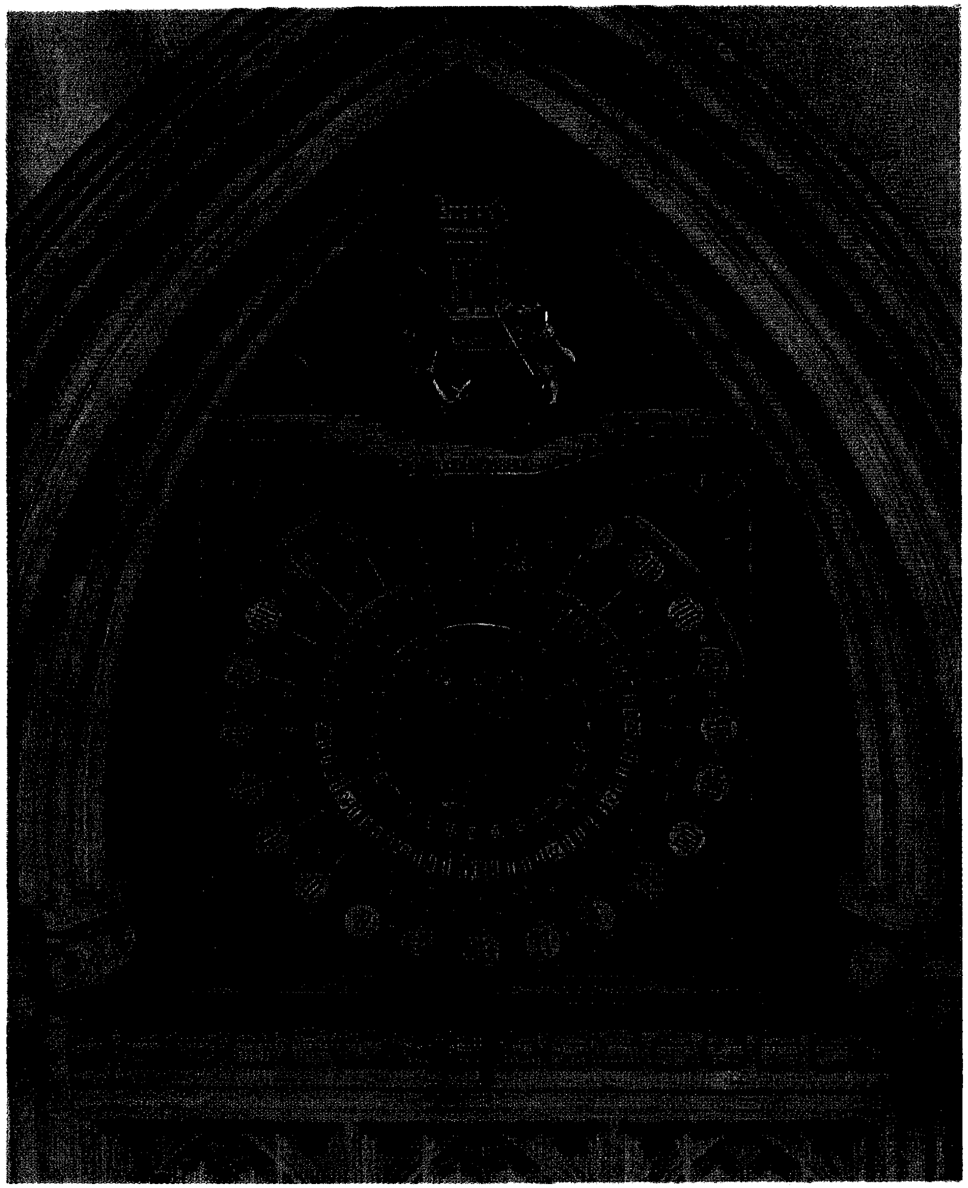

By courtesy of the Dean and Chapter of Wells Cathedral

THE FOURTEENTH-CENTURY CLOCK IN WELLS CATHEDRAL

Noon is at the top of the 24-hour dial, and a large gold star shows the hour. The smaller dials show minutes on the outer one, and the age of the moon on the inner; the circular opening in the centre part shows the moon's phases. At the hour, the figures on horseback above the dials chase round and charge each other, and one becomes unseated

How Time is measured

BY

PETER HOOD

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The Origin of the Calendar

When people first started to record time, the most obvious event was the rising and setting of the sun, caused by the daily rotation of the earth. For measuring longer periods, they used the phases of the moon, which recur month by month in the same order; and by noting the time of each new moon they were able to compile a calendar. But the lunar or moon-month does not consist of an exact number of days (it may be 29 or 30), and 12 such months do not make a complete year. A calendar of this sort would make each year begin a little earlier than the year before, and it would soon become obvious that the calendar was getting out of step with the seasons. To remedy this, an extra month, called an intercalary month, was slipped, now and again, into the calendar. There still exists, for example, a letter from Hammurabi, King of Babylon about 1900 B.C., ordering one of his governors to add a month to the calendar in this way.

The ancient Egyptians ~~also~~ used a lunar calendar and the year was given, from time to time, a thirteenth month, to keep it in approximately correct relationship to the seasons. While this lunar calendar continued in use for religious purposes, the Egyptians later made a more accurate calendar for civil purposes. They adopted 12 months of 30 days, with 5 feast days added at the end of the year, making 365 days. But the year cannot be divided into an exact number of days; it is in fact nearly a quarter of a day longer. So after this civil calendar had been in use for some centuries, it was found that it was gradually drifting with respect to the seasons.

Our present calendar dates from the time of Julius Caesar. He sought the advice of the astronomer Sosigenes of Alexandria in order to reform the Roman calendar, which had then become much confused. The reform was done by making every fourth year a leap year with 366 instead of 365 days. This, usually called the Julian calendar, was adopted in the year 45 B.C.; and at the same time the Romans changed their calendar year so that it began in January, instead of in March as was the previous custom. The Romans did not number the days of their months consecutively. Three dates were specially named: the Kalends ~~or first day of the month~~; the Nones, ~~which might be the 5th or the 7th of the month~~; and the Ides, nominally the day of the full moon, but fixed at the 13th or 15th. Any intervening day was said to be so many days before the next named day; though both days were included in the counting.

The names of the months we use are those used by the Romans. The Latin months were originally Martius, Aprilis, Maius, Iunius, Quintilis, Sextilis, September (seventh month), October, November, December, Ianuarius, Februarius. The summer month Quintilis was renamed Julius by Caesar; and Augustus who followed him gave his own name to the next month. There have been no changes since, and the lengths of the months now in use remain exactly as they were fixed by Julius Caesar.

The names of the week-days are mainly Anglo-Saxon, but they have a much older history. The seven-day week is unlike the day, month, or year in that it does not correspond to any celestial period. It had its origin in astrology, the seven days being named after the seven 'planets' or their divinities, as they were known to the ancients. This seven-day week was taken over by the Jews from the Assyrians, and then from the Jews by the Christians. So we have Sun's day, Moon's day; followed by the days of Mars, Mercury, Jupiter (or Jove), and Venus. These, in French, became Mardi, Mercredi, Jeudi, Vendredi; but in Anglo-Saxon they were named after the equivalent heathen gods, Tiw's day, Woden's day, Thor's day, and a heathen goddess, Figg's day; the seventh day being Saturn's day.

The Christian era began with the birth of Christ, and so we use B.C. for the dates 'before Christ', and A.D. or Anno Domini, 'in the year of our Lord', for dates subsequently. The method was first introduced into England by the Anglo-Saxon historian, Bede. It is believed that the original reckoning is a little in error, and that the actual birth of Christ may have been in 4 B.C.

I = 1 V = 5 X = 10 L = 50

C = 100 D = 500 M = 1000

ALTERNATIVE FORMS

IↃ = 500 CIↃ = 1000

Sometimes dates are given in Roman numerals. The original practice was to repeat the figures as often as required, like IIII on a clock dial. In later usage, a lesser figure before a greater one is always subtracted from it: thus, MCMLIX = 1959, and MCMLX = 1960

PERFECTING THE CALENDAR

A YEAR is the time it takes the earth to make one complete revolution round the sun. There are different ways of measuring this, and as the calendar must be made to fit the seasons, the year is measured from one March equinox to the next. This is known as the tropical year, and is not the same as the year measured by the stars. The Julian calendar was based on a year of 365¼ days, but the length of the tropical year is slightly less, to be exact, 365 days 5 hrs. 48 min. 46 sec. Consequently, over many centuries, there was an accumulating error, so that the Easter celebrations were getting too far from the spring equinox. Pope Gregory XIII decided that the error, which then amounted to 10 days, must be corrected. With the advice of the astronomers Clavius and Lilius it was ordered that the day following 4 October 1582 was to become 15 October. It was also arranged that century years should not be leap years unless divisible by the figure 400.

This, in effect, means a slight reduction in the number of leap years; and though this Gregorian calendar, as now used, is not absolutely accurate, nearly 4,000 years will have passed before it becomes a day in error. At the time of the change in the sixteenth century, Britain, having broken from the Roman Catholic Church, was in no mood to follow an edict of the Pope; so the revised calendar was not adopted in England until 1752; by this time the Julian calendar, which the English were still using, was 11 days behind. To put this right it was decreed that the day after 2 September should be called 14 September. This much disturbed some people, who thought that their lives had been made shorter or their pay deducted, and they cried 'Give us back our eleven days'. At the same time another change was made: the Church in the Middle Ages had adopted the practice of beginning the legal year on 25 March, and this was now altered to 1 January. But the British government did not change its ways, and to the present day the financial year is still reckoned from 6 April, being the new calendar equivalent of 25 March (11 days difference).

JANUARY

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

FEBRUARY

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

MARCH

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

APRIL

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

MAY

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

JUNE

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30 **L**

Our calendar is far from perfect. The disadvantage of having Christmas day fall on any day of the week, and Easter day anytime between 22 March and 25 April is well known. The fixing of Easter has always been a problem for the Church. As now celebrated, Easter day is the first Sunday after the full moon occurring on or next after 21 March. Tables making these calculations are to be found at the beginning of the Book of Common Prayer. There are other considerable inconveniences in the present-day calendar. The variations in the lengths of the different months, which have been continued since Roman times, are unreasonable. Any given date falls on different days of the week in successive years, and with much trouble we have to have a fresh calendar compiled each year. The number of pay-days in a year may vary, and the four quarters of the year are of unequal length.

A simple calendar, known as the World Calendar, has been proposed. It divides the year into four identical quarters, the first month of each quarter beginning on a Sunday and having 31 days, the second beginning on a Wednesday and having 30 days, the third beginning on a Friday and having 30 days. Every month thus has 26 week-days, whereas in our present calendar it may have 24, 25, 26, or 27. Each quarter contains 91 days, precisely 13 weeks. The four quarters make a total of 364 days. In order to bring it up to 365 an extra day as a universal holiday, and not counted as part of the week, is added at the end of each year. In leap years only, another extra day would also be added at the end of June. These extra days would have the dates 31 December and 31 June; but being outside the week would not be named by any week-day but would have their own names, World day and Leap day; after which the week-days would continue where they last left off.

When previous reforms of the calendar occurred, it was only a matter of changing a date, and the sequence of the days of the week was not disturbed. People are reluctant to change age-old habits; but, in fact, the idea of having an extra day during the week is not really entirely new. Already we have to add a day, or drop a day, when crossing the international Date Line, as described later in this book.

JULY

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

AUGUST

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

SEPTEMBER

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

OCTOBER

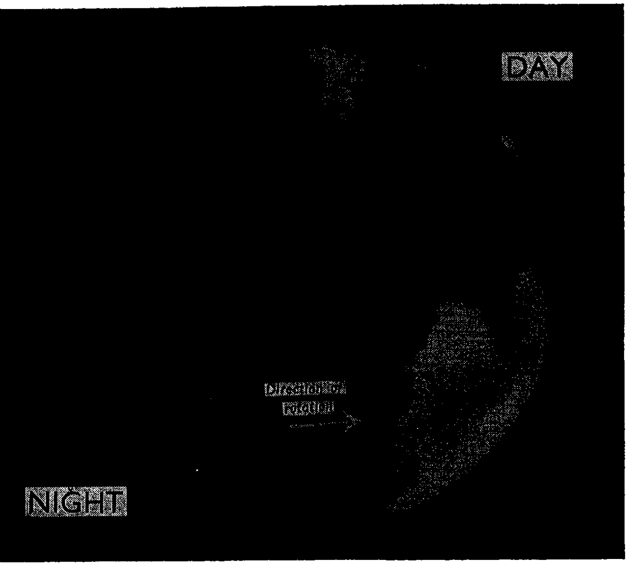
SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

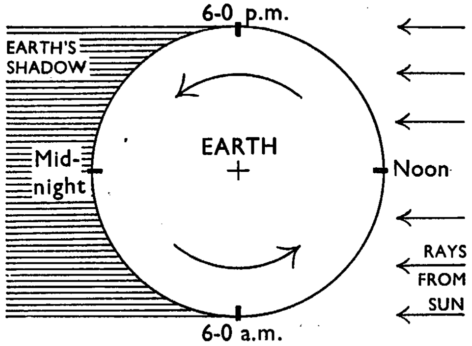
NOVEMBER

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

DECEMBER

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30 **W**



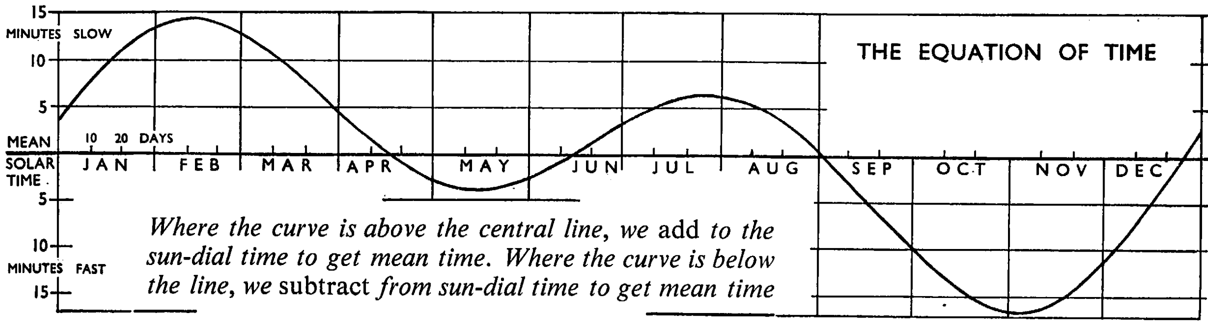


THE DEFINITION OF TIME

THE regular succession of day and night is due to the rotation of the earth on its axis. The rotation is towards the east, so when our part of the earth's surface moves into the sunshine, the sun appears to rise in the east. After the period of daylight, it appears to set in the west, because we are carried round into the night or shadowed side of the earth. This sequence is continually repeated. Since all time-keeping is based on the length of the day—the hours of daylight and darkness combined—such a measurement might seem quite simple, since it is only a matter of finding out how long it takes the earth to make one complete rotation. This is not really so easy to measure. The most accurate way of finding out is by observing the stars, since the stars, like the sun, appear to rise and set owing to the earth's rotation.

Such observations are made by a transit instrument, which is a telescope set in trunnions so that it may swing only in the meridian, or north to south line, and cannot turn sideways. If we note the instant when a bright star crosses the meridian, and the next night note the instant when the same star again crosses the meridian, the intervening time represents a complete day of 24 hours, in which the earth has rotated through exactly 360°. This is called sidereal time, after *sidus* the Latin for a star. Astronomers use sidereal time, but it is no use to anyone else, because it does not coincide with solar time, measured by the sun. The length of the day from noon, when the sun crosses the meridian, to the next noon, is some 4 minutes longer than the day measured by the stars. The diagram at the foot of the page opposite shows the reason for this difference between solar and sidereal time.

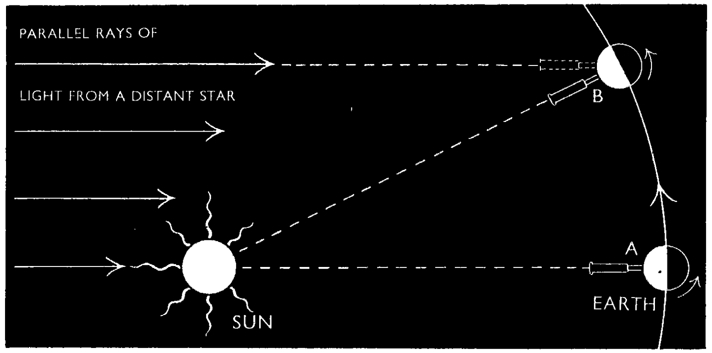
Ordinary solar time cannot be used for clocks for it is not quite uniform, and the solar day itself varies slightly in length. The explanation is rather complicated: the earth moves faster in its orbit in January when nearest the sun, than in July when farthest from the sun; and also, because of the inclination of the earth's axis, the sun's apparent movement relative to the equator is not uniform. To overcome these difficulties, we use for time-keeping an imaginary sun which moves at a constant, even rate, calculated for the mean or average positions of the real sun. This gives us mean solar time, and the difference between this mean solar time (as used for clocks) and apparent solar time (as seen on a sun-dial) is called the equation of time. It varies throughout the year, and may sometimes amount to as much as 16 minutes. There are only four dates when mean and solar time are the same. Therefore on all other dates, when reading time on a sun-dial, we have to add or subtract a few minutes, according to the scale shown in the diagram above, to get mean time.



Where the curve is above the central line, we add to the sun-dial time to get mean time. Where the curve is below the line, we subtract *from sun-dial time to get mean time*

Since the times of sunrise and sunset are variable, we use noon as the fixed event from which the hours are reckoned. Each day starts at midnight with the 12 hours up to noon, these hours being marked a.m. (for the Latin *ante meridiem*, 'before noon'); and the 12 hours following noon are marked p.m. (for *post meridiem*, 'after noon'). As it is often confusing to have to use a.m. and p.m., the 24-hour clock is now coming into more general use for official purposes. Beginning at midnight, the hours are counted 0 to 23. So the hours a.m. are the same as an ordinary clock; but 1.0 p.m. becomes 13 hrs., 6.0 p.m. becomes 18 hrs., and so on. For many years the 24-hour system has been in common use on the Continent, especially for railway time-tables. Scientists using this reckoning put the year first, then the month, the date and the time, thus: 1958 March 10, 00.25, which means 25 minutes past midnight on that date. And the minutes and seconds used in science are mean time, that is, of the 24 hours of the mean solar day.

The different lengths of the day measured by the sun or by a star. A fixed telescope at A, *pointing to a star, will again point to the star after the earth has turned once. In the case of the sun, rather more than one rotation is required, as at* B, *because the earth has moved on in its orbit*

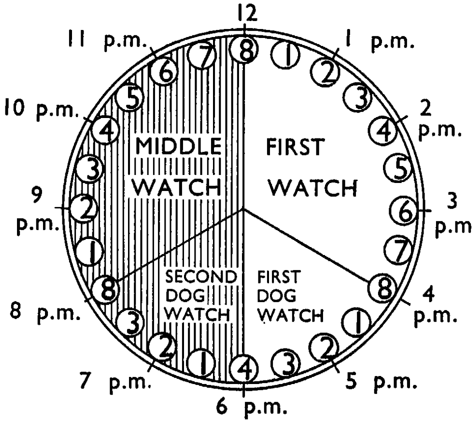


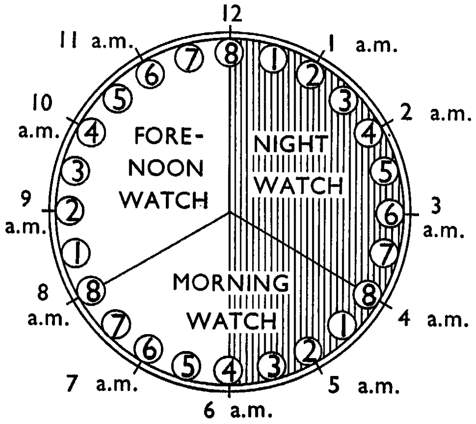
Ships and Navigation

The time on board ship, which sailors use, is rather different from that to which we are accustomed. The day is reckoned from noon, and is divided into 'watches' as in the diagram. The First Watch is a period of 4 hours from noon to 4.0 p.m., and at the end of each half-hour during the watch the ship's bell is struck an increasing number of times, 'eight bells' being at 4.0 p.m. In order to prevent the same members of the crew being on duty at the same hours day after day, there is no second watch, this period being divided into two Dog Watches, which gives 7 turns of duty in a whole day instead of 6. The ship's bell strikes the Second Dog Watch 1, 2, 3, at the half-hours, but 8 at the end of the watch. The subsequent watches are marked by one up to 8 bells at each half-hour. For passengers, and for much of the life on board ship, the ordinary hours of the clock dial are now used. As large ships have many dials—the *Queen Elizabeth* has 680—they are generally worked by electrical impulses from a master clock.

For the actual navigation it is necessary to have very exact time. To understand how this is used, we must first remember that local time is different in different places, according to the longitude. Since the earth rotates once in 24 hours it turns through 15° of longitude in 1 hour, or 1 degree in 4 minutes. This means that when it is noon at Greenwich it is over 4 minutes past noon at Canterbury, and 22 minutes before noon at Penzance. In the days when people used sun-dials to set their clocks, the different parts of the country each kept their own local time. But when railways were constructed, this was found to be altogether too confusing; so Greenwich time was adopted for the whole country—though this was not made legal for use throughout Britain until 1880. Now let us suppose that, when it is noon at Greenwich, it is only 11.0 a.m. by the local time on board ship on the Atlantic. A whole hour is equivalent to 15° of longitude, so we then know that the ship must be in longitude 15° west. In this simple way, the difference between local time and Greenwich time gives the longitude.

When out of sight of land, and without the aid of radio direction finding, a navigator who wishes to know his position must calculate his latitude and longitude. The latitude is found by direct observation of celestial objects; but for the longitude it is necessary to know the date and have Greenwich Mean Time (G.M.T.), which is sometimes known as Universal Time (U.T.), because by international agreement in 1884 the Greenwich meridian was adopted as the prime meridian from which all calculations are made—indeed, by then it was already used by most navigators. So every ship carries an accurate clock called a marine chronometer which is set to Greenwich time.



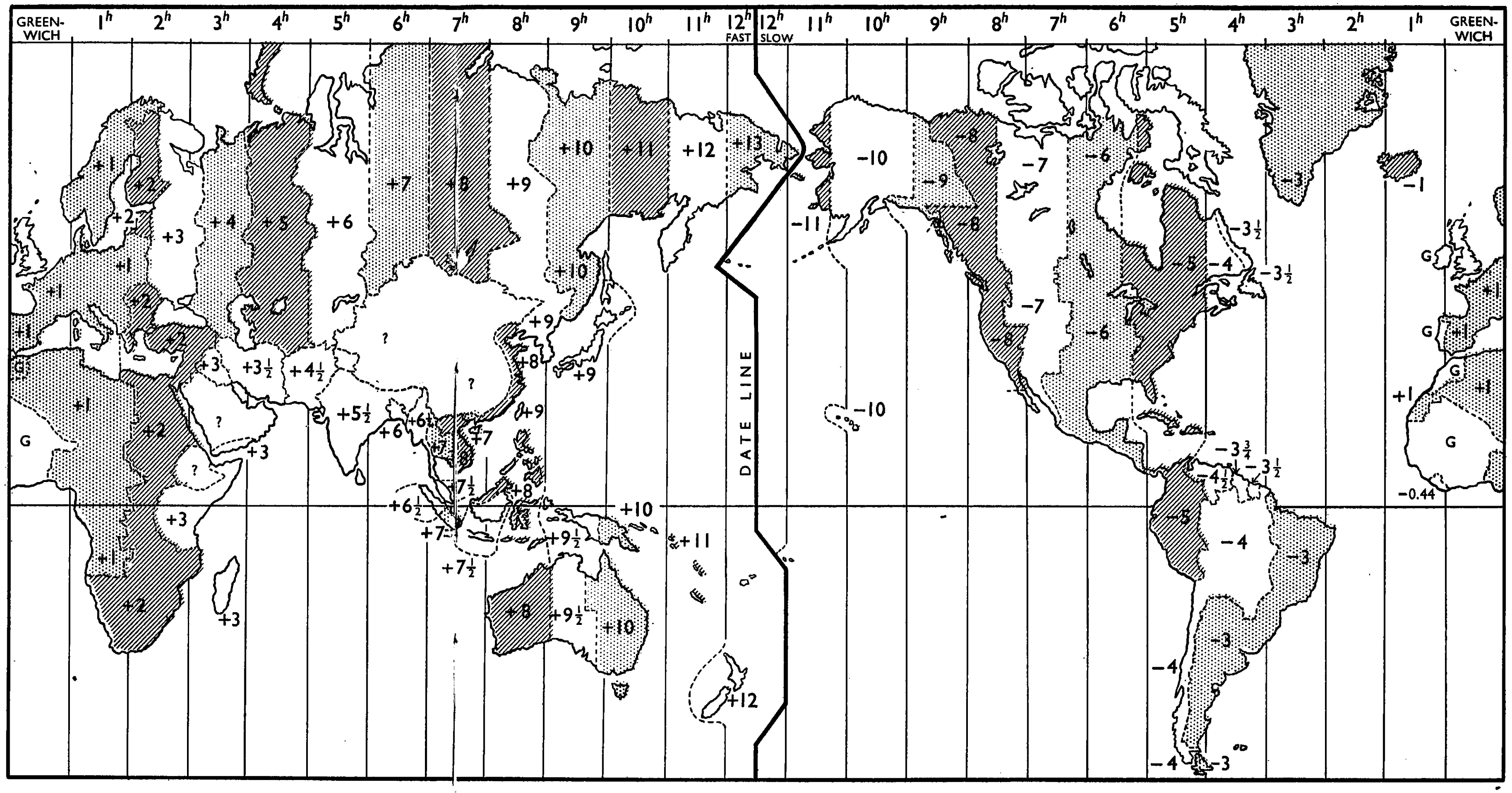


A navigator measures by a sextant the altitude above the horizon of a star, or the sun or moon, and two or more such observations are made, together with the time in each case to the nearest second. The *Abridged Nautical Almanac* gives, for different latitudes, the position of the heavenly bodies for every hour throughout the year; and with the aid of the printed tables the necessary calculations are made, and the resulting position of the ship is called a 'fix'. The chronometer must be as accurate as possible, because an error of 4 seconds may cause the fix to be in error by one nautical mile. Winds and currents cause a ship to drift off its course, so a fix taken at regular intervals is an essential check. For aircraft, the use of radio position finding gives a practically instantaneous fix. But when this is not available, the altitudes of two or more heavenly bodies are taken by means of a bubble sextant (the bubble in a spirit level serving as the horizon), and the Greenwich time noted in the usual way. Then by means of tables in the *Air Almanac* which gives positions every 10 minutes throughout the year, the position is calculated. One disadvantage is that, by the time the fix is completed, a fast aircraft may be 100 miles ahead; but such checks are necessary to maintain a required course.

TIME ZONES and THE DATE LINE

It has already been shown that time can be reckoned only for a particular place, and is different for other places not on the same meridian. In a small country like England, the difference between the true time of the eastern and western extremities of the country may be ignored by adopting the Greenwich meridian for the standard time throughout the country. In a large country like the United States, it is much more of a problem, because, as we have seen, for each 15° longitude westwards the time becomes one hour earlier. To avoid the endless confusion of varying times, a system of time zones was adopted in 1883, each zone being like a narrow band running north and south, and the boundaries being adjusted to suit territorial convenience. The time in

Time Zones and the Date Line (*continued*)



each zone differs from the next by one hour exactly. Thus, if the time is 11.15 a.m. in New York, which keeps Eastern standard time, it will be 10.15 a.m. in the Central time zone, 9.15 a.m. Mountain time, and 8.15 a.m. Pacific time.

This same system has now been extended to cover the whole world as shown in this map. The time kept in each zone is that of the meridian which runs down the centre of each zone. As a necessary compromise, the boundaries of zones on land generally follow political frontiers, and the time in some of these zones is not strictly correct for the longitude. But as far as possible, the time in each zone is arranged to be an exact number of hours ahead or behind Greenwich; in some countries the difference is to a half-hour, and in a few territories to an odd number of minutes. The largest countries have to be divided into several zones, and the oceans are divided by the lines of longitude shown, giving zones which differ by exactly one hour. In the navy a ship is expected to keep the time of the zone in which it is sailing, and so must put its clocks on one hour when reaching the next zone eastwards, or back an hour for the next zone westwards. In the merchant service, however, the usual practice is to keep time agreeing fairly closely with the actual local time, according to position. In passenger ships, the clocks are usually altered each night. For example, a ship sailing from Southampton must put its clocks back an hour on five occasions before reaching New York, where the U.S.A. Eastern time is five hours behind Greenwich.

On the opposite side of the earth, at 180° from the Greenwich meridian, is the international Date Line. By a fortunate chance it runs not across land, but over the Pacific Ocean; though the line makes slight deviations from the 180° meridian in order not to divide islands under the same administration. Since the time differs throughout the world according to the longitude, the date line is a necessary convention. Provided we remain in one place we do not need to think about these differences in time; it is only when we move about that they have to be allowed for, and only when we cross the date line that the date has to be changed. Suppose a ship travels eastwards round the world, and correctly puts on the clock one hour on entering each time zone, it will have added 12 hours by the time it reaches the date line. In other words, it will have gained half a day. Now if a ship sails westwards it has to put the clock back, and will have subtracted 12 hours by the time it reaches the date line. In other words, this ship will have lost half a day. So the difference between the two ships, as together they approach the date line, will be 24 hours, or a whole day. This means that each must make some adjustment so as not to get out of step with the calendar. The ship, therefore, that went eastwards repeats a day, and that which sailed westwards misses out one day altogether. Even when travelling a short distance, the same change must be observed whenever the date line is crossed, in order to keep the calendar correct. For example, if a man leaving the Fiji islands and sailing for the Samoa islands arrives at the date line on Saturday night at midnight, he finds, when he crosses the line, that he appears to have arrived on the previous night, for according to the local time it is only the early hours of Saturday, and he has to live all through Saturday again. But suppose, instead, leaving Samoa and sailing to Fiji, he arrives at the date line on Saturday night at midnight: he would then have to drop a day, and omit Sunday, because it would be Monday morning immediately he crossed the line.

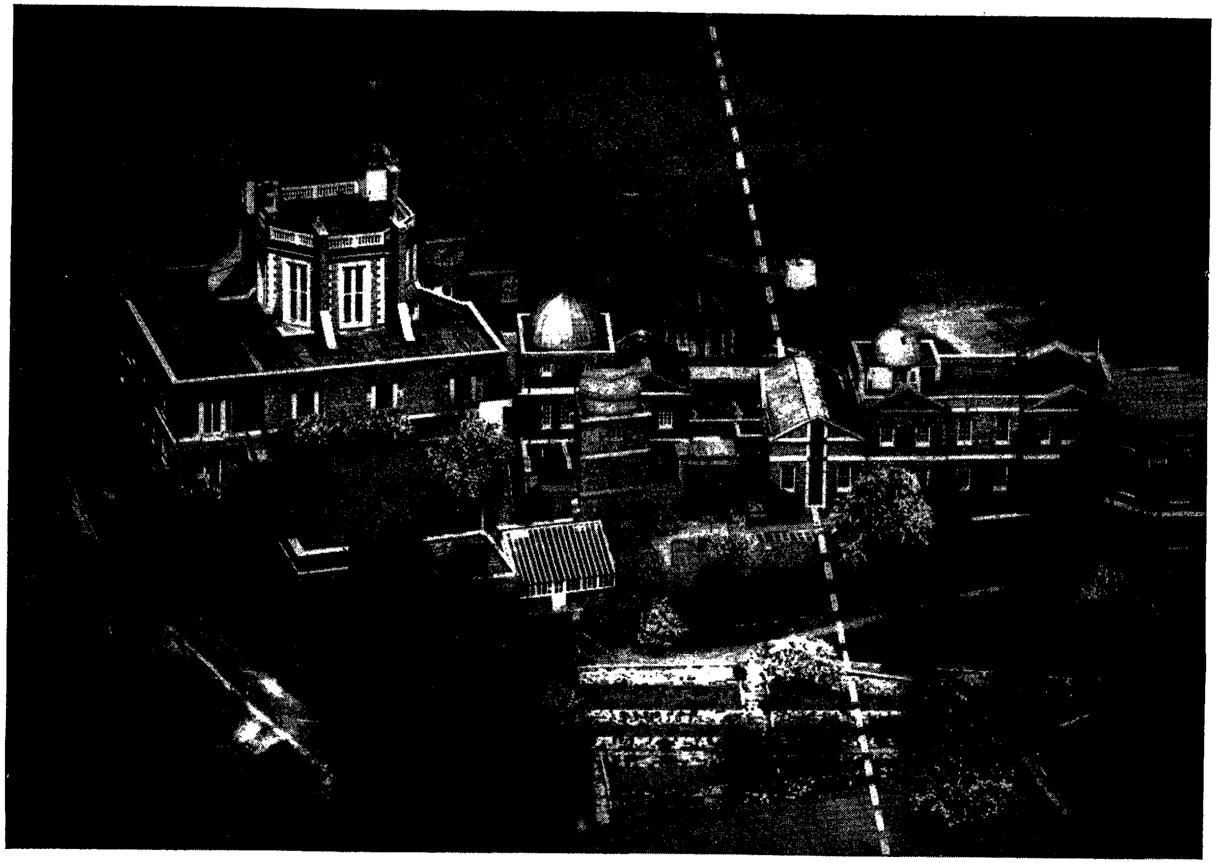
The Royal Greenwich Observatory

In the British Isles, the standard time is that of the meridian of Greenwich; this is the meridian that runs through Greenwich Observatory. The observatory was originally founded by Charles II for the purpose of making tables of the positions of the heavenly bodies to serve as a guide for mariners, and especially to enable them to find their longitude. The original building was designed by Sir Christopher Wren, and numerous additions have been made during its long history. The famous Airy Transit Circle dates from 1851 and is named after the Astronomer Royal, Sir George Airy, who was responsible for its erection. It is an instrument for observing the transit of heavenly bodies across the meridian, with a large circle divided in degrees for finding the positions of stars; through the centre of this instrument runs longitude 0°, the prime meridian of the world.

The work of the Time Department of the observatory is to supply with the utmost accuracy, for distribution by telegraph and by radio, Greenwich Mean Time based on the prime meridian. To do this, clocks must be continuously checked by direct observation of the stars, and by regular comparison with the time determined by other observatories, as received by radio time signals. In actual practice, various new forms of transit instruments are used; and though they are not on the prime meridian, allowance is made for the difference of position. During the 1939–45 war the chief Time Department was moved to Abinger near Leith Hill, Surrey. Although the time is determined at both Greenwich and Abinger, a further move is to be made to Herstmonceux near the Sussex coast, to which new site the Royal Greenwich Observatory is being re-established in clearer air, free from city lights. But both now and in the future, Greenwich Mean Time as determined and distributed by the observatory will still be the time for the prime meridian.

The Airy Transit Circle at Greenwich Observatory. Through the centre of this old instrument runs longitude 0°

Paul Popper



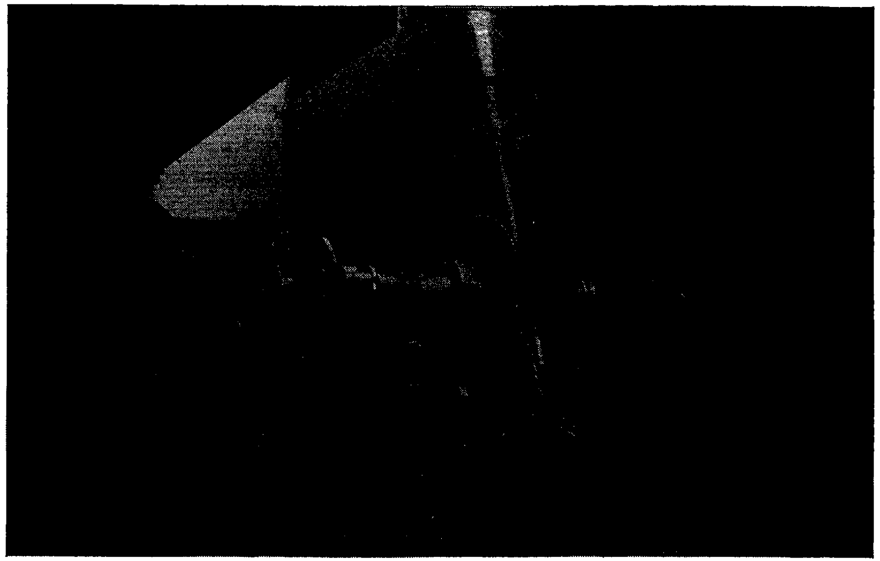
Photograph specially taken for this book by Photoflight Ltd.

Greenwich Observatory from the air: showing how longitude 0° runs through the building which houses the Airy Transit Circle

HOW TIME IS DETERMINED

The method of finding the time by observing the stars is relatively simple in principle. We have first to remember that the position of a star is defined by degrees of declination north or south of the celestial equator (the equivalent of latitude on the earth) and by hours and minutes of right ascension (which corresponds with longitude on the earth). The reason why this is generally given in hours and minutes is that the celestial sphere appears to revolve once in 24 sidereal hours, because of the rotation of the earth. The sidereal time at any place of observation is reckoned from the moment when the first point of Aries crosses the meridian. This is a point on the celestial sphere not marked by a star, but it is the position of the sun at the March equinox. When this point crosses the observer's meridian, the sidereal clock reads 0^h. If a star crosses the meridian 6^h 10^m later it is said to have a right ascension of 6^h 10^m.

In this way, the instant of time at which any given star crosses or transits the meridian is accurately known, and is expressed in sidereal



Royal Greenwich Observatory

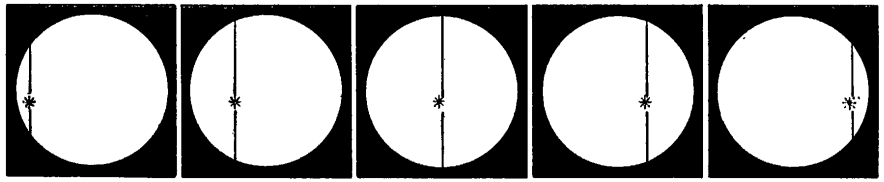
A small transit instrument at the Royal Greenwich Observatory, showing method of timing the transits of stars

HOW TIME IS DETERMINED

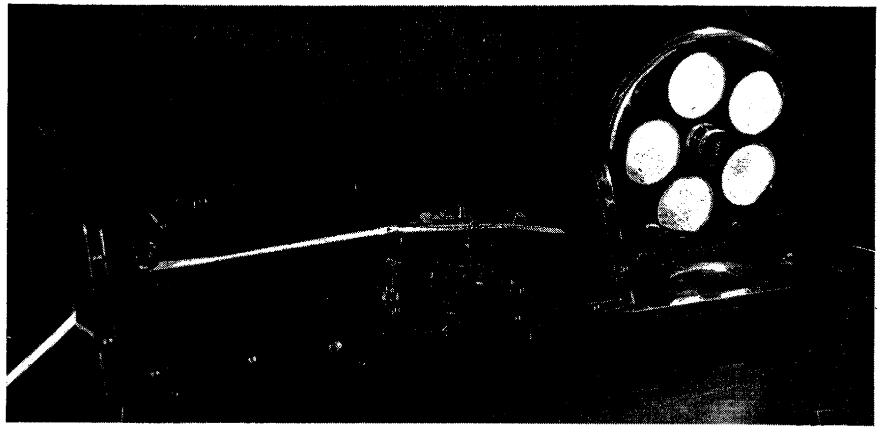
(continued)

time. If measured by a sidereal clock, it will be exactly the same each night. In practice, several stars are selected for observation, and there is a very slight difference between the time shown by the clock for each transit and the known right ascension of each star. The difference reveals the error of the clock. Thus, by continuing observations over many nights it is possible not only to find the error of the clock, but its rate of change; and once this is known, the true time can be found from the indicated time, if the rate is steady. As the time so determined is sidereal time, it is necessary to calculate the equivalent mean solar time for ordinary use.

A transit instrument is used to make the observations. It is first set to the correct declination for the star which is to be observed. The star is seen in the eyepiece coming into view at one side. The rotation of the earth on its axis, carrying the telescope with it, causes the star to move steadily across the field of view. There is a vertical thread in the plane in which the star image is focused, which can be moved across the field when the observer turns two small knurled-handwheels, one on either side of the eyepiece. To time the transit of a star, the observer places the thread so that it bisects the star-image and then, by means of the handwheels, moves the thread across the field, so that the star image is kept bisected. At certain known positions electrical contacts are automatically made. The time is, therefore, not taken by the passage of the star across a fixed thread representing the meridian, but is taken at several known positions of the moving thread, which can be averaged for greater accuracy. Routine observations of a dozen stars are made in this way at regular hours during darkness, weather permitting.



How the star appears to travel across the field of view in the eyepiece

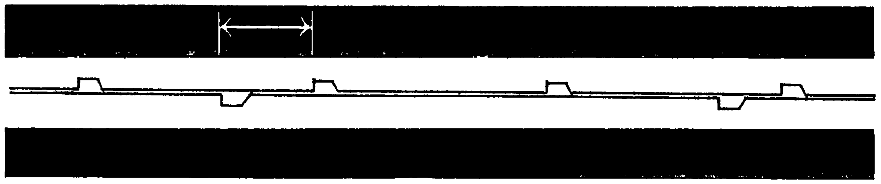


Royal Greenwich Observatory

The tape chronograph, showing the reel of tape, the electro-magnets that work the pens, and the motor which draws the tape along

The times are recorded electrically on a special instrument called a tape chronograph, through which moves a band of paper. Two mechanical pens draw a pair of red lines along the paper. These lines are straight except for the instants when each pen is momentarily jerked aside by an electro-magnet. One pen is connected by wires to the observatory clock which is to be checked; every second an electrical impulse from the clock operates the electro-magnet controlling this pen, so that the seconds are continuously recorded on the paper. The other pen is controlled from the eyepiece of the transit instrument, and each contact that is made by the travelling thread causes this pen to make a sideways mark on the paper. As the observations are thus automatically recorded, they can be studied the next day, when it is only a matter of comparing, by direct measurement, the observed times with the clock time.

Large transit instruments are used for the study of star positions, but for routine time observations a small instrument is convenient. When an observation is half done, the instrument may be raised and swung round so as to reverse it on its bearings before completing the second half of the travel of the moving thread. This is done in order to achieve greater accuracy, as it eliminates some errors of the instrument, particularly if the telescope is not exactly at right angles to the axis of the pivots.



Upper red marks record seconds from observatory clock; lower marks are the observed star times, and white arrows show how the difference is measured

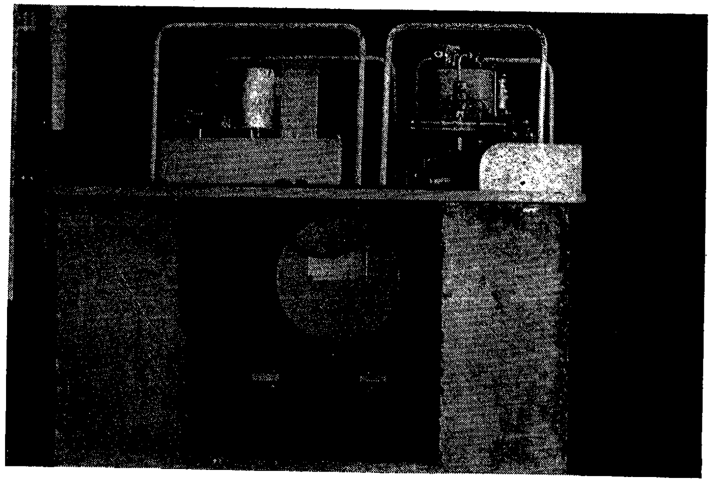
The Quartz-Crystal Clocks

Central Press Photos Ltd.

A quartz crystal, with its electrical connexions

THE time service at the Royal Greenwich Observatory no longer uses pendulum clocks but electronic clocks, which depend for their time-keeping on a vibrating crystal of quartz. These outwardly have the appearance of a complicated piece of radio apparatus, with switch gear, control boards, and masses of radio valves with elaborate wiring stacked in panels one above the other, forming huge racks, each with its special purpose. What is called a clock no longer looks like a clock at all. After hundreds of years of clockmaking this change is so revolutionary that we may wonder why it came about.

The quartz clocks have replaced the pendulum clocks because they have proved to be more accurate time-keepers. The principle of these clocks depends on a special property of quartz: when the opposite faces of a small piece of quartz are given electric charges of opposite sign, the quartz undergoes a slight expansion or contraction. If, then, the electrical charges are regularly reversed, the quartz is made to vibrate or oscillate. If the frequency with which the charges are reversed is adjusted to coincide with the natural frequency of vibration of the quartz, the quartz will maintain its natural frequency with extraordinary steadiness. The quartz is set into vibration by an oscillating electric circuit; when this is correctly timed to the natural frequency of the quartz, the crystal takes control and locks the frequency of the oscillating circuit with very high accuracy.



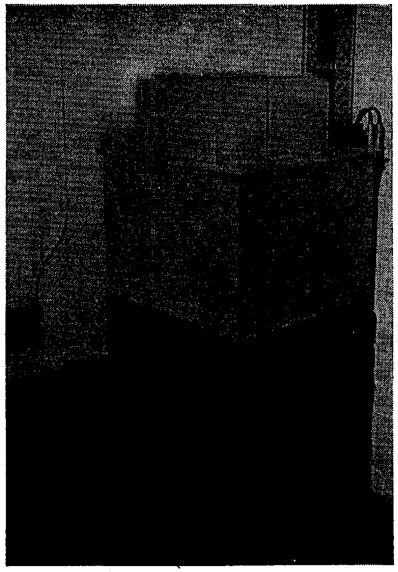
Royal Greenwich Observatory

A quartz-crystal clock with covers removed. In the centre is the cylindrical 'oven' containing the quartz crystal, and kept at a constant temperature. Below is the adjustment for frequency. Above, left, is the amplifier which maintains the crystal in oscillation; and on right, the circuit for temperature control

Vibrations or oscillations are measured as the number per second: we have seen that alternating current is usually given a period of 50 cycles a second. Frequencies may be low or high. As 1,000 cycles is called a kilocycle, a frequency of 1,000 cycles a second is called one kilocycle a second, and is written 1 kc/s; a million cycles a second is called a megacycle a second, and is written 1 mc/s. The frequency normally used for quartz crystal clocks is 100,000 c/s or 100 kc/s. One great advantage of this high frequency is that it becomes possible to subdivide each second into 100,000 parts, and thereby to measure intervals of time with high accuracy.

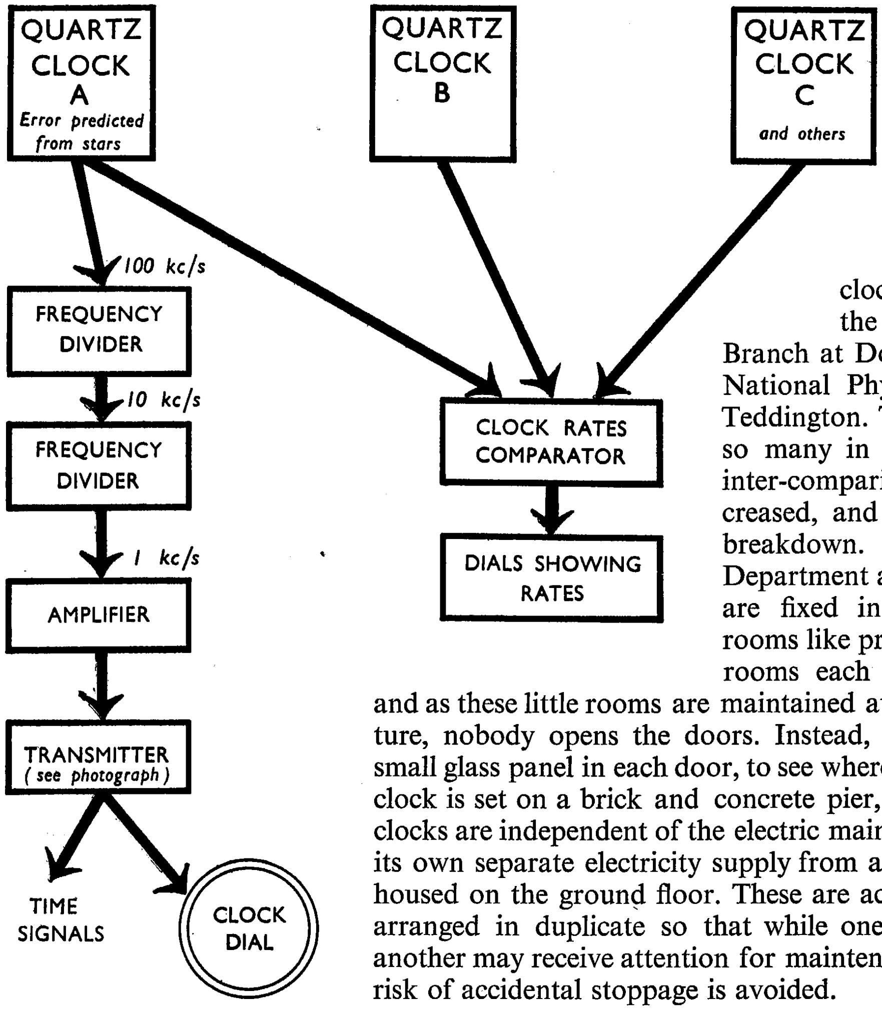
Quartz is a very common substance; it forms the glassy-looking crystals in granite, its grains are very numerous in sand, being hard and indestructible; and in fissures in rocks it sometimes forms huge six-sided crystals. A piece from a large crystal is cut to the required size, sometimes in the shape of a heavy ring, like a bangle, and sometimes as a small square flat plate, as in the picture. Either pattern, when used for a clock, is enclosed with its electrical connexions in a small cylinder called an oven, because it has heating elements to maintain it at a constant temperature. Quartz is chemically an extremely stable substance, which is the reason why the quartz crystal clock is such an excellent time-keeper.

The Royal Observatory uses 6 quartz clocks at Greenwich, and 12 at Abinger; in addition to these, similar



Royal Greenwich Observatory

One of the quartz-crystal clocks upon its brick and concrete pier



The operation of the quartz-crystal clocks

clocks are maintained by the Post Office Radio Branch at Dollis Hill, and by the National Physical Laboratory at Teddington. The reason for having so many in operation is that by inter-comparison accuracy is increased, and it avoids the risk of breakdown. At the main Time Department at Abinger, the clocks are fixed in small underground rooms like prison cells. There are 4 rooms each containing 3 clocks, and as these little rooms are maintained at a constant temperature, nobody opens the doors. Instead, one peers through a small glass panel in each door, to see where the clocks are; each clock is set on a brick and concrete pier, as on page 53. The clocks are independent of the electric mains, for each room has its own separate electricity supply from a large set of batteries housed on the ground floor. These are accumulators, and are arranged in duplicate so that while one set is in operation, another may receive attention for maintenance. In this way the risk of accidental stoppage is avoided.

As it is important to compare the rates of the different clocks to see which have the steadiest rate, the relative error of the clocks is recorded to an accuracy of one-hundred-thousandth of a second. This is indicated by a series of continuously moving dials, like meter dials, in the control room on the ground floor, above the clock cellars. These dials do not indicate the time, but only the difference in rate between clocks. To get an instantaneous reading, the whole set of meter dials is photographed each day. The readings from the previous day are subtracted from them, and in this way the relative gain or loss between clocks is known. Of course this can only be a test for relative error; the real error must be found by the astronomical observations.

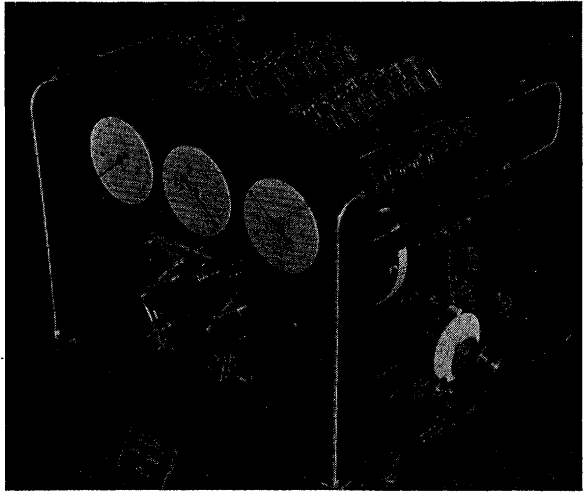
So far we have been talking of clocks, though nothing as yet has indicated the time. The various oscillating quartz crystals may be likened to a series of oscillating pendulums; in a pendulum clock, the movement of the escape wheel controls the clock train, which in fact counts up the oscillations of the pendulum and records the time by the movement of the hands of the clock. To obtain the time from a quartz clock we have to count up the vibrations to the quartz crystal. For this purpose electronic circuits called frequency dividers are used: the circuits are designed to divide the frequency by a factor of 10. One circuit divides the frequency of the oscillating circuit which maintains the quartz in vibration, giving a frequency of 10 kc/s. This is again subdivided to give a circuit with a frequency of 1 kc/s. The current of this frequency is then amplified in order to drive a small electric motor, called a phonic motor, which is similar in principle to the motor of an electric mains clock, but responding to a frequency of 1 kc/s or 1,000 c/s instead of to a frequency of 50 c/s. The phonic motor is provided with a contact disk, from which signals at intervals of one second are taken off. These signals can be used to control clock dials and to show the time.

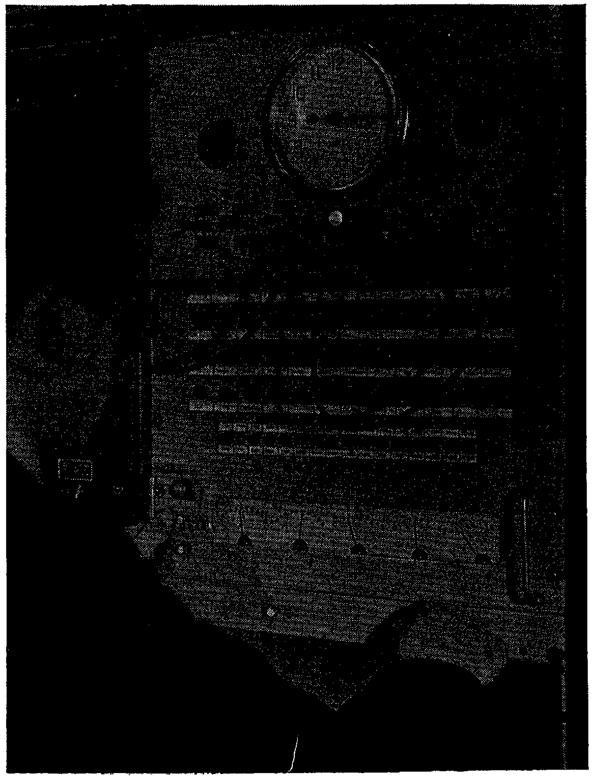
Transmitting instruments with a number of mechanical contacts are run in duplicate to avoid any breakdown, and each is driven by a phonic motor. Some of the revolving disks operate electrical contacts every second; by special gearing others give sidereal seconds: these are wanted for the transit observations, since the quartz clocks are set to mean solar time and not sidereal time. A special disk gives 61 contacts to the minute for the Rugby time signals later described. The contacts work relays, which in turn send a more powerful signal for transmission by land line to London and Rugby. Over this land transmission there is a slight time lag which has to be allowed for, so the phonic motors are set a tiny fraction fast. This is done by the knurled knob on the instrument which, by altering the position of the outer fixed part of the motor, adjusts the time of the signals by amounts as small as a ten-thousandth of a second.

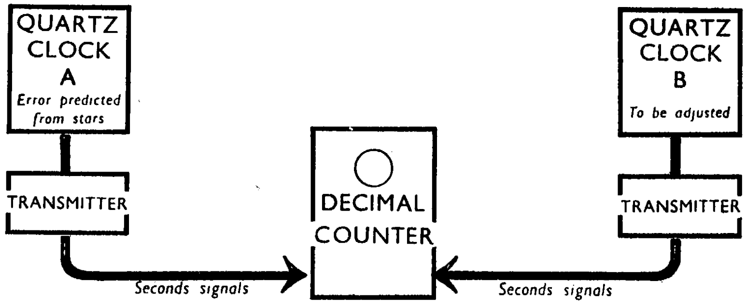
An important aspect of the time service is the checking of time signals, and regular comparisons with other observatories. We have seen how the time must, in the first place, be taken from the stars. For making exact and instantaneous comparisons between different clocks an electronic device called a decimal counter is used. The picture shows one of these

One of the transmitters, with various selector switches and contacts, including the 6 pips for the B.B.C. At the side is the knob for fine adjustment. The picture on right shows the switchboard of one of the decimal counters

Royal Greenwich Observatory





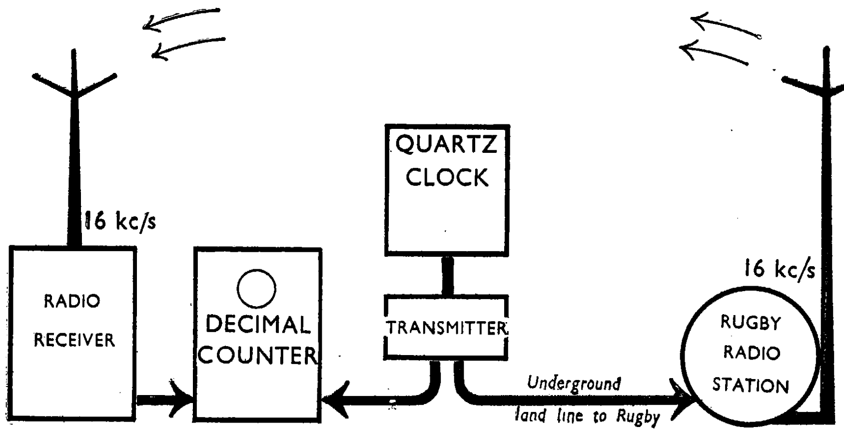


How two clocks are compared by the use of the decimal counter

instruments in the control room. Like a telephone switchboard, the connexions may be plugged into any of the numerous sockets, according to the test required. When any given connexion is switched on, an incoming signal from one clock starts the electronic counting, and the signal from another clock stops it. The difference in time is then seen below, where the indicators read decimals. In this way, differences are instantly measured in units which may be as small as hundred-thousandths of a second. Alongside the decimal counter are radio receivers which pick up time signals from other observatories. These signals may be compared with any selected clock in the same way. The transmitted signals to Rugby may be received back by radio, and the difference in time between transmitting and receiving may also be measured, as shown by the diagram. These are some of the everyday uses of the decimal counter, the operation of which is entirely electronic.

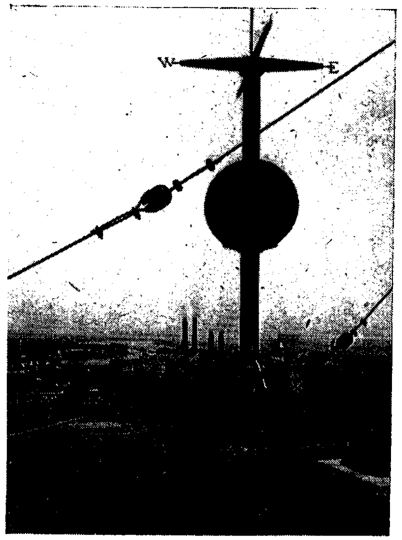
As the accuracy of a quartz clock is ten times that of a free-pendulum clock, the position has now been reached when the accuracy of the quartz clocks begins to surpass that of the available astronomical observations. The use of the transit instrument has been described in order to make clear the principles involved; but further progress makes it necessary to time the transits of stars with greater precision. This can now be done by a vertical telescope, called a zenith tube, which photographs the transits of stars; and other new instruments are being designed.

The quartz clocks maintain such a steady rate that they are able to reveal slight fluctuations in the daily rotation of the earth. These fluctuations in the length of the day may amount to as much as four or five thousandths of a second (milliseconds) in the length of the day. They could not be detected when pendulum clocks were used for time-keeping, because these clocks were not sufficiently accurate. The quartz clocks have proved, in fact, to be better time-keepers than the earth itself.



Showing how the time taken in transmitting time signals may be checked by the decimal counter

For all ordinary purposes, and for the navigator and surveyor, it is sufficient to say that the unit of time-keeping is the rotation of the earth. But for scientific work, and for those who must maintain accurate radio frequencies, it is obvious that if the rotation of the earth itself varies, it becomes more difficult to define what a second is; because at present it is defined as a fraction of the mean solar day.



Paul Popper

The original time-ball at Greenwich Observatory

TIME SIGNALS

The first public time signal was the time-ball, 5 feet in diameter, on a mast above one of the turrets of Greenwich Observatory, which since 1833 has been raised daily and dropped at precisely 1.0 p.m. At five minutes before the hour the ball is hoisted half-way up, as shown in the picture, and to the top at two minutes to the hour. As the observatory is on a hill, the time-ball could easily be seen by ships in the London docks, and by it they were able to set their chronometers. After the invention of the telegraph, time-balls were installed in other places; and by 1865 time signals were sent each hour to a telegraph company for distribution over the railway system. Subsequently the Post Office took over the telegraphs, and now receives and distributes the hourly signals for the use of its branches and for others who require the time.

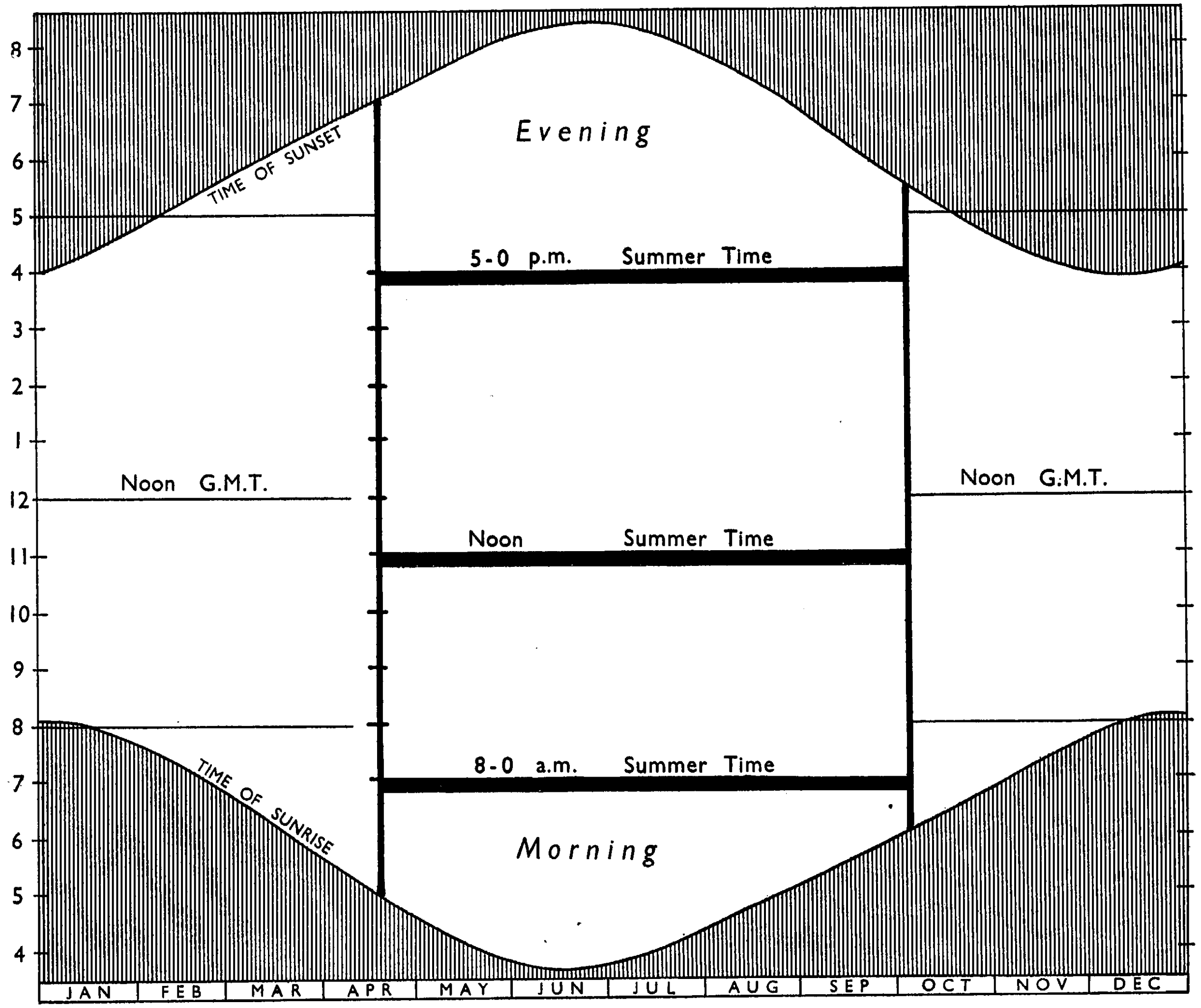
Everyone is familiar with the B.B.C. time signals in the form of the six pips. These signals are sent direct from the Royal Greenwich Observatory to the B.B.C. at every quarter-hour, and the B.B.C. can broadcast them at any quarter-hour as desired. The pips themselves are created by an oscillating valve and are of about $\frac{1}{10}$th second duration; from the beginning of one pip to the beginning of the next represents one second. The pips mark the 55th, 56th, 57th, 58th, 59th, and 60th seconds of the minute, the exact beginning of the last pip marking the hour, half-hour, or quarter, as the case may be. They are normally accurate to within a twentieth of a second. Very accurate time signals are sent out at 10^h and 18^h G.M.T. by the powerful Rugby transmitter, which maintains a world-wide radio telephone and telegraph service. There are two series of signals each of 5 minutes duration: the rhythmic series, and a series spaced at mean-time seconds. The rhythmic signals are 61 to the minute, instead of the usual 60, and by these it is possible to make accurate readings, the principle being similar to that known as a vernier scale. These series of signals are of such accuracy that the 24-hour interval between signals on consecutive days is very rarely in error by more than one-half millisecond. There is also a radio transmission of a standard frequency in kilocycles per second for the use of electrical engineers who wish to check a known frequency.

Summer Time

Daylight Saving was the invention of William Willett, a builder, whose firm in London still prospers. He had noticed that, in Britain, there were many hours of sunshine in the early summer mornings when people were still in bed, but that the evenings were too short for people who wanted to be out of doors after work; so he had the idea that clocks should be advanced in summer time so that, with our normal daily routine, we could have the benefit of more of the available daylight. He argued that as people thought nothing of altering their watches an hour at a time when at sea, there was no reason why they should not do the same on land. It was a revolutionary idea, and people at first thought it quite crazy. In spite of much propaganda for his scheme, he died in 1915 without seeing it adopted.

The very next year the British government introduced Daylight Saving as a war-time economy of fuel and power. The advantages were soon appreciated, and the idea was unexpectedly popular; consequently, Summer Time has been in force each year since and has also been adopted by many other countries. In Britain, the dates for altering the clocks are generally the third Saturday in April (or the second, if by chance the third coincides with Easter), when the clocks are advanced one hour to Summer Time; and the first Saturday in October, when we return to Greenwich time and the clocks are put back an hour. The time for alteration is always a Saturday night, as this causes the least inconvenience; 2.0 a.m. on Sunday morning is the legal time of change.

For 6 years, during the Second World War, Double Summer Time was introduced. In 1940, instead of putting the clocks back an hour in October, Summer Time was continued all through the winter. The next summer, on 4 May the clocks were put forward a second hour, and thus Double Summer Time was kept until 10 August.



The diagram shows the lines of sunrise and sunset throughout the year, for the latitude of London. The space between the lines represents the period of daylight, which is much greater in summer. If we start work at 8.0 a.m. and finish at 5.0 p.m. it is obvious that much daylight is wasted in summer before we get up; yet in the evenings there is only a limited amount. By going on to Summer Time, we call it 8.0 o'clock when it is really only 7.0 o'clock, and the hour taken from the early morning gives us an extra hour of daylight in the evening. In the British Isles the benefits of Summer Time are obvious. In much lower latitudes the change has not quite the same advantage because the difference between the amount of daylight in winter and in summer is not so great.

DIALS

THE dial of a clock is generally called the face, and the pointers we always refer to as the hands. A clock face must be legible, and the famous clockmakers, whose work is admired for fine craftsmanship, always made plain, well-proportioned dials. Nowadays some of the numerals on a dial are omitted, leaving only a small mark or 'baton'. These marks may serve well enough on a wrist watch, but a large dial of this sort is not easily read unless we stand squarely in front of it. Some dials, especially those of watches and alarm clocks, have luminous paint on the hands and numerals. This usually contains a phosphorus substance which 'stores up' the light it receives on a bright day and emits a glow in the dark. Sometimes dials are treated with a radio-active paint which gives an emission of true radium clearly seen in the dark. Because such rays are harmful, a strong emission must be avoided; but tests show that the amount on the dial of a watch is too small to have any ill effect.

TESTING WATCHES and CHRONOMETERS

WATCHMAKERS send their best watches to the National Physical Laboratory to be tested. For many years they were given an award of marks in open competition; but now tests are confidential and are only given professionally. It takes about 6 weeks to test a watch, and a complete record is made of its day-to-day performance. It is tested at normal temperature, at a high temperature in a specially heated room, and also in a refrigerator; and it is placed in different positions, horizontal, upside-down, vertical, and so on. In such tests the daily rate is not so important as consistency of rate: over a period of days the rate on any one day should not deviate greatly from the average daily rate. Chronometers are likewise tested at different temperatures, except that they are kept horizontal—their usual position.

A drum chronograph is used for testing. Its chief feature is a revolving drum on which is fastened a sheet of ruled paper. The drum is turned at a uniform speed by a phonic motor, and marks are electrically recorded on the paper every second from a quartz crystal clock; alongside these, other marks of the readings of the watch on test may be electrically recorded. Differences in time are then found by direct measurement on the paper. When chronometers with electrical contacts are being tested, they may be connected directly with the chronograph. Otherwise, in order to get accurate readings of a watch or chronometer, the position of a moving hand is timed by a special instrument using a photo-electric cell and connected by wires to the chronograph.

HOW WE THINK OF TIME

IF we are doing something pleasant, such as swimming or playing a game, an hour passes before we know what has happened; but if we are ill or in trouble, the hands of the clock seem to drag round so slowly. Early in history, people were apt to think of time as a series of disjointed events, such as successive harvests or notable battles. It was only gradually, as mechanical clocks came into use, that people began to think of time as something flowing continuously and uniformly. To us this seems the obvious explanation; and yet time has no ultimate and absolute measure: it depends on where it is being observed.

If we look up at the stars on a clear night, we fancy that we see them all at a given instant of time. But the stars are very far away, and it takes several years for the light from the nearest of them to reach us. For those farther off it may take thousands of years for the light to come; and the light we see from the distant nebulae left them millions of years ago. So when we look into space, we are also looking into time, and seeing things as they were at various different times in the past. According to the theory of relativity, time has no fixed rate of flow, and may appear differently when measured from different places in space. For example, the rate of flow depends on the speed at which a body may be travelling; and if a body is travelling very fast, the slower will time advance, as measured by anything moving along with it. It has been pointed out that if it were possible to travel in a rocket at nearly the speed of light, we could circle the distant stars, and on returning to the earth find that, in the rocket, time had only advanced a few months, because of its great speed; whereas on the earth itself a million years would have passed.

This sounds queer, but there are strange things we can find out for ourselves. We have seen that, on crossing the date line, a day is lost or gained according to which way we happen to be travelling. Suppose we set out one early morning from London airport and travel westwards at supersonic speed. If we travel fast enough we shall circle the world and return to the airport, having all the while kept up with the sunshine, so that it would be continuously early morning during the whole trip, and would still be morning when we were ready to land. But, of course, on landing it would be the next morning, even though we had experienced no night.

The reason for Daylight Saving, simple though it is, causes some people to get quite confused. They will have none of it, and say they think it impious to tamper with nature, and that we should keep the real time, and no nonsense about it. But if this is Greenwich Mean Time, it is only correct for the Greenwich meridian, and the 'real' time must be the sun-dial time at any given place— and this is no use for catching a train. In reality we cannot strictly follow nature; and in both the Jewish and Christian calendars, the moon used for finding the dates of religious observances is a fictitious moon, not the real moon; for the same reason that we use the mean sun and not the real sun. All time-keeping is a compromise, for there is nothing fixed in nature.