How it Works

The Clock
THE CLOCK
HOW IT WORKS

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1. Early man, recording time by observing shadows

2. Sundial

3. Grandfather (pendulum) clock

4. Portable timepiece

5. Digital quartz wrist-watch

6. Atomic clock—the ultimate timekeeper
Miniscule atoms vibrating at 23, 870, 129, 300 cycles per second. A radio frequency charged to match their strength. Trapped in a mass of pipes, pumps and tubes. The result—an explosion! Or so one would imagine.

All this is just to tell you the time. Time as recorded by an atomic clock. And time so accurate that if you were to go by it, you would be late for school by only one second in 1,700,000 years!

The atomic clock has made man's powers almost magical. Today we can record not only every second but every nanosecond and picosecond of any occurrence, even the slowing down of the Earth.

Once Upon A Time

Man's need for accuracy and perfection is not new. More than 4000 years ago he began to realize the importance of measuring time. Earlier, he spoke of events that happened so many 'suns' or 'moons' ago or at the time of the 'heavy snows' or the 'big flood'.

In ancient India, just as a month was divided into thirty days, a day was divided into thirty 

muhurtas. (Day and night were taken together). Distinctive names were given to each of the 
muhurtas.

Both 'day' and 'night' appeared as natural units of time in our earliest literary productions. Expressions like 'many dawns and nights' or 'days subdue the nights' occur in the Rig Veda. The 'ahoratra' (that is, day combined with night) meant a duration of 24 hours.

Aryabhata, one of our greatest mathematicians and astronomers, discusses the units of time in his masterpiece, the Aryabhatiya, written around 500 A.D. In the
chapter Kalakriya Pada, he talks about a year being divided into twelve months; a month into 30 days; a day into 60 *nadis* and a *nadi* into 60 *vinadis*. (A *nadi* was equal to 24 minutes, a *vinadi* to 24 seconds).

Meanwhile, Babylonian priests, fascinated by mathematics, were making efforts to achieve precise methods that would divide each day into 24 hours and each hour into 60 minutes.

Those of you who are adventurous, take a cue from King Alfred—the Saxon King who invented the candle-clock.

Candles of the same size, he noticed, burn down at the same rate. So, Alfred took a handful of candles, each a foot long, and marked them with a number of bands. Each band represented a certain division of time, say, one hour. He could tell how much time had passed by noting how many divisions had burned away.

The Babylonians noticed that the position of a shadow changes during the day. So, they fixed a pole in a sunny place and observed its shadow as it moved. The shadow, they discovered, was long at sunrise and gradually got shorter and shorter until it reached a certain point when it began to lengthen again. At sunset the shadow was as long as at sunrise and at noon it was the shortest.
Similarly, the Indians who were studying the movements of the sun, the moon and other planets, developed several simple astronomical instruments like the gnomon, staff, arc, wheel and the armillary sphere. They cast the almanac, that is, a calendar listing the days, weeks and months of the year, calculated on the basis of the movements of the sun, moon and other heavenly bodies.

Even as early societies measured the year, the month and the day, they felt the need for devices that would monitor and indicate time precisely. Gradually, one development led to another and, as with most things scientific, literary or religious, it was an exchange of ideas and achievements between India on the one hand and West Asia and the Mediterranean world on the other that produced the so called 'first' clocks.

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**Day Time**

The study of shadows led to the making of shadow clocks and sundials.

A shadow clock consists of a length of wood with a crosspiece and a traverse bar whose shadow marks the passage of the sun, while a sundial is basically a dial face with a pointer in the centre. The pointer, also known as gnomon, is a flat piece of metal which points north in the northern hemisphere and south in the southern hemisphere. Its upper edge slants upwards at an angle corresponding to the latitude or the distance that it is away from the Equator. The shadow of the gnomon moves across a scale around the dial as the sun moves across the sky.
Night Time

Shadow clocks and sundials recorded time during the day, provided, of course, it was a clear, sunny day, but when night came they were of absolutely no use. That was when people thought of making water-clocks.

A water-clock consists of a container with a small hole at the bottom through which the water can escape. The gradual fall in the level of the water marks the passage of time. As the level drops, it exposes more and more of a scale marked with the hours. To ensure that the water drops steadily, the container must have sloping sides.

The Greeks and Romans used water-clocks for limiting the time of speeches in the law courts. The amount of water put into the container at the start of a speech depended on the importance of the case to be argued!

Alas! If the winter happened to be too severe, the water froze and these clocks could not operate.

The Sands Of Time

As the world progressed, a better method of measuring time had to be thought of. A reasonably accurate and reliable timekeeper developed was the hourglass.

An hourglass is a particular kind of sand-glass or ‘ghantika yantra’ as it was known in India. It consists of two glass bulbs joined by a narrow neck and set in a stand. One of the bulbs contains very fine, dry sand. To measure the hour, the glass is inverted so that the sand-filled bulb is on top. Gradually the sand drains into the bottom bulb and after exactly one hour the top bulb is empty. The sand drains at a steady rate, no matter how much is left in the top bulb. This method was quite successful and very soon sand-glasses were made in groups of four. There was a 1/4 hour, a 1/2 hour, a 3/4 hour and an hourglass.

That, incidentally, was the origin of the expression, ‘the sands of time are running out’.
If you look at the flowers carefully, you will notice that some open at 6 a.m., some at 7 a.m. and others at 8 a.m. Similarly, some flowers close early and some late. So it was that in 19th century England, flowers were laid out in beds in the form of a clock face. The blooming or closing of each bed depicted the hour of the day.
Ding-Dong

While the sun, the sand, shadows and water helped man record the hours, there was still no sign of a clock that ticked.

The exact date of the invention of mechanical clocks is unknown. The earliest examples, apparently, go back to about 1250 A.D. These were based on the massive clock-work models that had been devised by astronomers and mathematicians to study the heavenly bodies. They were made of wrought iron and were used atop cathedrals and other buildings. The regulation of these clocks was clumsy and they were as much as one hour wrong each day.

By 1389, however, clocks had improved greatly. They had bells to ring not only on the hour but at every quarter as well.

Strictly speaking, a clock is an instrument that has a bell and strikes the hours and sometimes the quarters too though we tend to call any instrument that measures the passage of time a clock. Other kinds of time-measurers should be called timepieces.

It was not until the 16th century that clocks small enough for the house were developed. The first movable clocks became possible when weights were replaced by the spring drive. Clocks became the newest and most expensive toy in the royal courts. Princes and noblemen took great delight in organising their day by it. A banquet would be arranged to begin at 8 o'clock instead of at sunset and people spoke in terms of a place being five hours away instead of half a day. That was also when ‘appointments’ were first made.

The clock incidentally was the first complex mechanical device to enter the home.
Swinging Time

Around 1660 the pendulum came into use. It was the Italian astronomer, Galileo who contributed largely to the discovery of the pendulum. In 1581, during an earth tremor, Galileo is said to have timed the swings it caused in a hanging lantern in Pisa against the beats of his pulse. He found that beginning from a central point, the lantern swung the same distance to the left as to the right, in the same length of time. From this he formed the theory of isochronism or things performed in equal times.

In 1641 Galileo started applying this theory to timepieces. He died in the following year. His son Vincenzio continued his father’s work and made drawings for pendulum timepieces in 1649. But he too died without completing a clock.

Finally in 1656, a Dutchman, Christian Huygens designed the first practical pendulum clock.

Enter The Grandfather Clock

Despite the discovery of the spiral spring and the pendulum, some clocks continued to be weight-driven. They were cumbersome and ugly. So someone thought of enclosing the weights and cords in a cupboard-like case. Lo and behold! the grandfather clock was born. And what a stately clock it turned out to be! Even today grandfather clocks are specially designed for those who like to use it as a clock-cum-furniture piece and bring a bit of old-world charm into their homes.
‘Spring Time’

By this time the value of a clock was beginning to be realized by more and more people. They wanted timepieces small enough to be carried about.

It was a German, Peter Hele, who made this possible. He invented the coiled spring which formed the foundation of all future spring-driven clocks and watches. But the power of a spring becomes less as it uncoils. So Hele’s timepieces, though unique, were no good as timekeepers. A few years later this problem was overcome by the incorporation of a device known as the fusee and spring which enabled more reliable small clocks to be made.

By and by further improvements were made as people the world over worked on various methods of keeping time.

Maharaja Jai Singh II of Jaipur was motivated by a strong desire to set up highly efficient, modern observatories for producing accurate astronomical data. With the result, during the early 18th century a large number of giant instruments, including the Samrat Yantra (Sundial) were constructed in stone. This was the first time that sundials were set up in India. Jai Singh constructed several observatories. The one at Jaipur is the most famous. It has a huge masonry gnomon or sundial pin, whose shadows show the hour of the day perfectly. New Delhi’s ‘Jantar Mantar’ (observatory) is a big draw.
'Time And Tide'

Ocean navigations were still controlled by calculations based on the position of the sun, moon and stars. This inaccurate method invariably produced navigation errors because every minute lost by mistiming could put a ship as much as 15 kilometres off course.

John Harrison of England spent many years designing a clock for sailors. His fourth attempt proved successful and in 1761 a chronometer accurate to half a minute a year was produced. A chronometer keeps time in all variations of temperature and tells people at sea exactly how long they have been plying east or west.
The world gets its time from the sun—a day being recorded from noon to noon. But, owing to the rotation of the earth on its axis, noontime would differ from place to place. To avoid this confusion the world has been divided into 24 time zones by imaginary lines, known as meridians. Each time zone is 15 degrees apart and represents a difference of one hour.

At Greenwich Observatory, England, is the prime meridian, where Greenwich Mean Time (G.M.T.) is recorded. This is the absolute standard of time, on which all other times are based.

When the sun is directly over the prime meridian, it is 12 noon at Greenwich. At Stockholm, in the next zone east, it is past 1 o'clock. On the other hand the time zones to the west of Greenwich are hours behind. New York, for instance, is five hours behind G.M.T.

In scientific technological work, G.M.T. has now been replaced by Coordinated Universal Time (UTC) which is based on data collected by Bureau International de l'Heure (BIH), Paris. BIH collects data from atomic clocks around the world and provides an international atomic time scale which is more accurate than G.M.T.
It was in 1900 that the possibility of transmitting electrical impulses from a central source to drive clocks was developed. Electric clocks were made in 1918 by Henry Ellis Warren, an electrical engineer from Massachusetts.

The French brothers, Pierre and Paul Jacques Curie, had identified the 'piezo electric effect' in 1880, which meant that certain crystals vibrate at a constant frequency when a controlled alternating voltage is applied across them and also that bending or striking the crystals produces an electric charge.

In 1929, Warren Alvin Marrison of New Jersey was the first to apply quartz crystals to electric clocks.

With this it became possible to measure time spans of a few thousandths of a second. Today with the atomic clock being used in high-speed calculations, all one seems to be doing is catching up with time!

Day after day time moves on—not a second slower or faster than the previous day!

How does this happen? What is it that makes the hands of the clock go round so accurately?

Let us take an ordinary mechanical clock and turn it inside out.

The first thing you do is to wind the clock. When you do this, you are actually winding a coiled spring or the mainspring within the clock. One - two - three - four - round and round goes the coil until it is tight. But remember, easy does it. For, an extra turn and—snap—the spring goes!

So, you have wound the mainspring just enough and left it. Now what? The coil at once begins to unwind. In this way it releases a certain force which drives all the wheels that actually make up a clock.

But if these wheels just went round and round merrily, it would serve no purpose. Their movement has, therefore, to be regulated.
Regulating Time

The heart of the clock is the part known as the regulator. This is a device that controls the rate at which a clock keeps time. There are different kinds of regulators. The balance-wheel is one that is commonly used in most mechanical watches. This is a delicate wheel with a pivot at the centre which is connected to a very fine spiral spring called a hairspring.

The hairspring turns the balance-wheel. But again, not round and round. Its movement is arrested by a lever called a rocker which has two pallets. Whichever way the balance-wheel turns, the rocker stops it and the hairspring immediately pulls it back the other way. Thus the balance-wheel is kept twisting a half turn one way, a half turn the other way. And this is repeated over and over again. Once the balance-wheel is set in motion it will move to and fro in the same length of time.

The balance-wheel is connected to a device known as the escapement which, in turn, is
The rocker engages one tooth of the escape wheel and the clock goes ‘tick’.

The escapement consists of a toothed wheel known as an escape wheel and the rocker (the same as the one mentioned earlier). It has two jobs. One is to ensure that power ‘escapes’ from the mainspring. The other, that it ‘escapes’ at the rate laid down by the regulator, so that eventually the hands of the clock can turn accurately. How does it do this?

We said earlier that when the balance-wheel turns, its movement is arrested by a rocker and immediately the hairspring pulls it back. This movement is exactly in step with the movement of the escapement. For, when the
balance-wheel takes a half turn one way, one of the pallets of the rocker releases a tooth of the escape wheel and allows it to rotate till it is stopped again by the other pallet. The time taken by a tooth of the escape wheel to push aside the first one and then the other pallet of the rocker is the time taken by the clock to go first 'tick' and then 'tock'. Thus the clock moves in a series of jerks controlled by the escapement and the regulator.

Now we have a perfect, isochronic motion going. This means, a movement that goes to and fro in the same length of time constantly. This movement has to be transmitted to the hands of the clock.

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**Gearing Up**

The hour, the minute and the second hand must necessarily go round at different speeds. For this reason their movements are controlled by gear wheels.

Gear wheels, as you may know, are discs with teeth cut out of them. These teeth link together with the teeth from other wheels so that, when one wheel turns, the others also turn—but in the opposite direction.

If two gear wheels of the same size are interconnected, they would rotate at the same speed. If one of the wheels is half the size of the one that it is connected to, the smaller wheel will go round twice in the same time as the big wheel would take to go round once.

The arms of the clock work on this principle. They are thus connected to gears of different sizes so that they can go round at different speeds.
Falling weights were used to power the earliest clocks, especially the grandfather and grandmother clocks. They worked through a series of wheels driven by a falling weight on a cord. The pendulum, which acted as the rocker, regulated the rate at which the wheels turned. The pendulum and escapement together produced the ‘tick’ or forward jerk in the clock. This was transmitted to a finger that showed the time.

A pendulum is a very good regulator. This is because the swings or oscillations of a pendulum are regular and steady. You can see this for yourself if you tie a weight on a piece of string and allow it to swing back and forth.
Electronic Clocks

While the method of working remains the same for all modern clocks, the material used varies. For instance, in research laboratories and for astronomical observations two extremely precise kinds of electronic clocks are used today. They are the quartz crystal clock and the atomic clock.

Quartz is one of the commonest minerals. Sand is made up almost entirely of small grains of quartz. Usually it is milky white or has shades of various colours, but sometimes it is as clear as glass. This form is called rock crystal. In bulk form quartz is crystalline.

Pure quartz has interesting electrical properties which make it suitable for regulating the mechanism of a clock. When an electric current is passed through a quartz crystal, the crystal vibrates at an almost perfectly constant rate. The rate of the vibration depends on the thickness of the crystal. The thinner it is, the faster it vibrates. The faster it can be made to

The front of a quartz crystal clock
The atomic clock is the most accurate time-keeping machine to date. It can measure time intervals of a millionth of a second. It uses the vibrations of either ammonia or caesium atoms as a regulating device. These atoms vibrate very regularly and rapidly—thousands of millions of times every second.

At major sports tracks events are filmed and a quartz-crystal timing mechanism in the camera runs all through the race. It directs the figures through a prism on to the film to give split-second timing of the finish.

A quartz crystal clock can have a dial or digital face. The battery makes the crystal oscillate at its natural rate. A divider circuit in the watch converts the natural vibration rate to one pulse per second. A motor converts these vibrations into one-second ‘ticks’. These are transmitted to the clock face again by a set of wheels.

To look at, the atomic clock is nothing like an ordinary clock. It is a complicated mass of tubes, pipes, pumps and electronic gadgets. A radio frequency is charged to match the...
The atomic beam chamber of a caesium atomic clock

strength of the atom that is used. The radio frequency (maintained at the correct rate by constant electronic checking) makes the clock advance one second after the number of vibrations has been counted off electronically.

Atomic clocks are used for high-speed navigation calculations and by advanced research scientists and astronomers.
For the rest of us there are a variety of clocks available these days. Aside from mechanical clocks there are those that run on electricity. Some of them merely use electricity as a source of power to drive the clock mechanism. In some battery-operated ones, the electricity powers a small electric motor which rewinds the mainspring of the clock every few minutes. In large public clocks electricity is used to power a motor which winds up a weight driving the clockwork.

The most common electric clocks, however, use electricity not only to power them but also to regulate them. They are called synchronous clocks. In these clocks the motor driving the mechanism keeps in step with the rapid alternation of the electric current.

And if you attempt to listen to the 'ticks' in an electric clock, you will not be able to hear them, because an electric clock has no 'tick-tocks'. It has no rocker and no hooks. A small electric motor turns the wheels and the wheels turn the hands. As the electric motor always runs at the same speed the hands of the clock point to the right time without the 'tick-tock' sound.
Fun ‘Times’

Many of us have come across delightful clocks that chime or say ‘cuckoo’ and wondered how they work. At times one has even been tempted to go behind the ‘cuckoo clock’ and see if there is a real bird in there!

There are actually two whistles that make the ‘cuckoo’ sound. Little boxes, called bellows, blow air through the whistles. If you listen carefully, the first ‘coo’ is shorter than the second. The two whistles tooting, one after the other, make the ‘cuckoo’ sound.

At one o’clock the clock ‘cuckoos’ one time. At two o’clock two times and so on. What makes the clock ‘cuckoo’ the right number of times?

A catch flips out of a notch in a special wheel when it is time for the clock to ‘cuckoo’. The wheel turns a short way, the little door pops open, the bird comes out and bows and the whistles go ‘cuckoo’! As long as this wheel turns, the clock ‘cuckoos’ over and over again.

The wheel turns when the catch is out of the notch. The catch slides on the edge of the turning wheel. The wheel stops when the catch falls into the next notch. With that the ‘cuckoo’ sound also stops.
A Real Holiday

From the moment the alarm clock wakes us up we know it is one mad rush—to catch the bus, to school, to work, to get back home, to play and to sleep. All this must be done within the 24 hours we have allotted ourselves each day.

It is not surprising then that people discard their watches to counteract the pressure of work when they want to go away to a quiet place on a real holiday!

When we say a clock has jewels, what exactly does it mean?

The moving parts of a watch, that is, the escape wheel, the balance-wheel and so on turn in bearings often made of jewels. Such bearings, called jewelled bearings, are used because they are hard and can withstand year after year of constant use. So next time you see a watch that claims 17 jewels, don't look puzzled!
This book, one of a series of information books, introduces the child to a variety of clocks—ancient and modern. It explains in a simple manner how the clock works.

Others in this series include:

- The Television
- The Telephone
- The Motor Car
- The Aeroplane
- The Ship
- The Railway Train
- The Computer

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