Measuring the Billionth of an Inch

Physics

A new instrument of science can measure the billionth of an inch. An iron wire gets hotter when it is magnetized, the heat expands the wire by a billionth of an inch, and science can measure the expansion.

How big is the billionth part of an inch? What fraction of an inch can you measure?

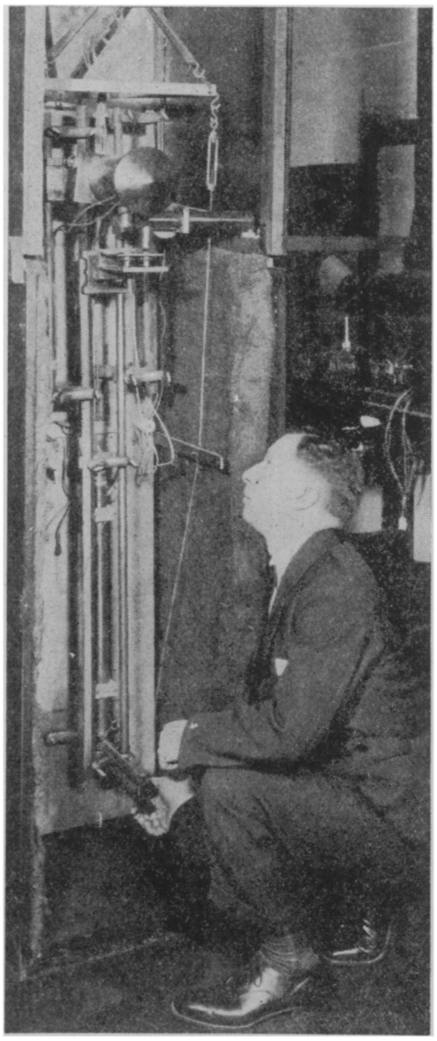
Take up your foot rule and look at it carefully. It is probably marked off in sixteenths of an inch. You could easily estimate a half or a quarter of those spaces. That would enable you to measure 1-32 or 1-64.

If you are going to work very much with small parts of an inch, you will find it more convenient to divide the inch by ten instead of 16, for the same reason that our money is easier to use than English money. Our money is counted by tens, which takes almost no thought. Inches divided by tens can be subdivided by ten again without mental calculation. If your rule is marked in tenths of an inch, you can easily imagine each space marked off again in ten parts, and so can estimate, with little error, to the nearest hundredth of an inch.

The wave-length of one single light-wave is often used as a standard of measure. There are so few really constant quantities in our changing world that it used to be embarrassing to find suitable standards for our units of measures. The original yard is said to have been the length of the arm of a King of Britain. The foot was the length of his foot, and the inch the length from the last joint to the end of his thumb. The king has been dead for many years, if indeed he was not a myth in the first place. His proportions keep marching on because they are a convenient size for measuring things and we have gotten in the habit of using them. The standard to which all yard-sticks are ultimately referred is the distance between two marks on a metal bar suitably preserved in a safe place and carefully guarded against changes of temperature which would expand or contract the bar and so change the measure.

What should we do if the standard yard were to be lost? Its length is a perfectly arbitrary quantity.

When the metric system of measurement was devised, this difficulty was thought to be overcome. The standard meter was defined as a certain exact fraction of the circumference of the earth. But since that day we have found that the earth's crust is changing too much to be a reliable standard. The metric system is too valuable to be depreciated by this discovery, but it, too, now rests on the length of a standard meter, the distance between two scratches on a platinum bar.



T. T. CIOFFI of the Bell Telephone Laboratories, with his photoelectric apparatus for measuring to the billionth of an inch

One of the most important applications of a wave-length of light as a measuring rod is that we are able to define our standards of larger measures in terms of so many times the wave-length of the light of a definite line in the spectrum of the metal cadmium. That is, so far as we know, a definite, unvarying quantity, which can be reproduced at any time.

Light, as every kindergarten child knows, is made up of many colors. The waves which make up the light of each color are different in length from those which make up the other colors. When a small beam of light shines on a ribbed surface, whose roughnesses are nearly as small as the waves of light themselves, the waves reflected from the surface cross and recross like ripples in a stream, and the result is a beautiful band of rainbow colors, because some of the reflected waves combine to form a wave-length which looks blue to us, others to form green, yellow and red. Physicists make diffraction gratings to exhibit this effect by ruling 20,000 to 30,000 parallel lines per inch on glass or metal.

If, however, instead of breaking up the sun's composite white light, pure light of only one wave-length is used, or if the rough surface is just right to send back all the waves of white light without scattering them too much, and if the returning waves are half a wave-length out of step with those they meet, then instead of diffraction of colors we get "interference," and a band of alternate strips of light and darkness.

The most delicate measurements made with light use those light and dark bands, called interference fringes. Dr. A. A. Michelson conceived a remarkable measuring instrument on them when he designed the interferometer.

It might seem that smaller measurements than those with light-waves could not be made. But beyond light waves lie X-ray waves, just like them but much shorter. They are invisible to the eye, but, fortunately, the photographic plate can record them.

In using X-rays for measuring rods, the finest diffraction grating that could be ruled would have ridges a thousand times too coarse to reflect them, but the atoms of matter are about the right size to serve the purpose. If millions of atoms could be lined up in uniform rows, a diffraction grating for X-rays would result.

Physicists had long suspected that the crystals which almost all mineral substances, from diamonds to rock salt, form naturally, have such a regular arrangement of atoms in their make-up, so they tried them out with X-rays, and found the results just what they had expected. The procedure works both ways. Knowing the wave-length of the rays, it is possible to measure the distance between the atoms and

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Billionth of an Inch—*Continued*

to show the pattern of their arrangement. Knowing the arrangement and size of the atoms, the wave-length of the ray may be found.

X-rays have wave-lengths measured in hundred-millionths of an inch. By their use, the former limit of a millionth of an inch has been divided by one hundred. A further division of an X-ray wave-length by ten, and we would have the billionth of an inch.

Quantities of this size are not unknown to physicists who study the series of radiations which includes radio waves, heat waves, light waves, X-rays and the other shorter waves recently studied by Dr. R. A. Millikan and named cosmic rays.

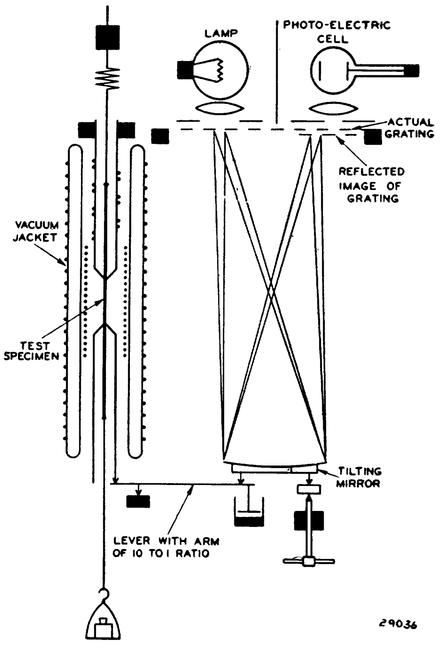
Not wishing to deal with such large fractions as would be necessary if the short waves were measured in parts of an inch or a centimeter, they have other units more in keeping with the size of the quantities they have to measure. The smallest of these, the Angstrom unit, is about a quarter as large as the billionth of an inch.

The new apparatus which measures the expansion of an iron wire to the billionth of an inch is the invention of T. T. Cioffi of the Bell Telephone Research Laboratories. It is used to measure one of the effects of magnetization, because magnetic phenomena play such an important part in telephony.

The Cioffi apparatus is fundamentally a mechanical and not an optical method of measurement. The iron wire which is to be magnetized is hung in a cylinder made like a thermos bottle, so that change of temperature of the air may not cause any part of the expansion to be measured. A coil of wire around it carries the electric current which, when turned on, will magnetize the iron.

When the current flows the iron becomes magnetized. Accompanying the magnetization is the phenomenon of hysteresis which appears as heat. This is the real quantity to be measured. The heat makes the iron wire expand to the extent of about a billionth of an inch. The heat caused by the hysteresis can be measured by the amount of expansion of the iron wire, provided that expansion can be measured accurately enough. The end of the wire is attached to a very delicate lever which will magnify the movement by ten.

Theoretically it would be possible to construct a train of levers, each magnifying the motion of the one before it, as large as one would wish.



HOW TO MEASURE TO A BILLIONTH OF AN INCH. Diagram of the apparatus invented by T. T. Cioffi, of the Bell Laboratories, for making extremely delicate measurements

Practically, however, the friction of the moving parts and the mechanical errors make such a method quite impossible. It is better to use a beam of light for a lever, as it has no friction, and requires no bolts and screws to hold it in place.

So the hundredth-inch push of the lever attached to the magnetized iron wire is used to tilt very slightly one side of a concave mirror, which forms part of such an optical lever. A beam of light from an electric lamp shines upon one side of this mirror, but on its way passes through a piece of glass on which are drawn a number of black lines. Each line and the clear space between each two lines is 1/32 of an inch wide. Bands of alternate light and shadow thus fall upon the mirror and are reflected by it.

The concave mirror does not reflect light back in straight lines to its source, but toward a point out somewhere in space in front of its center. A sheet of paper may be held at that point, called the focus, and an inverted image of the source of the reflection be seen on it. If the eye is placed still farther on, and looks at the focus, the image can be plainly seen hanging in air and entirely transparent, as ghosts are supposed to look.

In the Cioffi apparatus the image of the light and dark lines reflected by the mirror is made to fall on another part of the real sheet of ruled glass. If the apparatus is so adjusted that the dark shadows of the image fall exactly on the dark lines of the glass, the maximum amount of reflected light shines through the glass. If, on the other hand, the image so falls that its bright parts fall on the dark lines, its dark spaces will cover the clear spaces on the glass screen, and none of the reflected light will pass through.

Behind the grating, and cut off from the nearby electric light, is a photo-electric cell, the heart of the whole measuring device. It looks something like an electric light bulb, perhaps like a radio tube, as it is partly silvered inside. Within it is a film of the element potassium, which has very unusual electric powers. Instead of supplying that bulb with electricity and getting light, you reverse the process. Let light shine on it and you will get electricity. The amount obtained is very small, but it can be made to measure itself. It can thus, in the Cioffi apparatus, measure a billionth-of-an-inch expansion of the magnetized wire.

Before the wire to be measured is magnetized, the apparatus is so adjusted that the images of the black lines reflected by the mirror fall on the real black lines of the screen. The cell is then giving out current as strongly as though the lamp were shining directly upon it through the ruled glass.

Throw the switch, magnetize the iron. As the iron expands it pushes the 1 to 10 lever and the lever tilts the mirror about a hundredth of an inch. The image of the grating reflected by the mirror is slightly displaced on the screen. Part of the clear spaces through which light was shining before are now covered by the dark bands of the image. Less light is now shining through the screen to the photo-electric cell. The cell, accordingly, gives off less current. The lessening of the current shows on the indicator, and after a simple calculation, the exact change in length of the magnetized wire is known.

Science News-Letter, May 5, 1928

The best wearing fur is otter.

A considerable proportion of the people of Siberia are farther from the seat of their government at Moscow than they are from the center of the earth.