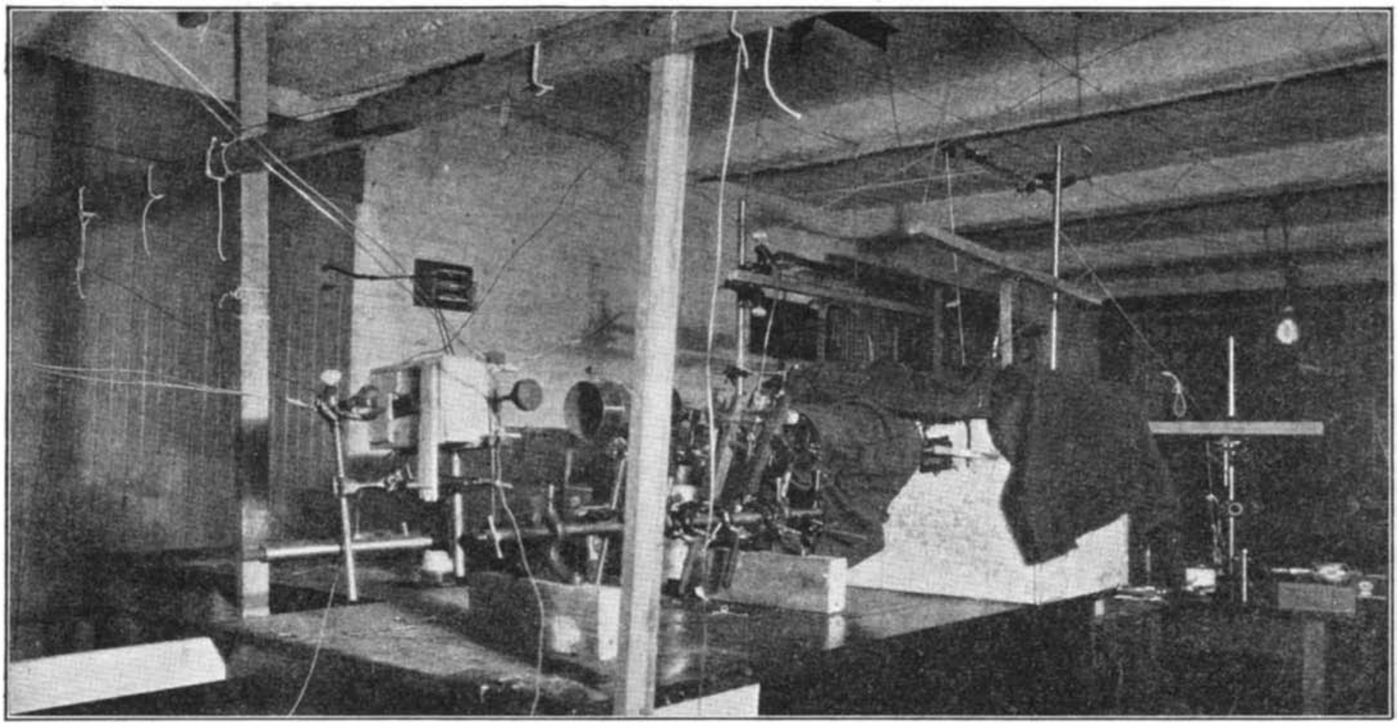

THE APPARATUS EMPLOYED IN THE EXPERIMENT AT SLOANE LABORATORY AT YALE

The photo-electric cell is in the wooden box in the foreground. To the left of the box are the Kerr cells, the lenses and the spark gap. The latter is connected to a system of wires, which control the timing, extending out of the photograph for a distance of 20 yards

What Is Light?

With An Apparatus Which Turns Light Off and On In One Thousand Millionth of a Second, It Has Been Shown That Light Quanta Must Be Less Than a Few Feet In Length

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LIGHT is one of the most familiar physical realities. All of us are acquainted with a large number of its properties, while some of us who are physicists know a great many more marvelous characteristics which it displays. The sum total of our knowledge of the physical effects produced by light is very considerable, and yet we have no satisfactory conception of what it is.

At first sight it seems a bit odd that we should fail to understand something about which we know a great deal. A moment's thought resolves the paradox, however, for we realize that a thing which exhibits a large number of different characteristics is most difficult to form a picture of. And so, from time immemorial, man has wondered about the nature of light.

More than two centuries ago Newton conceived that light was corpuscular in nature; he believed that light consisted of little darts shooting through space. Others regarded light as a wave phenomenon; in a manner analogous to the propagation of waves in water, light waves were propagated in a medium pervading all space, called the ether. A lively controversy ensued between the adherents of these two conceptions of the nature of light and as new experiments were carried out revealing more of its properties, it appeared that the undulatory theory accounted for many things quite unintelligible on the corpuscular hypothesis.

TOWARDS the close of the nineteenth century, physicists settled down to the complacent notion that they fully understood the nature of light—for the picture of waves flowing in the ether explained practically everything known about light at that time.

They were soon disturbed from their complaisance, however, by the discovery of some effects produced by light which were quite unintelligible on the undulatory theory. For example, it was found that when a metal surface is illuminated by light of a suitable color, electrons are ejected from the surface with velocities depending only on the color of the light and quite independent of the intensity of the light. This phenomenon is now called the "photo-electric effect." It was quite as surprising to observe that electrons were ejected with great velocities from metals by faint light as it would be to observe a small ripple on the surface of the ocean suddenly causing a timber to be torn loose from the side of a ship and thrown high into the air.

The observation that the velocity with which the light ejected the electrons was quite independent of the intensity of the light, but depended only on its color (wavelength) strongly suggested that Newton was right after all; for if light consists of darts of energy of definite amounts shooting through space, it did not appear at all improbable that a "collision" of such a light dart with an electron would result in the absorption of the entire energy of the dart, the electron acquiring thereby a definite velocity.

As time has progressed, many additional phenomena concerned with the interaction of light and matter have been discovered which are impossible of understanding on the wave theory and which have compelled scientists to revert to the conception of light which was in Newton's mind centuries ago. Such recent facts of observation suggest that light beams contain amounts of energy which are exact multiples of a definite smallest amount—a light quantum—just as matter seems to be made up of definite multiples of a smallest particle of matter or electricity—the electron. Thus, we have atomicity of light as well as atomicity of matter and electricity.

A SEEMINGLY very peculiar circumstance exists in this modern quantum theory of light, for the very thing concerned in the theory is entirely obscure. The quantum theory tells only what effects the light quanta produce when they are interacting with matter, and does not tell very much about the quanta themselves. It is as though in describing an artillery battle we told where the shells went and the damage they produced, but refrained from mentioning how large the shells were and how they were constructed to produce the explosive effects which were observed. It would have facilitated the description of the battle if the size and kind of ammunition were known, and in just this way the quantum theory of light would be much more complete if the precise physical nature of the quanta was given.

And so the question of the physical nature of quanta presents itself. Are they a yard or a mile or an inch in length, or are they of infinitesimal dimensions? Many experimental facts can be interpreted as indicating that quanta are at least a yard in length, yet nothing really certain can be inferred from past observations. The dimensions in space of the quanta remain complete mysteries.

THERE is at least one way of measuring the length of quanta, provided that the scheme may be carried out in practice, which is essentially as follows: Suppose one had a light shutter that could obstruct or let pass a beam of light as quickly as desired. Such an apparatus would be able to cut up a beam of light into segments, much in the same way that a meat cutter slices a bologna sausage. It is clear that if the slices of the light beam so produced were shorter than the light quanta in the beam, the short light flashes coming from the shutter would contain only parts of quanta. In effect, the apparatus would be cutting off the heads or tails of quanta. To eject an electron from a metal surface a whole quantum is necessary because part of one quantum does not contain enough energy to do the trick. One therefore would definitely establish an upper limit to the length of light quanta by simply observing the shortest light flashes able to produce a photo-electric effect.

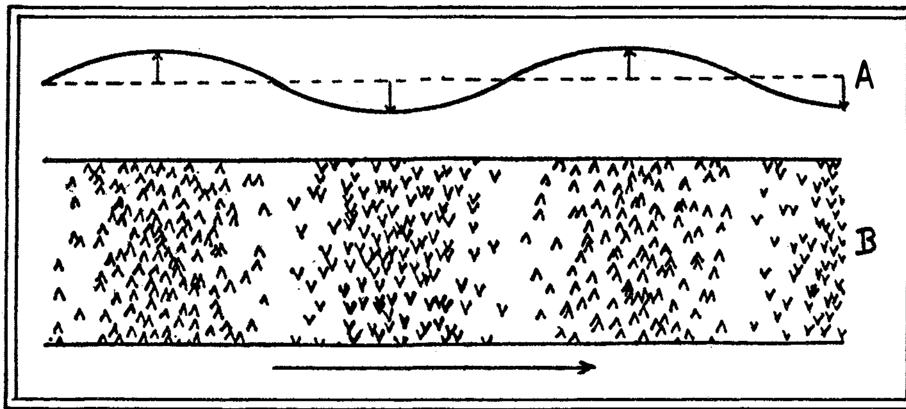
Since light travels with a velocity of 186,000 miles per second — fast enough to go around the world more than seven times in one second—a light shutter capable of cutting a beam into segments a few inches in length obviously must operate with tremendous rapidity. To produce a slice of light one inch or three centimeters long, for example, the shutter must remain open only one ten thousand millionth of a second. A camera shutter which remains open for one ten thousandth of a second is considered very fast indeed. A shutter able to produce these short light flashes is necessarily a million times as fast.

ONE does not have to be very familiar with mechanical things to realize that no mechanical shutter could possibly work at this speed. Earlier in this article it was noted that quanta are probably not much longer than a yard or so, and hence mechanical difficulties would seem to render it impossible to carry through the experiment. Happily, however, Nature has endowed matter with properties other than purely mechanical ones. By making use of a certain electro-optical property of some liquids a device was conceived which actually operated as a shutter, turning on and off in about one ten thousand millionth of a second. To understand fully the operation of this electro-optical shutter a considerable familiarity with optical things is required. The general idea, however, may be made clear from the following account.

A beam of light readily passes through two crystals of tourmaline

THE TWO EXPERIMENTERS, DR. LAWRENCE AND DR. BEAMS

Dr. Lawrence (left) holds in his hands the photo-electric cell which creates a current automatically when light impinges upon it. *Dr. Beams holds a double Kerr cell containing brass plates and carbon bisulfide. This is described in the text of the article*



TWO CONCEPTIONS OF THE NATURE OF LIGHT

A *is the wave theory, the arrows indicating the direction of the electric field. In* B, *each check mark represents a quantum moving to right and generating a force as in* A

when the crystals are placed exactly similarly along the path of the beam, but it cannot pass the second crystal if it is turned about the light beam as an axis through an angle of 90 degrees. The light from the first tourmaline which possesses this remarkable property of being unable to pass through a second crystal placed a certain way in the path is called plane polarized light.

It is known also that if liquid carbon bisulfide is placed between the crystals these polarization effects are unchanged except when the liquid is in a strong electric field. Then it is found that no matter how the second tourmaline crystal is twisted, a part of the light passing through the first crystal and through the carbon bisulfide manages to pass through the last tourmaline.

IT is further true that on introducing a second tube of carbon bisulfide between the tourmaline crystals in which there is an electric field of equal intensity but having its direction at right angles to the direction of the field in the first cell, the combination acts as though only air filled the space between the crystals. That is to say, light does not pass the combination when the second crystal is suitably oriented.

These facts make it clear that the problem of allowing light to pass through for a very short time is simply reduced to finding a way of turning off the electric field in one of the carbon bisulfide cells a corresponding length of time before cutting off the field in the other.

Thus, this scheme makes it possible to produce light flashes of one thousand millionth of a second duration, provided a means is at hand to cut off an electric field across one pair of condenser plates immersed in carbon bisulfide one billionth of a second before cutting off the voltage across a similiar pair in another cell of the liquid. Perhaps one would at sight be tempted to regard as nearly impossible the feat of turning off two electric fields in such a way that it was known that one dropped to zero only one thousand millionth of a second before the other—or as nearly impossible as would be the construction of a mechanical light shutter able to turn on and off a light beam in the same short time. But again Nature happily has provided electricity with properties which make the stunt quite easy.

A finite time is required for the propagation of electrical effects along wires. For example, if two wires are attached to a battery, the other ends of the wire are affected, that is, they acquire a voltage, at a time after the wires were attached to the battery equal to their length divided by the velocity with which electrical effects are propagated along wires. This velocity is very nearly the same as the velocity of light.

AND so, if wires are attached to the two pairs of condenser plates immersed in carbon bisulfide and charged to a high voltage, and the other ends of the wires are short-circuited, one pair will discharge before the other if the length of wire to one is greater than to the other.

In the actual experiment, the short-circuiting was accomplished by having the wires attached across a spark gap. The moment a spark jumps, the resistance of the gap is reduced.

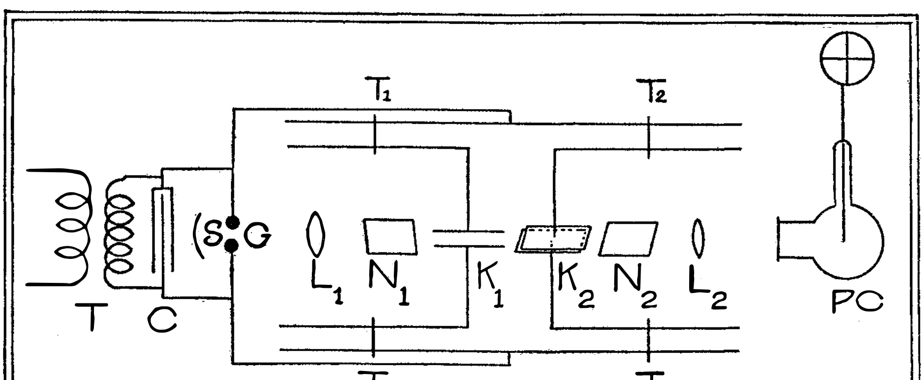


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DIAGRAM OF THE SET-UP SHOWN ON PAGE 301

Two lenses L; *two Nicol prisms* N; *two sets of parallel brass plates* K; *two sets of variable wire lengths* T; *and a potassium photo-electric cell* P C, *make up the bulk of the equipment*

Thus the time between the disappearance of the electric fields in the two tubes of carbon bisulfide was varied by simply increasing or decreasing the lengths of the wires connecting one of the cells to the spark gap. It is outside the scope of this article to describe the operation of the shutter in further detail, but the general idea has been made clear.

The short flashes of light produced in this way were allowed to fall on a sensitive photo-electric cell, and it was found that the cell responded to the shortest flashes obtained—which were only a few feet in length.

Of course the short flashes did not produce as great a photo-electric emission of electrons, because the total amount of light energy was less. But the important observation was that the shortest light flashes were able to eject some electrons from a metal surface.

THE importance of this simple experimental observation cannot be overestimated, for it definitely demonstrated that light quanta are less than a few feet in length and probably occupy only very minute regions of space. The experiment also showed that an electron absorbs enough energy in one thousand millionth of a second to fly out of a metal with a terrific velocity.

This result is in accord with very recent theories of light. Dr. W. F. G. Swann, Professor J. C. Slater and others have a short time ago suggested that light has a dual nature; that there are both waves and quanta, the waves merely determing where the quanta may go. Quite independently, Sir J. J. Thomson also has developed this idea in considerable detail. According to Professor Thomson's views, the quanta are little rings of electrical lines of force, like doughnuts riding along on the waves, so that in the short light flashes of the experiment described above there were many whole quanta able to knock out electrons from a metal—just as the experiment has demonstrated.