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THE DEVELOPMENT AND USES OF HIGH SPEED PHOTOGRAPHY

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SUMMARY

This paper deals with the development of speed in photography from the latter part of the nineteenth century up to the present time.

The material is divided into two parts, the first dealing with the mechanic~~al~~s of obtaining very short exposures, and the last part with the development of speed photography through the use of flashes of light of very short duration.

The applications of each camera are dealt with in the discussion of the camera.

Inadequate Summary!

Subject of Thesis – poor choice – should deal with some definite project!

THE DEVELOPMENT AND USES OF HIGH SPEED PHOTOGRAPHY

During the past fifty years photography has developed from an unreliable toy to an integral part of engineering and research. There are several reasons for this growth. First, there is the fact that a photograph furnishes a permanent record of a large number of details without requiring the time necessary to make a detailed drawing. Secondly, a photograph properly made records things as they actually are as against the eye which tends to observe only those things which the eye is directed to look for by the mind. Thirdly, a photograph of a moving object shows clearly the position of the object at an instant of time (sometimes less than one millionth of a second in duration), whereas the eye sees only a blur of continuous motion. In this paper the latter subject will be discussed, that is, the development of speed in photography.

There are four factors which limit the shortness of the exposure in a camera. They are the speed of the lens; the intensity and quality of the light on the subject; the speed of the emulsion on the film; and a method of exposing the film for a very short period of time. In the very early experimental days of photography the emulsion and the lens were so slow that exposures of several seconds or minutes were required and obtaining a suitable mechanical shutter was not a problem. However toward the latter part of the nineteenth century the emulsions and the lenses were improved to such an extent that the ordinary mechanical shutter became useless for very high speed work.

TYPES OF MECHANICAL SHUTTERS

Mechanical shutters may be divided into two general classifications; those which operate at or near the optical center of the camera; and those which operate near the focal plane of the camera. Each of these types has its own advantages and disadvantages.

The shutter which operates at the optical center of the lenses is advantageous in that all portions of the plate or sensitive film are exposed through the same period of time. However as this type operates by having an opening in a flat piece of metal move across the film or by causing two or more leaves to move outward exposing the film and then inward closing off the light, at high speeds the camera is not operating at full aperture throughout the exposure and hence the effective speed of the lens is less than indicated.

In the focal plane type of shutter the plate is exposed by allowing a piece of metal or cloth containing a narrow slit to move rapidly across the film a short distance in front of it. The exposure may be controled by varying the width of the slot and the speed with which it travels across the plate. A high speed and a narrow slot will give a short exposure, and conversely a low speed and a wide slot will cause the exposure to be relatively long. For instance, if the slot has a width of one tenth of an inch and travels at a speed of fifty inches per second every point on the plate will be exposed for a period of one-five hundredth of a second. This camera has the advantage that the camera is operating at the same aperture throughout the exposure. However all of the portions of the plate are not exposed at the same instant and if the subject is moving rapidly its image will be distorted. In the case cited above the exposure was one-five hundredth of a second but if the plate were seven inches long one side of the plate would be exposed fourteen-hundredths of a second after the other side.

DAYLIGHT PHOTOGRAPHY WITH A MECHANICAL SHUTTER

One of the first means of obtaining photographs of very short duration by a mechanical shutter was perfected by Charles Francis Jenkins, who began his experiments in 1890. In these experiments Jenkins located a number of lenses on the periphery of a wheel. The image from the lens was reflected by a prism onto a strip of moving film and the lenses moved at a speed such that the velocity of the film and the tangential velocity of the lens as it passed the prism were the same. Due to this the image was stationary with respect to the film and the exposure was dependent on the speed of the revolving wheel. There existed a very slight blur in the negative caused by the fact that the lens moved in an arc rather than in a straight line. However with a wheel of fairly large diameter this effect was negligible.

With this camera Jenkins was able to obtain up to three thousand two hundred images per second with exposures of as little as one-twenty thousandth of a second. The camera was valuable in that it took a series of pictures of rapidly moving objects such as projectiles rather than one single picture as is the case with some of the methods to be treated later. Another advantage of was the fact that the camera was complete in itself and no special laboratory conditions such as special lighting or spark discharges were necessary to obtain a series of photographs. Due to the nature of the camera it has a splendid ratio of time of exposure to time of operation. As it takes three thousand two hundred pictures a second and each exposure is one-twenty thousandth of a second the total time of exposure is sixteen-hundredths of a second per second.

Another type of daylight camera was devised in 1917 in Germany which is in reality a modified moving picture camera. The shutter of the ordinary moving picture camera is a circular metal disc with a slot cut in it as shown in Figure 1. The film is stationary while the slot is in front of the film and the film is being exposed. During the interval when the film is not being exposed it is advanced one frame. The number of pictures taken and the exposure given each picture is controlled by the speed with which the disc revolves. The regular value is sixteen frames per second. However this is not suitable for photographing projectiles, and even if the speed is boosted to one hundred and twenty frames per second the results are not satisfactory. At this speed continuous operation is not satisfactory and even if it were, the that the velocity of the film and the tangential velocity of the lens as it passed the prism were the same. Due to this the image was stationary with respect to the film and the exposure was dependent on the speed of the revolving wheel. There existed a very slight blur in the negative caused by the fact that the lens moved in an arc rather than in a straight line. However with a wheel of fairly large diameter this effect was negligible.

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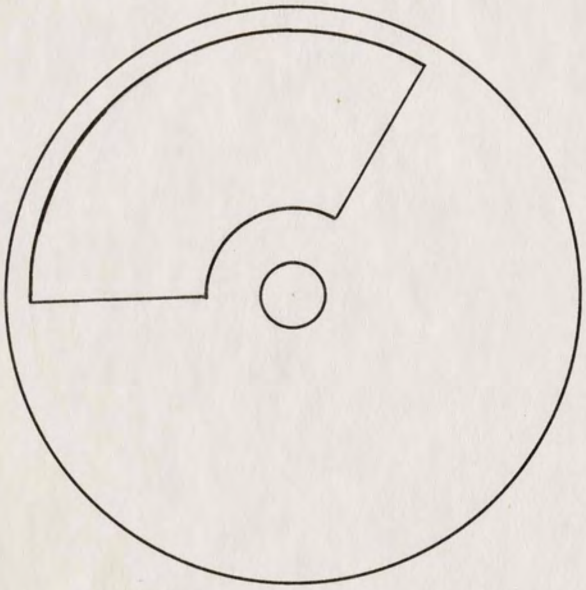

Figure 1

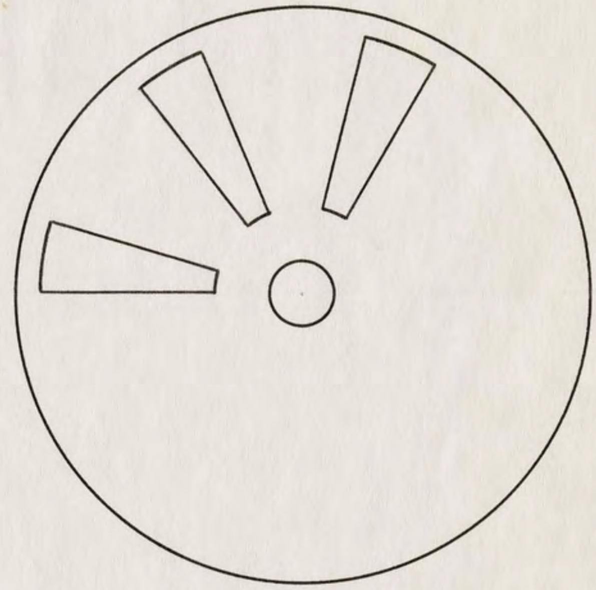

Figure 2

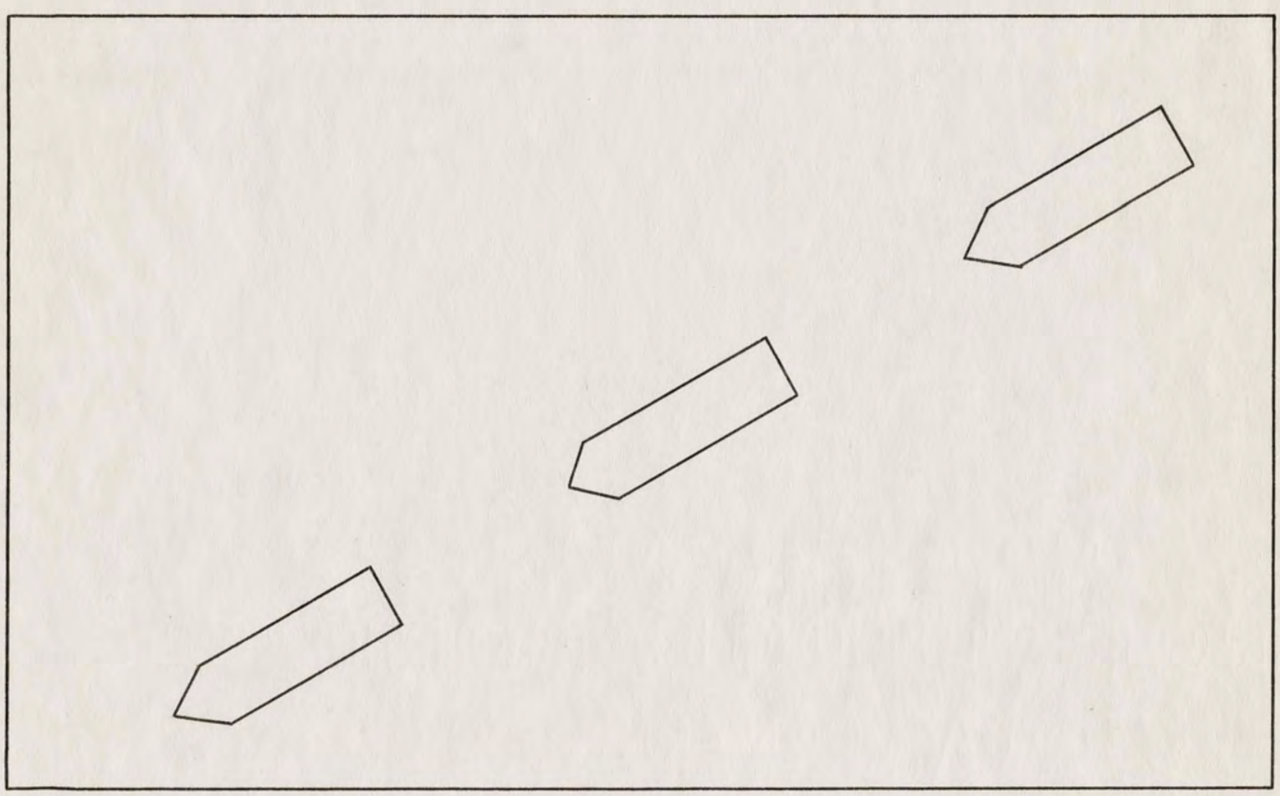

Figure 3

projectile is blurred and the interval between frames is so great that the projectile might pass entirely through the field of the camera while the shutter is closed. Because of this the shutter was changed to the type shown in Figure 2 in which the single opening is replaced by three narrower ones. When this type is used three exposures are made on each frame thus giving the relative position of the projectile at three instants as shown in Figure 3. This facilitates the calculation of the trajectory of the shell and any deviation of the axis of the shell from its path at that instant. With this type of shutter the projectile may be photographed three times while it is in the field of the camera and the distance between the successive positions of the shell may be no greater than twice its length.

When it is desired to obtain pictures with a phase difference less than in the case above the camera is modified further so that the shutter is as it appears in Figure 4. Each of these four staggered slots is behind a separate lens, and in operation four pictures are made across the width of of the film with a phase difference of one - twelve thousandth of a second. Figure 5 illustrates the type of picture which is obtained by this system and it may be seen that the projectile moves very little between the successive pictures.

This camera is especially useful in obtaining pictures of large projectiles in flight, as such pictures could hardly be made in a laboratory under controlled light. In order for the shell to be distinct it should be photographed against a brilliant background such as the sky or snow.

Still another method of stopping a rapidly moving object was devised by H. R. Curtis, W. H. Wadleigh, and A. H. Sellman in 1924. A diagram of their camera is shown in Figure 6. The film drum contains one loop of film on the surface and the film drum rotates at such a speed that the surface of the film on which the image is east is moving in the same direction and

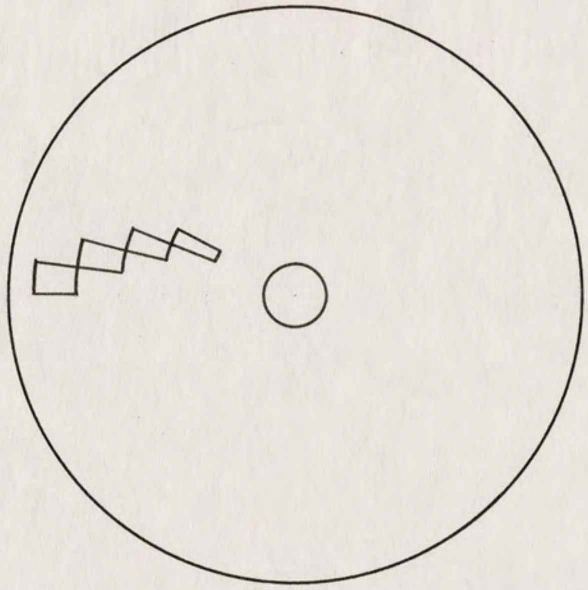

Figure 4

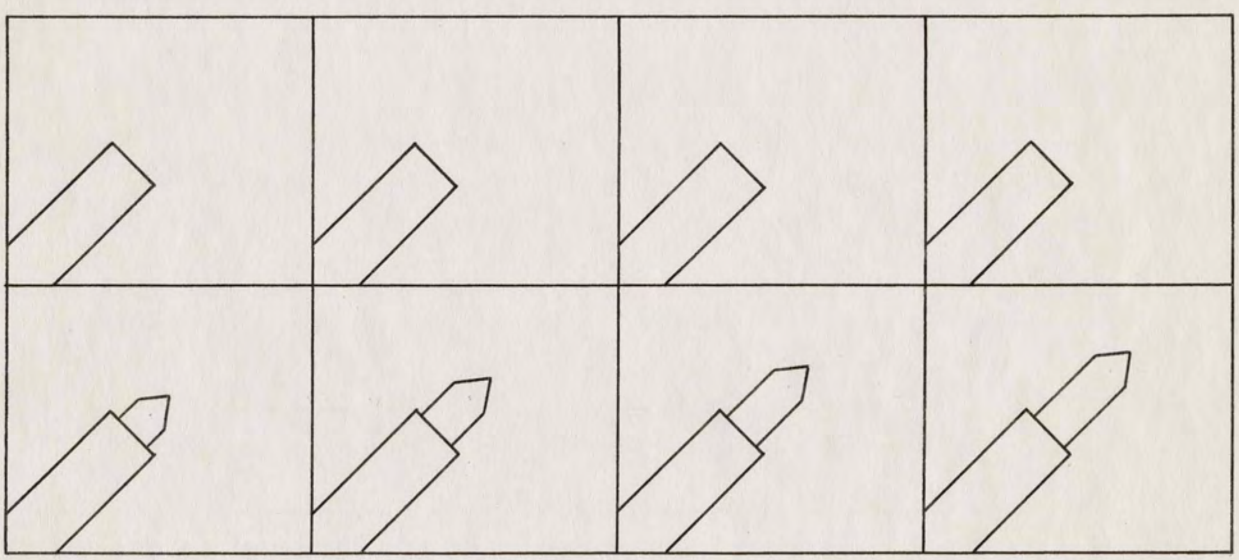

Figure 5

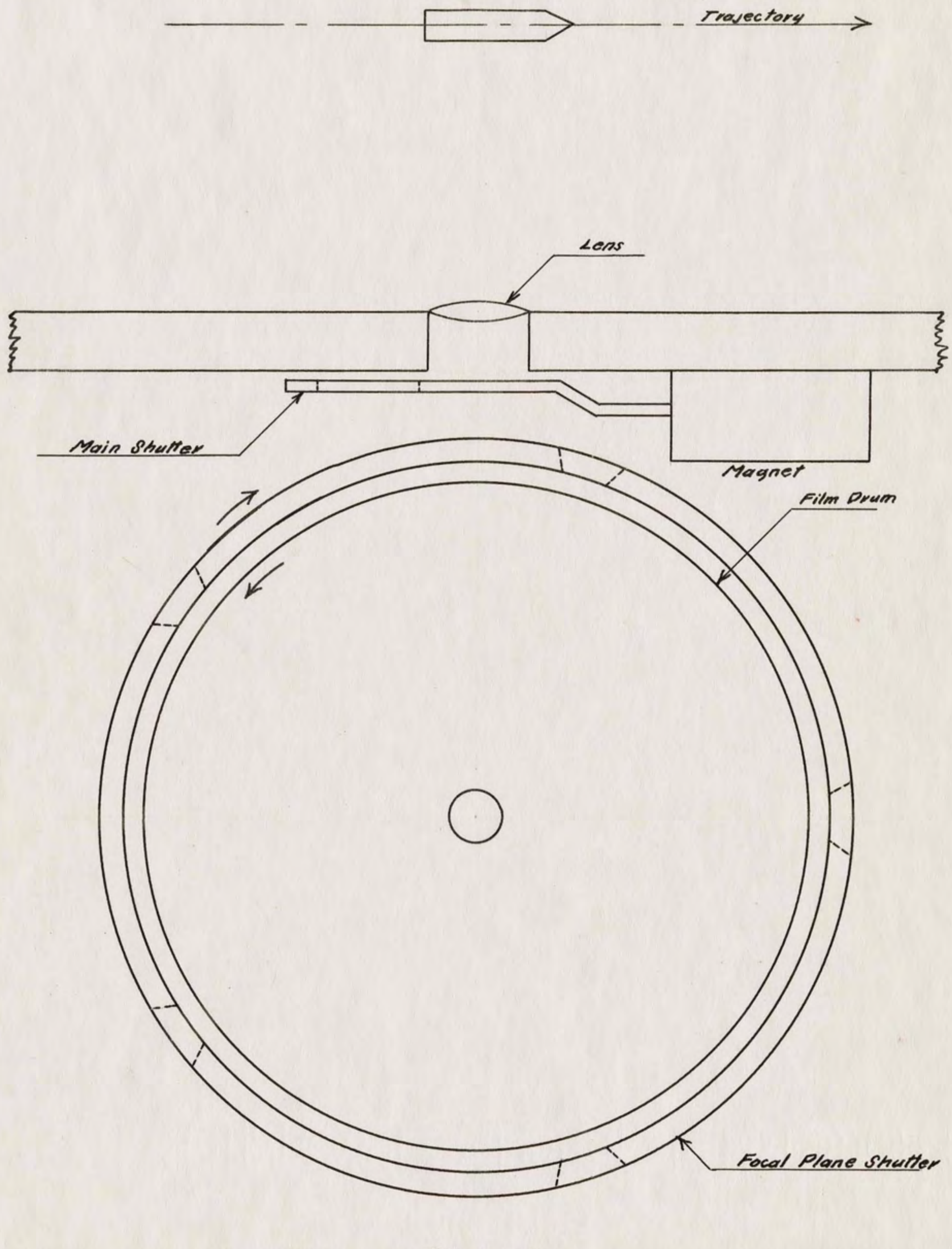
Trajectory
Lens
Main Shutter
Magnet
Film Drum
Focal Plane Shutter

Figure 6

at the same speed that the image is moving. The focal plane shutter is another cylinder which fits closely over the film drum and contains narrow slots parallel to the axis. The shutter revolves in the opposite direction from the image and at a speed several times as great. Since the film is moving at the same speed that the image is moving, the image is stationary with respect to the film. The slot passing in front of the lenses controls the length of the exposure. The fact that the image is stationary on the film means that a longer exposure may be obtained without blurring than could be obtained if the image were moving. Of course the approximate velocity of the moving object must be known in order to adjust the speed of the film drum.

The main shutter is placed behind the lens for the purpose of exposing the film at the proper instant and then closing the aperture after one complete revolution of the film drum. When it is desired to make a series of pictures with a very short time interval in between them, the camera is modified by replacing the single lens by a number of lenses and the single slot in the focal plane shutter by the same number of staggered slots, as shown in Figure 7a. If five lenses are used the camera will take five times as many pictures in a given length of time, and there will be five rows of pictures around the film as shown in Figure 7b.

The field in which this camera might be used would be rather specialized, as the velocity of the subject must be known and the motion must be in a straight line. Like the above cameras it requires no special lighting conditions, and may be used under natural light. The features of the camera make it especially useful in work with projectiles. With it it is possible to study the yaw of the projectile, its velocity, the speed of rotation, and the blast.

A method similar to that above was developed in France in 1932.

In this camera 35 millimeter film ran through the camera in the manner that it does in an ordinary moving picture camera except that the film moves continuously through the camera rather than stopping at each frame . The focal plane shutter is of the same type shown in Figure 3, there being a large number of rows of slots rather than just one. When the camera was made with four concentric rows of slots there were four lenses, and four rows of images were formed on the film staggered similarly to the pictures shown in Figure 7a. The individual pictures are quite small , the space ordinarily occupied by one image contains 12 smaller ones. By varying the speed of the shutter, up to 12,000 pictures a second may be obtained. This camera was used in France largely for the purpose of studying the flight of insects.

Despite these accomplishments in mechanically controlled photography it is still difficult to obtain a fair sized clear picture of a rapidly moving object at the precise position that the picture is wanted. In order to get the subject at a certain point it is necessary to photograph it in a whole series of positions.

THE DEVELOPMENT OF LIGHT CONTROLLED PHOTOGRAPHY

Over fifty years ago it occurred to experimentors in photography that a plate might be exposed to light by leaving the camera in a dark room with its shutter open and then flashing a light off and on in the room. The length of the exposure would then be the length of time that the light remained on.

ELECTRIC SPARK PHOTOGRAPHY

In 1893 C. V. Boys delivered a talk telling of his accomplishments in the field of spark photography. He had patterned his apparatus somewhat after that of Professor E. Mach's. The electrical circuit of Professor Mach's apparatus consisted of two spark gaps and a condenser in series.

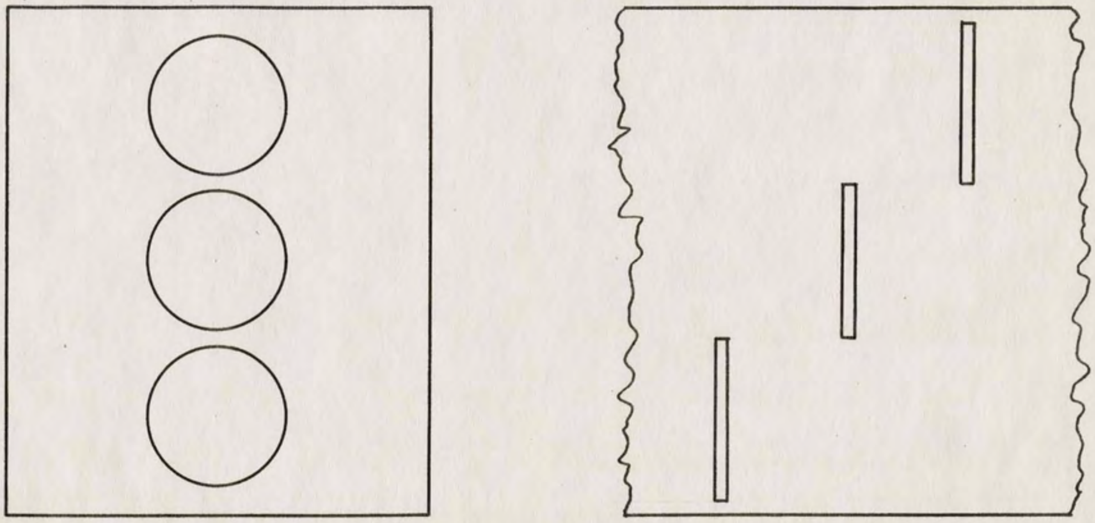

Figure 7(a)

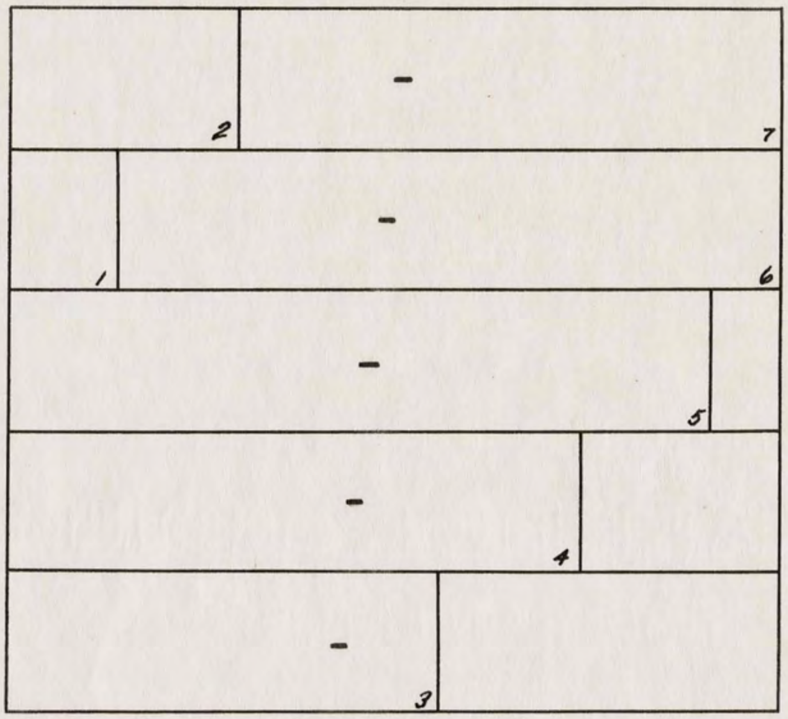

Figure 7(b)

One of the spark gaps was located on a point in the path of the projectile and the other was located in front of a lens so that its light would be concentrated on the projectile. On the other side of the first spark gap was the camera focused on the first spark gap. The condenser would be charged to such an extent that the voltage would be almost enough to cause a spark to jump the two gaps. Then with the shutter of the camera open the gun would be fired. The bullet reaching the spark gap in its path would short circuit it and cause a spark to jump the second gap, thus giving a brilliant light of a short duration. The flash of light would accomplish the same result as a shutter being oppenned for the same length of time, and the bullet would be photographed.

Boys' apparatus is shown in Figure 8. It consisted of a condenser constructed from a square foot of tinfoil placed on either side of a piece of glass, in series with two spark gaps E and E'. C' is a small capacity Leyden jar, S is another spark gap in the path of the bullet and the dotted line represents a string wetted with calcium chloride. The system is charged until both of the spark gaps are about to break down and the gun is fired. When the bullet short circuits the gap S. The voltage is able to break down the gap E'. With this gap broken down the large condenser can now discharge through E causing a brilliant spark lasting about one millionth of a second. Very little of the charge goes through S as the condenser C' is quite small and the string is practically a non-conductor during the discharge. The spark generated at E being small casts a sharp shadow of the bullet on the pl plate.

With this apparatus Boys conducted a series of experiments to determine just how the apparatus should be constructed to obtain the maximum illumination with a minimum duration.

The original apparatus was set up with ordinary wire for the connect-

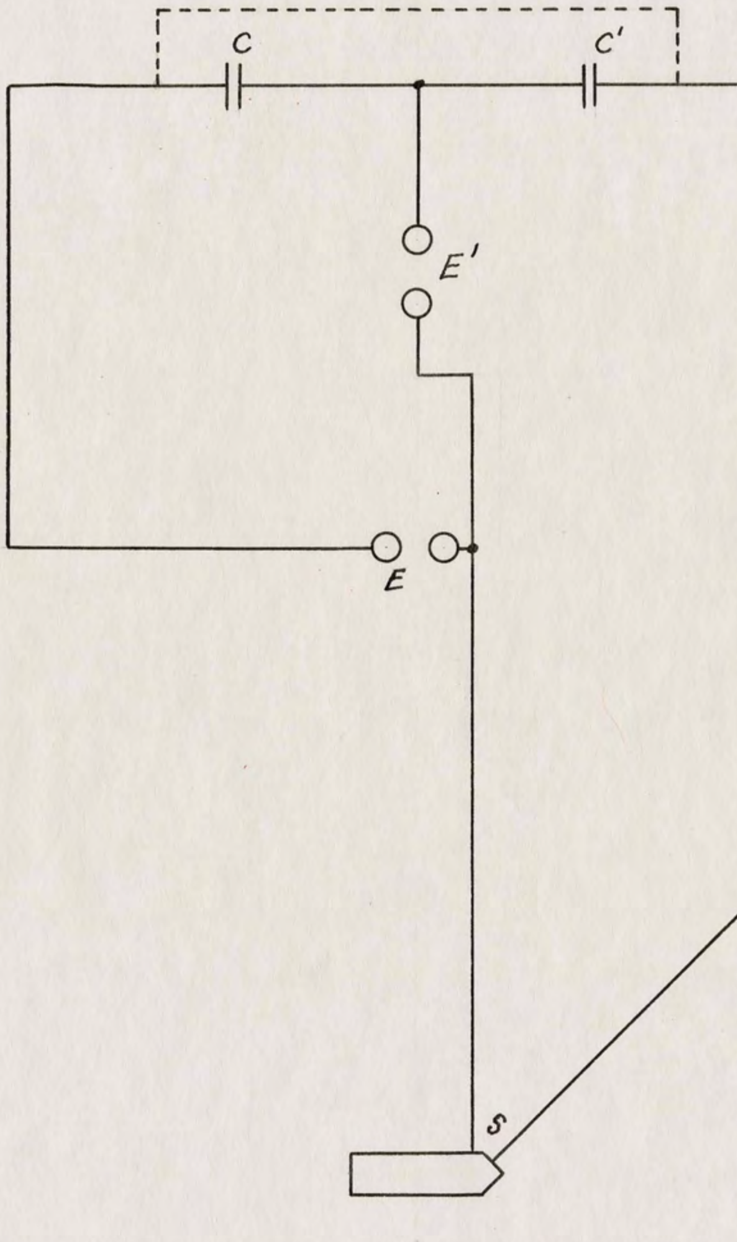

Figure 8

ions and the spark tips at E made of magnesium. The projectile was traveling 2,100 feet per second and the spark lasted long enough for the projectile to travel half an inch, blurring the image on the negative. Upon investigation it was found that while the main spark lasted one millionth of a second, the magnesium tips glowed for about seven millionths of a second. It was concluded that a less volatile metal such as platinum should be used at the spark gap and this substitution was made. It was found that the time of discharge could be materially reduced by replacing the wires carrying the main discharge by heavy bands of copper made as short as possible. With these changes made it was found that the whole spark was extinct in less than one millionth of a second, and the first blaze which supplies most of the light was extinct in less than one ten millionth of a second. The bullet traveled one four hundredth of an inch in this time.

While the images obtained by this method are shadows they are remarkably clear as the source of light is small and the time is very short. The images show the projectile, the wires which initiate the discharge and in the case of projectiles moving over eleven hundred feet per second the air waves set up at the nose and tail of the bullet are clearly visible.

Today this apparatus has changed somewhat into several specialized types of apparatus.

Frank S. Wyle, a student at the Massachusetts Institute of Technology in Cambridge constructed a high speed camera which represents one of these types. His apparatus uses one hundred and ten volt alternating current, stepping it up to 3,000 volts, and then converting it into direct current. A bank of condensers is charged with this current. This charge is discharged through a tube filled with krypton at the same instant that a high voltage is passed through a spark coil into a wire around the tube. The electrical charge passing through the gas causes a five million candlepower flash which lasts only one-fifty thousandth of a second. The light may be timed either by an electrical contact or by the impulse from a microphone placed near the source of a sound connected with the motion to be photographed. When the microphone was used Wyle was able to delay the flash by moving the microphone away from the source of the sound.

On the following pages some of the results obtained with the camera are illustrated. Figure 9 illustrates the set-up used in investigating a defect in the operation of a drop hammer. The drop hammer was forming a duralumin air scoop for an airplane and part of the metal was torn away. Examination of the photographs showed the cause and it was corrected.

Figure 10 shows how a fine stream of milk appears when photographed by this method.

In Figure 11 ? at the top one sees a bullet which has passed through two glass bulbs and is about to pass through a third. At the bottom the action of a light bulb on being struck by a hammer is shown.

A variation of this apparatus was constructed by Francis Behn Riggs, Jr. of Harvard University and an example of its work is shown in Figure 12. The three pictures show the bullet about to enter the bulb, entering it, and leaving the bulb. The bullet was from a forty-five caliber revolver and was traveling at a speed of eight hundred feet per second when photographed.

Perhaps the most recent and complete apparatus is that constructed by K. V. Germeshauser, H. E. Grier, and Harold Eugene Edgerton of the Massachusetts Institute of Technology. In this apparatus the film moves continuously through the camera and the light source is similar to that used in the stroboscope. The camera is known as a stroboscope camera. The light flashes on and off 6,000 times a second and each flash lasts for one-hundredth thousandth of a second. It is the most complex of the apparatus which has been mentioned so far, indeed one whole room is occupied by apparatus concerned with pro-

Figure 9

Figure 10

Figure 11

Figure 12

ducing the suddenly released high voltages which produce the photographic sparks. The camera is linked to the stroboscope and runs at closely regulated speeds so that acceleration and velocity may be measured on the films.

The instrument is extremely useful in clocking projectiles, whirling engines and propellors, and other mechanical devices. The stroboscope camera is used in studying the dangerous shiver of high speed machines and is even used in medicine to study action of high speed micro-organisms.

CONCLUSIONS

Several types of cameras have been discussed, but each has its field in which it is extremely useful. The mechanical cameras which are able to take pictures in natural light cannot be replaced by the ones using artificial light. On the other hand if a series of clear pictures of rapidly moving objects which can be photographed in a laboratory are desired the stroboscope camera is the logical one to use. For very high speed projectiles it might be best to use Boys' apparatus which has an exposure time of less than one millionth of a second.

The value of this high speed photography cannot be over-emphasized. The illustrations show but a few of its uses. Whenever it is desired to study fractures, deformation, or motion occurring at high speeds the camera is the most effective and reliable means of conducting this study.

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