they do not have any *consistent* relationship, as their relationship is sexagesimal, whereas the SI strives to define units with a decimal relationship. As such, the units of time given in minutes or hours need to be converted. The second is fractioned **decimally**, whereas the hour and minute are fractioned **sexagesimally**.

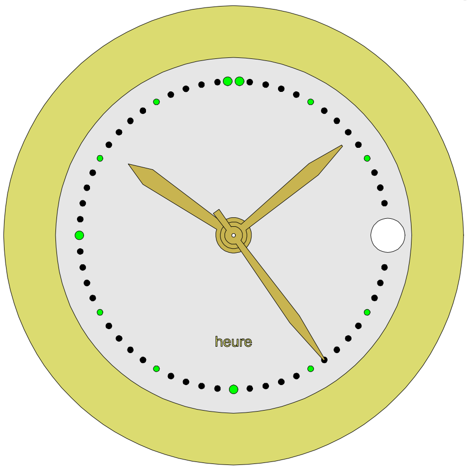
Examples

- The duration of a film is generally indicated in minutes; a conversion must then be made in order to determine the number of hours ;

- Sporting disciplines are timed in hours, minutes, seconds, tenths of a second, hundredths of a second and thousandths of a second.

On the dial (fig. 6), the position of the hands shows 10 hours, 8 minutes and 24 seconds.

Fig. 6



The second, current base unit for measuring time, is therefore not compatible with the decimal system. In order to make it *consistent*, a new unit would have to be created.

Mathematical logic and the SI plead in favour of a decimal division for the measurement of time. **The division of the duration of the average calendar day** (currently 24 hours, or two periods of 12 hours) **in 2 x 10 units would comply with the SI**.

The decimal unit of time would be **the divide** (decimal division).

Language	Verb	Name	Adjective
Latin	divisus dividere	divisio	decem = dix decimalis decimus
French	diviser	division	décimal - e
German	dividieren	Division	dezimal
English	to divide	division	decimal
Spanish	divide	división	decimal
Italian	dividere	divisióne	decimale
Dutchman	divisie		decimale

However, the replacement of the sexagesimal division by a decimal division of the measurement of time would require a period of adaptation, from which arises the need to create a comparative and simultaneous display on a two scale dial of the two types of measurement of time.

Created in 1999, a concept of revolutionary clocks offers the simultaneous display of the sexagesimal divisions (hour and minute) and the divisions by ten (divide) on a two scale dial.

On the dial (fig. 7), the tip of the hour hand shows the correspondence of the decimal unit in terms of the sexagesimal units.

The Comparative Watch (fig. 8) is born!

Language	**Verb**	**Name**	**Adjective**
Latin	comparare		comparativus
French	comparer	comparaison	comparatif - ive
German	vergleichen	Komparation	vergleichend
English	to compare	comparison	comparative
Spanish	comparar	comparación	comparativo
Italian	comparare	comparaziòne	comparativo
Dutchman	compareren	comparatieven	comparatief

Fig. 7

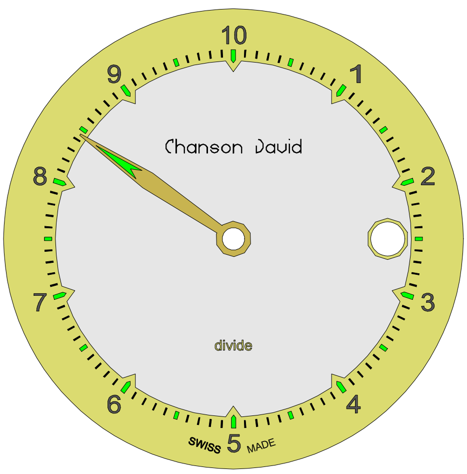


Fig. 8