MACHINES *that* MEASURE TIME

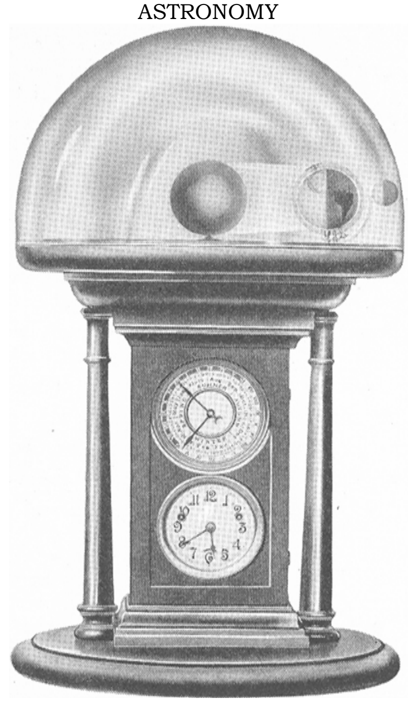
What time is it?" you ask. Centuries of scientific progress, with vast labor and years of patient study, have been necessary to answer that question correctly. Go back through the factory where the little ticking watch is made – trace the history of those tiny wheels, of those measurements so delicate that the naked eye cannot follow them. You'll find that men had to delve into the intricacies of mathematics, the mysteries of astronomy, the wonders of physics and chemistry, before they could force the hands on the dial to tell you when to start for school or to catch your train. The vast sweep of the earth's whirling journey around the sun had to be measured before those ticks could be spaced to mark off an accurate second. As you look at a clock, remember that every time the minute hand passes from one of its marks to the next, it shows that this huge globe on which we live has covered more than 1,000 miles of its headlong journey. Now read how clocks and watches were invented and how they are made today.

CLOCKS AND WATCHES. At first men had no way of measuring time by day except by the position of the sun in the sky and the shadows it cast, and by night they could only guess from the position of the stars. This was of course a very rough-and-ready method, and did not mark time out into such exact intervals as we have in the hour, minute and second. For ordinary purposes even the highly civilized Greeks of the age of Pericles usually indicated time by only such vague terms as "dawn," "full market," "noon," and "sunset." The ancient Babylonians were the first to hit on a sharper way of measuring time, by making "sundials." They stood an upright rod so that it cast its moving shadow on a smooth surface marked off into equal intervals, roughly equivalent to our hours. The Greeks used this instrument when they needed sharper divisions of the day, and it remained the most general time measuring device down to the 14th and 15th centuries of our era.

But sundials can only tell time when the sun is shining. A more reliable kind of clock was invented by the Egyptians, and copied by the Greeks and Romans. This clock, known as the "clepsydra" or water clock, marked off the hours by the dripping of water through a tiny hole in the bottom of a jar. As the surface of the water lowered, marks came into sight which told the hours – or a receptacle below was filled, or the weight of the water was used to operate a pointer traveling around a dial.

In the Middle Ages the "hour glass" or "sand glass" came into use. In this instrument sand runs from one hollow glass cone to another through a tiny hole in the centre, the quantity of sand being carefully measured out to take just an hour or a certain part of an hour to run from one compartment to the other. Hour glasses were often used in churches during the 17th and 19th centuries to mark the length of the sermon. Smaller sand glasses, taking three minutes to run out are still used in some districts for marking the time for boiling eggs.

A CLOCK THAT UNDERSTANDS ASTRONOMY



This clock shows how the earth revolves on its axis, how it moves around the sun, keeps track of the seasons, and even foretells eclipses

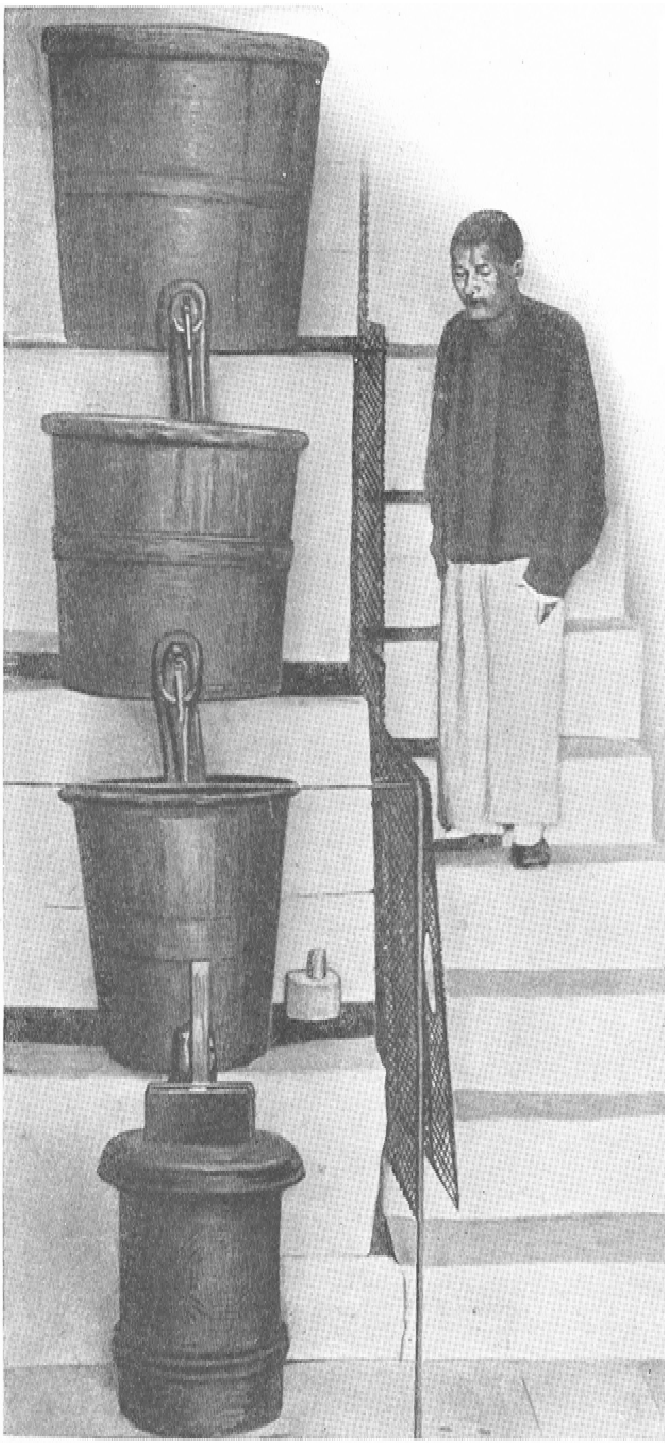
Some time during the Middle Ages, no one knows just when, a form of clock which is still in common use was invented – the form in which a weight attached to a cord or chain turns a set of geared wheels which operate a pointer traveling around a dial, as in our "grandfather's clocks." Various devices were invented to regulate the speed at which the weight falls, but the best and simplest device, the pendulum, did not come into use until after Galileo in the 17th century had discovered that the successive small vibrations of a pendulum are made in equal times (*see* Galileo; Pendulum).

In olden times people didn't have to catch trains, and life was far less complicated; so minutes were not very important, and some of the early clocks had no face at all – the bell at the end of the hour was the only means of knowing what time it was. Indeed, the word "clock" comes from the French word cloche, meaning "bell."

To understand how clocks are operated let us study the mechanism of a "grandfather's clock." In plain sight are the weight which furnishes the power, and the pendulum, which regulates the speed. Up behind the dial is a Chinese puzzle of wheels. The pendulum rod is hung by a thin spring of steel that bends easily and allows the pendulum to swing just so far and then gives it a slight push back. The cord or chain to which the weight is hung is wrapped around and around a drum or barrel, like a rope on a windlass. But the barrel cannot move until the pendulum is set swinging. Start the pendulum and the whole clock wakes up, like the palace in the story of 'Sleeping Beauty'.

Attached to one end of the barrel is a cogged wheel, and attached to the pendulum is an anchor-shaped piece of metal with its two points shaped so they can catch in the teeth of that wheel. As the pendulum swings, the "anchor" or lever-catch rocks up and down; the point on one side lets go of a tooth of the wheel, but just as soon as it has turned forward one cog, the point on the other side catches the wheel again. It is this constant catching and letting go which makes the ticking sound. Every time this happens, the pendulum is given a little push which keeps it swinging.

THE WATER CLOCK OF CANTON



This is a monster hour-glass, 500 years old, in Canton, China. The water drips slowly from one copper jar to the next, and in the lowest a float marks on a scale its gradual rise. This clock, you see, instead of saying "tick, tick, tick" says 'drip, drip, drip!"

The other wheels of the clock are geared to the barrel wheel and are made of such size that they run at different speeds – one turning the second hand (if there is one), another the minute hand, and another the hour hand. The pendulum you might say is the engineer; the lever-catch is the throttle; and the barrel, cord, and weight furnish the power to drive the slow-moving engine.

The whole duty of the clock-work is to drive the hour hand at a regular rate of travel around the dial, twice in 24 hours. Sometimes a clock goes too fast or too slow and must be regulated. A pendulum clock is regulated by pushing the "bob" of the pendulum up or down on the rod. The time it takes a pendulum to swing depends upon the length of the rod. The longer the rod, the slower the beat; so if the clock is fast, we screw the bob down, and thus increase the length of the pendulum.

Curious Members of the Clock Family

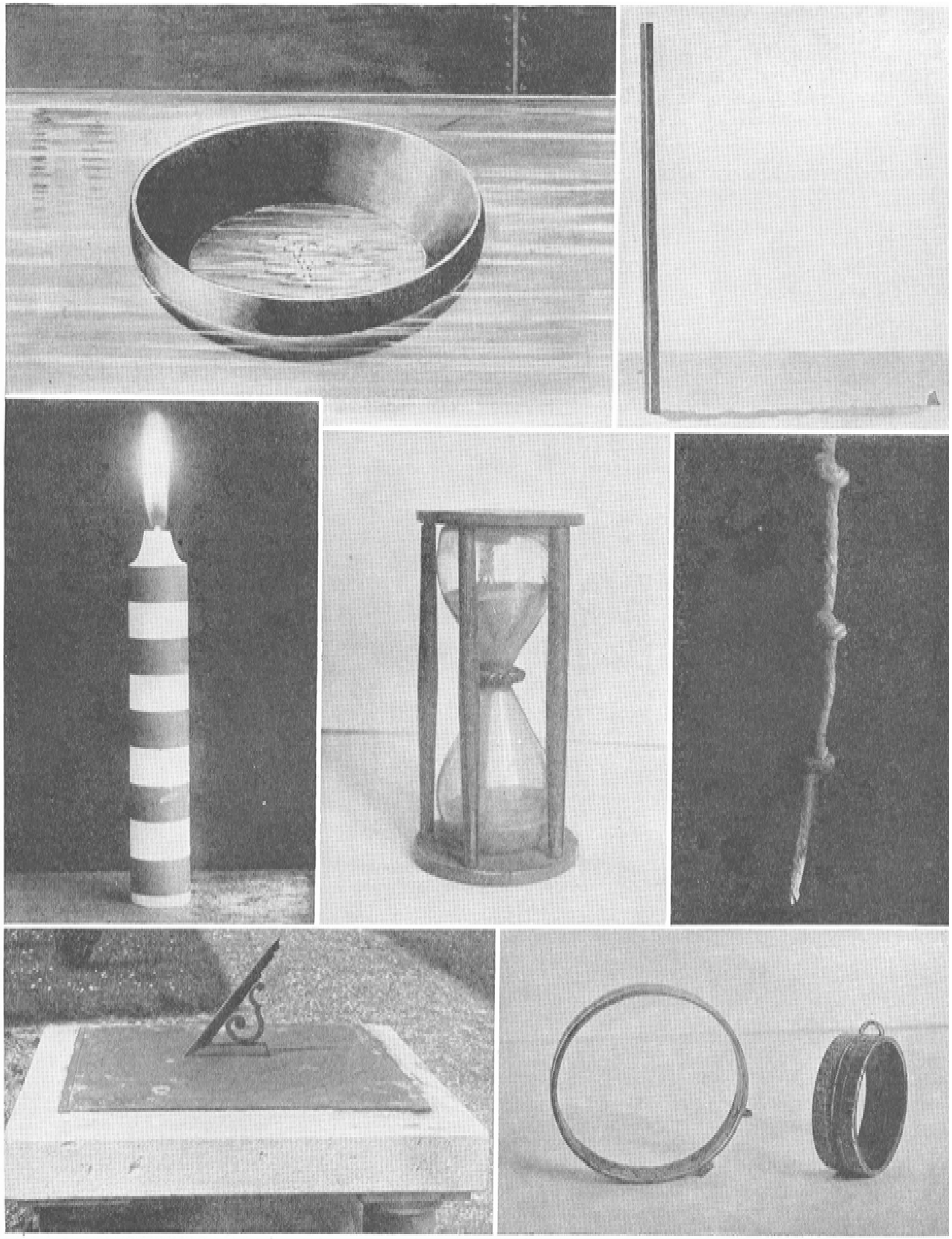
Some of the early clocks were very wonderful, indeed, and it took years to make them. There is a famous old clock at Strasbourg which not only tells the time of day, but also the day of the week, the month, and the position of the moon and the planets. At various times processions of tiny figures cross a stage, including a cock that crows. The day of the week is indicated by a separate little figure that takes its place on a tiny platform. Another of these remarkable performing clocks can still be seen in the city of Munich, Germany.

A clock in Venice has two bronze giants that strike a bell on the hours. Other clocks had figures that appeared and danced to a strain of music each hour. Cuckoo clocks, from which a little wooden bird pops out, sounding the hours, are quite common today.

The largest clock in the United States was built for the Colgate factory in Jersey City in 1908. The two hands weigh together more than half a ton, and the great 400-pound pendulum is kept going by a little gravity arm that falls against it. Its dial is nearly 40 feet in diameter and can easily be read at a distance of three miles. The tip of the minute hand, which is 19 feet long, travels 23 inches every minute, or more than one-half mile a day.

It was obviously impossible to make small clocks or watches, so long as the weight and pendulum were the only methods of furnishing and regulating the power. Small clocks and watches are made possible by the use of a coiled spring to furnish power, and a balance wheel to time the speed. The first clocks small enough to be carried about were made in Germany about the end of the 15th century.

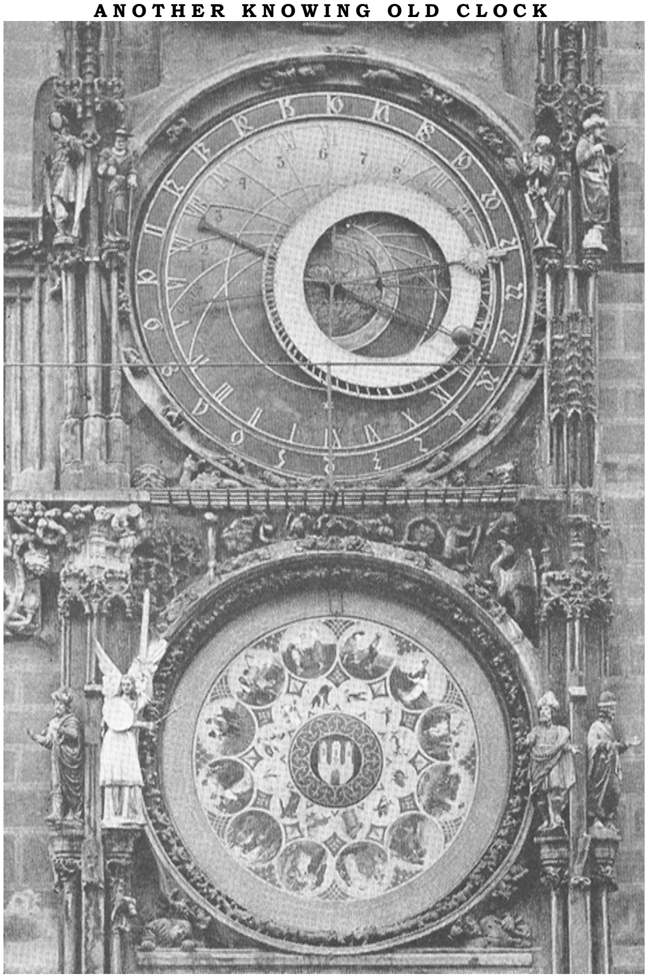
If you open the back of a watch, you will see a fussy little wheel turning back and forth rapidly, while



Here are a few of the simple devices which men have used in various ages and in various lands for measuring units of time. At the top a stone dish with a small hole in the bottom is set afloat on water. It takes perhaps three minutes to sink and strike bottom – just long enough to boil eggs. Next is the "stick and shadow" method; then the candle which burns from stripe to stripe every 30 minutes; next is the hour-glass with its running sand; next a rope smoldering away from knot to knot; and at the bottom two types of sundials. All such time-measuring devices were of course more or less unreliable; and, except for the sundials, they were not really "time tellers" at all, since they only measured brief periods without telling the true time of day.

a tiny hair-spring contracts and expands. This is the balance wheel, which takes the place of the pendulum. If you look closely you will see near by a small wheel with hook-shaped cogs, which is turning around quite fast; this takes the place of the barrel cogwheel of the grandfather clock. Those little hooks catch in a tiny rocker fastened to the balance wheel, just as the lever catch did in the clock; and, as they strike that rocker, they give it a little "kick," which swings the balance wheel around, tightening the hair-spring. Then the tension on the hair-spring swings the balance wheel back again, another little hook is released, and the next hook strikes the rocker-and so on.

ANOTHER KNOWING OLD CLOCK



This old clock at Prague, in Czecho-Slovakia, not only tells the time of day, but the time of year and the position of the heavenly bodies. The figures at the sides go through pantomimes at certain hours just as do those of the famous Strasbourg clock.

In most watches there is a little pointer over the balance wheel, which can be moved back and forth between the letters "F" and "S" engraved on its metal support. When you move it toward "F," you tighten the hair-spring which gives the balance wheel a quicker swing and makes the whole watch run faster. When you move it toward "S," the hair-spring is loosened, and the watch runs slower. Great care must be used in regulating a watch in this way, for the parts are exceedingly delicate and sensitive.

Small clocks operate on the same principle as watches. Alarm clocks are equipped with an extra spring attached to a bell, and are set off with a trigger which is pulled when a certain wheel, moving 12 times slower than the hour hand, reaches the set point.

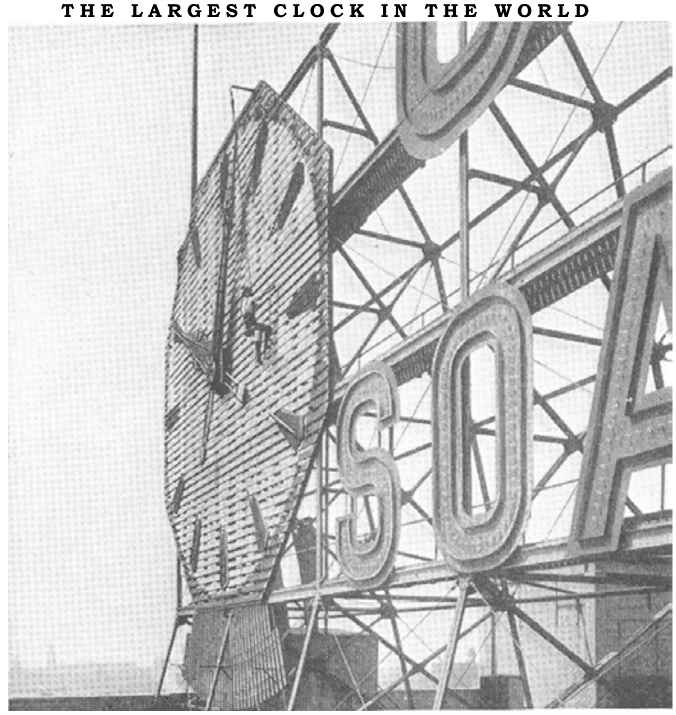
A watch is perhaps the most wonderful little machine in the world. Packed away in a case sometimes no bigger around than a 25-cent piece and less than a quarter of an inch thick, are from 150 to 800 separate parts. There are wheels of many sizes and shapes, pinions, plates, screws, rivets, pins, springs, and "jewels"-the latter used as durable bearings for the watch pivots. Many of these parts are so small that watchmakers have to pick them up with tweezers or magnets, and find the places for them with the aid of a magnifying glass held in one eye.

Big Machines that Make the Little Ones

For a long time watches were made entirely by hand, and they were so expensive that only the rich could afford them, and if one of the little parts broke, what trouble and expense there was in getting another part to fit! These early watches were often big clumsy things that were almost too large for the pocket.

But now machines, most of them invented in America, make watch parts in such quantities and so

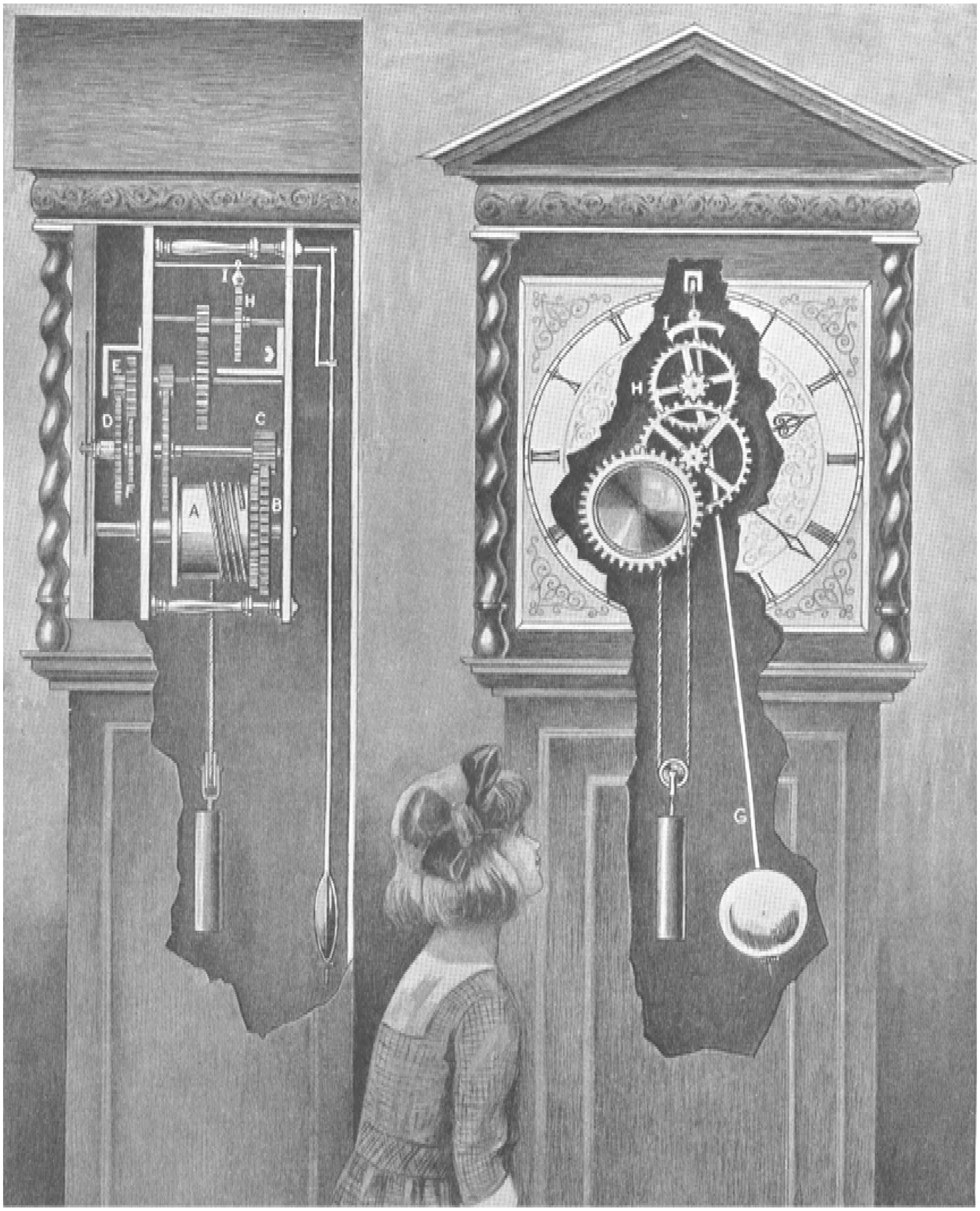
THE LARGEST CLOCK IN THE WORLD



This clock, which is used to advertise a famous brand of soap, stands in Jersey City. It measures 38 feet across its face. The minute hand projects 19 feet from the center, and weighs 640 pounds. In the course of a day, the tip of this hand covers more than half a mile.

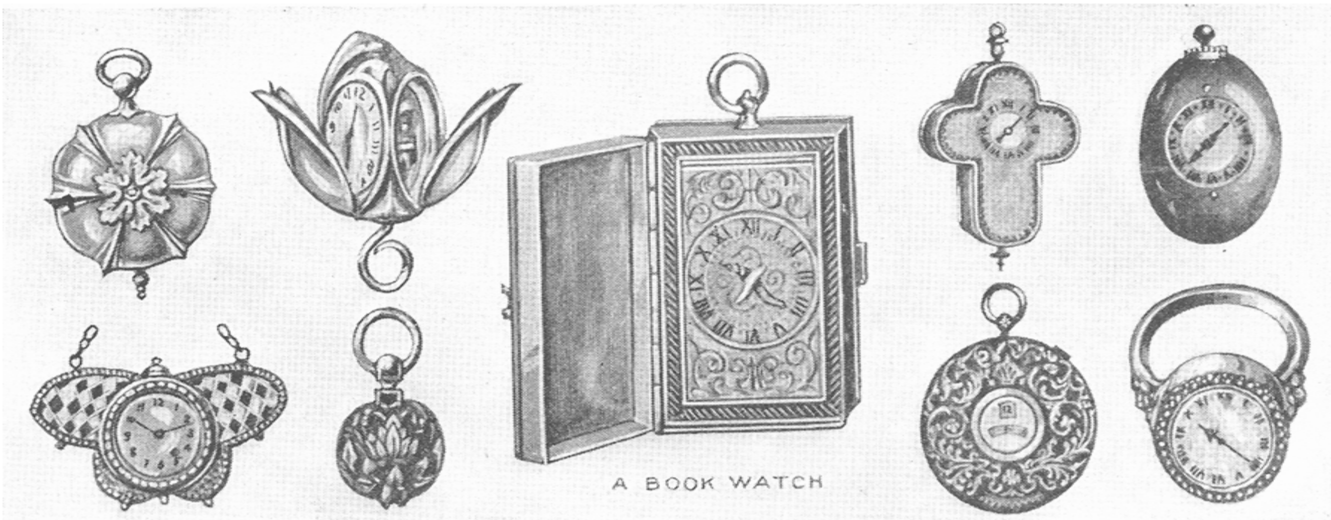
cheaply that a dollar or two will buy a small neat watch which will keep good time for quite a long while. And each part is so standardized and made with such

HOW CLOCKS COUNT THEIR TICKS



The famous “tick, tock” of Grandfather's clock isn't mere idle chatter, by any means. What the clock is really doing all the time is counting the strokes of the pendulum, and it is the swing of the pendulum (G) that makes the tick by causing the anchor (I) to stop the wheel (H) just so often and just so long with every swing. It is as if the anchor said to the wheel each time, “Stop a moment while I put that down-now go on!” The whole train of wheels (shown in side view at the left) is set going by the turning of the drum (A), moved by the weight; then B turns C, which passes the motion on to D, then it goes from D to E, then to F. Owing to the different sizes of these wheels, the minute and hour hands that record their rate of movement on the clock's face turn at different rates. If B has 64 teeth, for example, and C has only 8 teeth, it follows that C must turn eight times while B is turning once. The minute hand is fastened to the end of a rod which is turned directly by the wheel F. Over that rod fits a tube which carries the hour hand. This tube is fastened to the wheel D, which, on account of the intervening gears, turns only 1/60th as fast as F. The other wheels at the top act as brakes, governed by the anchor and pendulum. At the same time they transfer to the pendulum the “kick” that keeps it swinging. Psychologists tell us that the clock really says “tick, tick,” all the time, and not “tick, tock”; but that the mind, which instinctively dislikes monotony, makes two different sounds of it.

MAKING A PET OF THE WATCH



Watches are so small, so friendly, – snuggling in your vest pocket or hanging about your neck, that it isn't strange that they have been made pets of and dressed up in all sorts of quaint forms. And this has been done for a long time. The oval watch at the right, for example, belonged to Oliver Cromwell and the ring watch once adorned the royal finger of George III.

accuracy that it will fit into any watch of the same kind. It is largely through American ingenuity in devising the wonderful machines which make these standardized parts that watches have been put within the reach of all –rich and poor alike.

But while machines make all the parts, a skilled watchmaker has to assemble them and fit them together; for no machine has been invented which will take the place of human hands in this complicated task. It is one of the marvels of human skill to see the speed with which a good watchmaker can fit together the tiny wheels and screws.

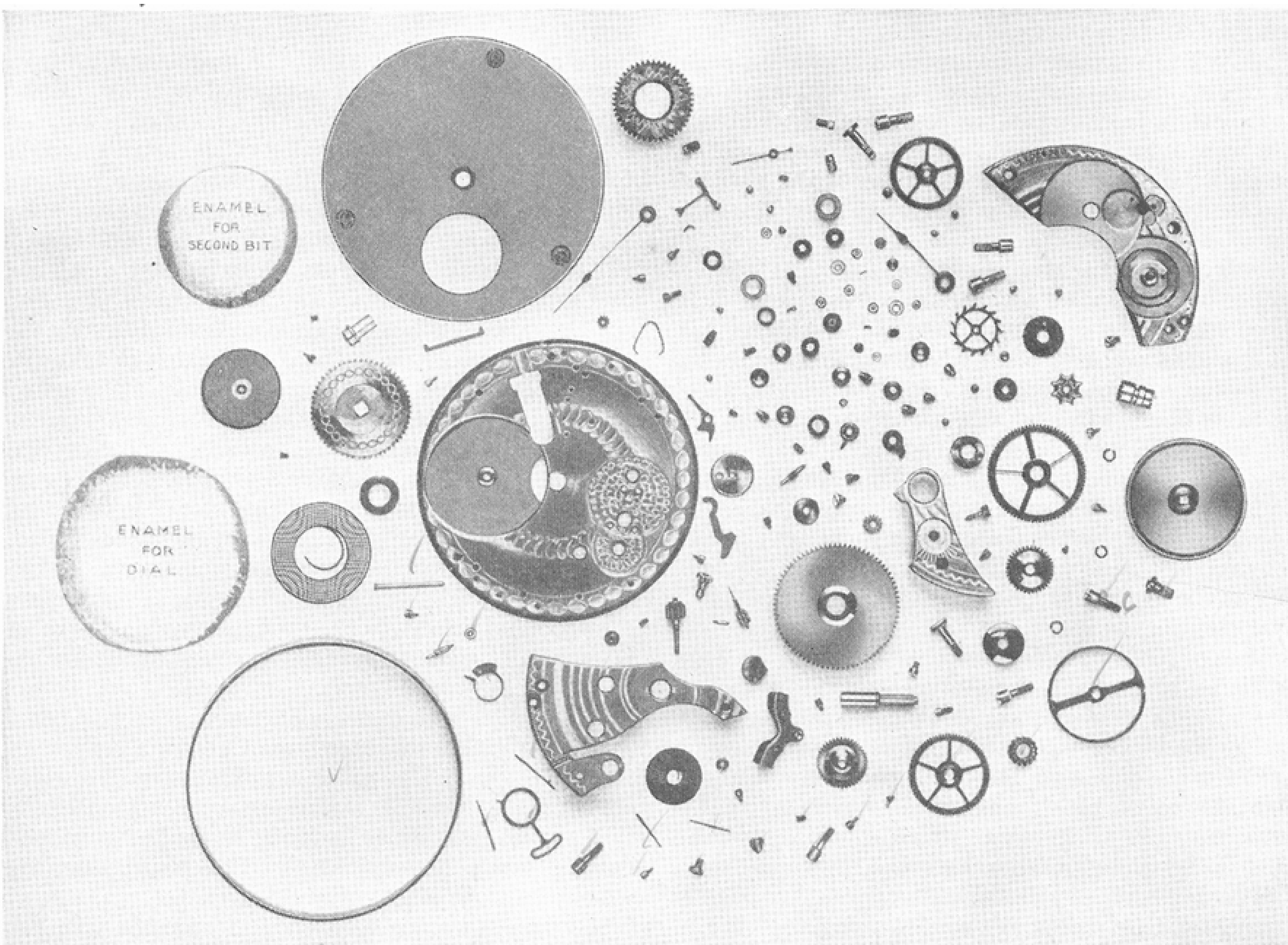
When you visit a watch factory the first things you see are little whirling tables, rows and rows of them, connected by belts with flying pulley wheels overhead. These are lathes, to cut threads on the outside of screws and the inside of screw-holes. Other machines stamp out the round skeleton “blanks” from which the wheels are made. Holes are drilled in the middle of the wheels and a number of them are strung on a rod like beads on a string. Then the rod is clamped into a lathe. The operator slips a belt over the wheel -whir-r-r, how it hums! A steel chisel cuts a row of teeth up and down in all the blanks at once. *Click!* the rod turns a little, and another tooth is cut.

A screw making lathe clips a tiny bit of brass wire from a coil, whirls it under a chisel to point one end, strikes a blow that flattens the other end into a head, and saws a slot across the head for the screwdriver. Then another chisel cuts a threadlike spiral groove from near the head down to the tapering tip. When it is done some of the smaller screws are not much bigger than grains of sand - hundreds of them can be put into a pill box.

A WORLD TIME CLOCK

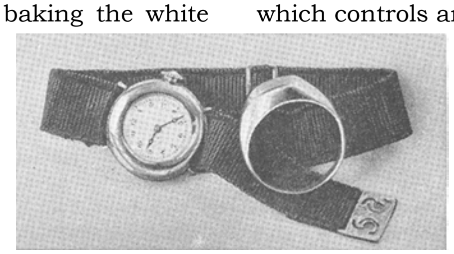
The globe is turned by clock-work and tells what time it is at any given moment in any part of the world.

THE TINIEST WATCH AND ITS MANY TINY PARTS



The picture below shows you one of the smallest watches ever made smaller, in fact, than an ordinary finger ring. The picture at the top shows the parts of such a watch, much enlarged, of course. There are nearly 300 separate pieces in this picture. When you realize that some of those tiny specks are screws with notches and threads cut into them smoothly and accurately, you appreciate the painstaking skill required of the watchmaker. The mere task of putting these pieces together would seem a hopeless undertaking, yet the experts who do this work show great speed.

In a watch factory are also big fire-clay ovens or kilns, as there are in potteries, for baking the white enameled dials. Some dials are gilded or plated with gold, but most of them are enameled on copper plates with fine white porcelain. A pattern printed on a fine transfer paper is laid carefully on the dial and pasted smooth. Into the oven it goes again. The paper is burned up, but the pattern is burned in!



The most delicate parts of a watch are the springs – the mainspring and the hair-spring. They are tiny ribbons of blue steel, so flexible that they can be coiled up tight, but so strong they can pull the wheels along.

Electricity Used in Clocks

When the development of electricity provided a new form of power, clockmakers were among the first to adapt it to their uses. While there are some clocks which operate entirely by electricity, the ordinary "electric clock" is merely a mechanical clock of the old type, which controls an electric current. This current in turn is used to move and regulate the hands on a distant dial or on several dials at the same time. The thousands of "regulated" clocks you see over the country work on still another principle. Every hour they are set automatically by the master clock, and while they provide their own running power they are wound and controlled by electricity.

The hands of great tower clocks are usually turned by powerful and heavy machinery, so they will not be influenced by wind pressure or the weight of ice and snow. This machinery, however, is controlled by delicate devices, often operating in rooms far below the towers.

Exceedingly delicate little instruments, made to keep time with remarkable precision for use in astronomical observations and for determining latitude and longitude at sea, are called *chronometers*, from the Greek words for "time" and "measure," Chronometers, as well as the finer sorts of watches, are "compensated for temperature"; that is, changes in the period of the balance wheel caused by changes of temperature are corrected by providing weights along the rim which are automatically thrown nearer the axis as the temperature rises. *Chronoscopes* or *chronographs* are instruments of great precision made to record as well as measure minute periods of time. They are used in astronomical observations, in determining the velocity of projectiles, and for similar purposes. One type of chronoscope can register time to the 5,000th part of a second. The familiar "stop-watch," used to time athletic events, registers fourths, fifths, or tenths of a second.