# A Photometric Study of Flash Light Sources Associated With Photographic Emulsions

PAPER B—2

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*Lamps with brief discharges are often employed to photograph rapid phenomena. Now the photometric characteristics of these lamps are as little known as the reactions of the photographic emulsions to brief exposures. We studied the overall photographic effect of the rays emitted by the lamp, as a function of time independent of all consideration of spectral range.*

*An optical layout with a rotating mirror, and a photometric wedge placed near a slit, allowed us to obtain photographic records which gave directly the curve of the logarithm of the intensity of the light as a function of time. The photometric characteristics of the different sources were compared with one another by taking their ratio to a reference source of steady intensity recorded through the same optical layout, so that the same duration of exposure was obtained.*

FLASH LIGHT SOURCES, such as gas-filled discharge lamps, are frequently used for the photography of fast physical or chemical phenomena. The photometric characteristics of such lamps, however, are often poorly defined, particularly with regard to their utilization with photographic emulsions.

The object of the present study was to determine a simple experimental method for the photometric study of flashes in direct association with the photographic receptor. This method makes it possible, in particular, to determine for each flash the relative intensity curve as a function of the time, and the effective photographic duration for the emulsion used. Furthermore, by the use of a continuous reference light, it becomes possible to establish for each emulsion a numerical comparison of the photographic efficiency curves of various types of light sources.

## Experimental Equipment

### *Optical Layout*

The optical arrangement used is shown diagrammatically in Fig. 1. Two different optical paths may be considered:

(a) A condenser C forms the image S′ of the source S to be studied on the reflecting face of a rotating mirror M after reflection from the stationary mirror m. The rotating mirror consists of a steel cube with only one face polished. It is fastened directly onto the shaft of a motor R (Fig. 2).

(b) A slit F, parallel to the axis of rotation of the mirror, is placed in the light beam at the focus of the front objective $L_1$. The rear objective $L_2$, of the same focal length as the objective $L_1$, re-forms at unity magnification the image F′ of the slit on the photographic emulsion E. The velocity $v$ of this image is a function of the speed of rotation of the motor; $v = 4\pi NL \times 10^{-6}$ mm/$\mu$sec, where $N$ = number of revolutions per second and $L$ = focal length of objective $L_2$ in millimeters. Example: $N = 200$ rps; $L = 400$ mm; $v = 1$ mm/$\mu$sec.

A photometric wedge P (with linear variation of *density*) is placed in front of slit F. This makes it possible to obtain on the emulsion an image F′, the illumination of which varies in accordance with a logarithmic law from one end of the slit to the other. As this image moves at a high velocity, the emulsion records at every instant a photographic track, the height of which is related to the luminous intensity of the light source.

### *Synchronizing Device*

To record a flash, it is necessary to synchronize the electric discharge with the rotating mirror, so that the image is formed on the film. At the other end of the shaft of the motor R, driving the mirror M (Fig. 2), a drum T is attached. A slit $f_2$, parallel to the axis of rotation, is cut in the cylindrical surface. A condenser $C_1$ forms an image of a continuous source $S_1$ on a stationary slit $f_1$ very close to the drum T. A small mirror $m_1$ reflects the light beam onto a photoelectric cell N. This optical assembly, which forms an integral unit, can be

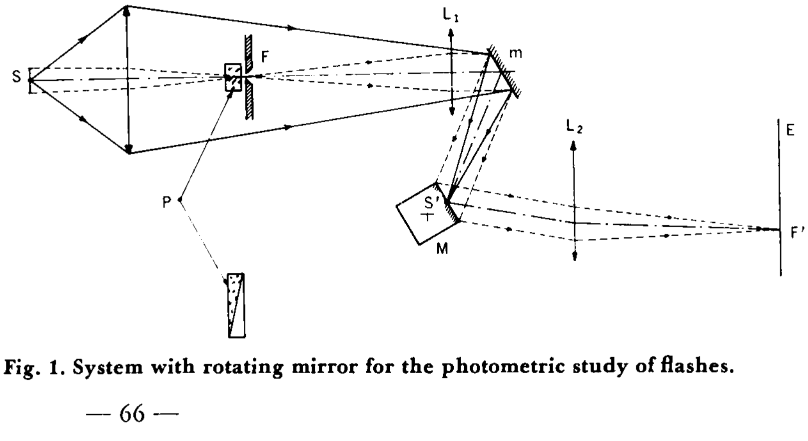

**Fig. 1. System with rotating mirror for the photometric study of flashes.**

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Presented on October 20, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by Michel Philbert and Claude Veret (who read the paper), Office National d'Etudes et de Recherches Aéronautiques, 29–39 Av. de la Division-Leclerc, Châtillon-sous-Bagneux (Seine), France.

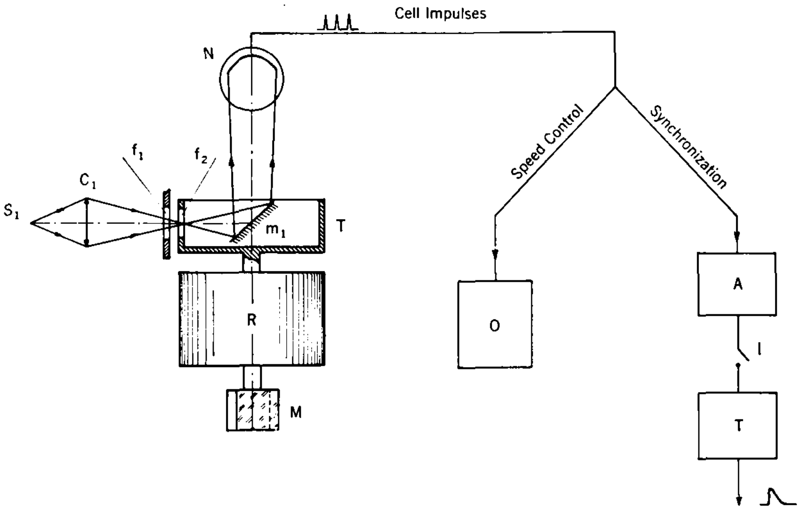


**Fig. 2. Synchronization of the flashes.**

moved around the axis of rotation by means of a toothed sector and tangent screw. It is thus possible to adjust the synchronism with precision. At each revolution of the drum, the cell N receives a brief flash of light which gives rise to a sharp electric impulse. The impulses are sent:

(a) to a cathode-ray oscillograph with a 50-cps time base to permit an accurate regulation of the motor speed at the time when the record is taken;

(b) to an electronic synchronizing device consisting of an amplifier A, a contactor I and a thyratron T associated with a resistance-capacity circuit.

In these conditions, the controlling impulse for the light flash is created by the discharge of the capacity through the thyratron. This discharge occurs at the precise instant that the first photocell impulse, transmitted by the contactor I, reaches the grid of the thyratron. This occurs at a well-defined position of the mirror M. The image of the slit is then formed on the emulsion. The time constant of the circuit is sufficiently long (approximately 0.5 sec) for only a single flash to be produced after pressing briefly on the contactor. Figures 3 and 4 show the equipment.

## Measuring Procedure

Owing to the presence of the photometric wedge, the emulsion records at every instant a photographic track having a height which is related to the intensity of the luminous flux emitted by the flash. It is thus possible to reconstitute from the complete recording of the flash, its intensity curve as a function of time.

The measurements are normally made in two stages: a determination of the relative intensity curve; and a comparison of photographic efficacy levels in relation to a reference source.

### *Determination of the Relative Intensity Curve*

Figure 5 shows the recording of a flash. On this recording, each iso-density curve represents a curve of equal luminous energy for the photographic emulsion.

Now, as the recording is made with a constant time of exposure (the time of passage of the image slit at each point of the film), the curves of equal luminous energy coincide with the curves of equal illumination.

If the luminous intensity remained constant, the lines of equal illumination would be straight lines parallel to the time axis. Because the intensity varies, the lines of equal illumination are curves. They are identical curves, and may be derived from one another by a simple vertical translation. The same is true for the curves of equal darkening of the photographic emulsion; however, owing to the limited range of luminous energy which it is capable of reproducing, the negative may be divided into three regions by the curves $S_1$ and $S_2$ corresponding, respectively, to the sensitivity and saturation thresholds. See Fig. 6. Region 1, since it has received only luminous energies below the sensitivity threshold, remains uniformly light; region 2 is bounded by the curves $S_1$ and $S_2$ between which are inscribed all the iso-density curves

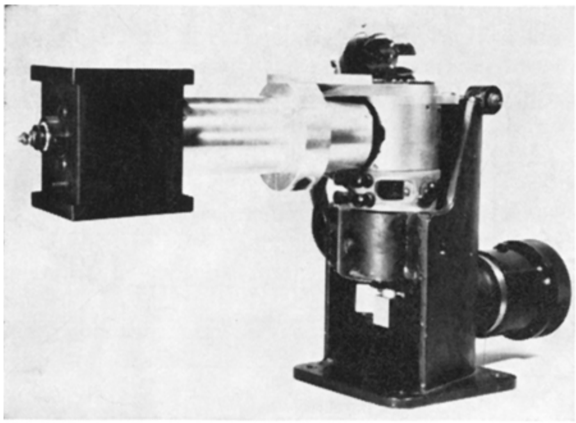


**Fig. 3. Motor and rotating mirror.**

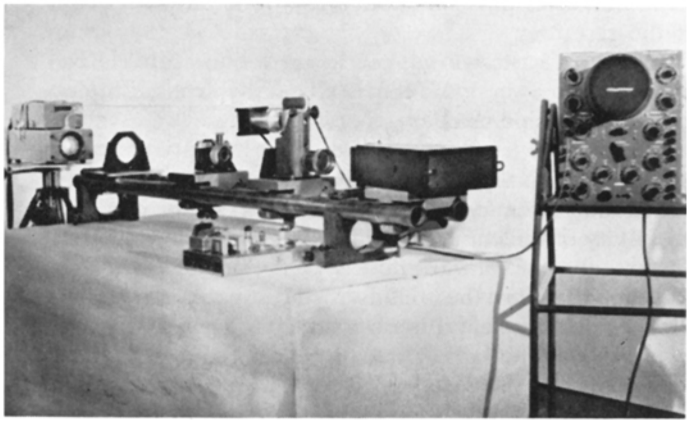


**Fig. 4. View of the entire system.**

of the range of normal exposure; region 3, since it has received only luminous energies above the saturation threshold, remains uniformly dense.

Any iso-density curve of region 2 represents in logarithmic ordinates the relative variations of illumination on the wedge, and hence also the relative variations of the luminous intensity of the source.

Let $I$ be the instantaneous intensity of the flash, and $I_0$ any reference intensity. Any iso-density curve in a rectangular coordinate system may be represented by the function $f(t)$, i.e.,

$$\log \frac{I}{I_0} = f(t)$$

See Fig. 7. If $d$ is the slope of the photometric wedge (increase of density per unit length), and $y$ is the ordinate,

$$\log \frac{I}{I_0} = yd$$

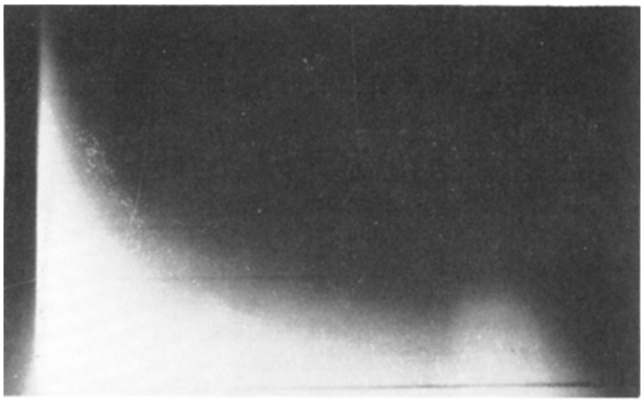


**Fig. 5. Recording (positive) of a flash.**

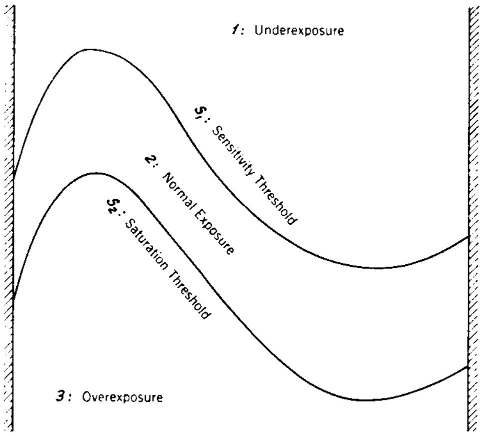


**Fig. 6. Diagram of the recording of a flash.**

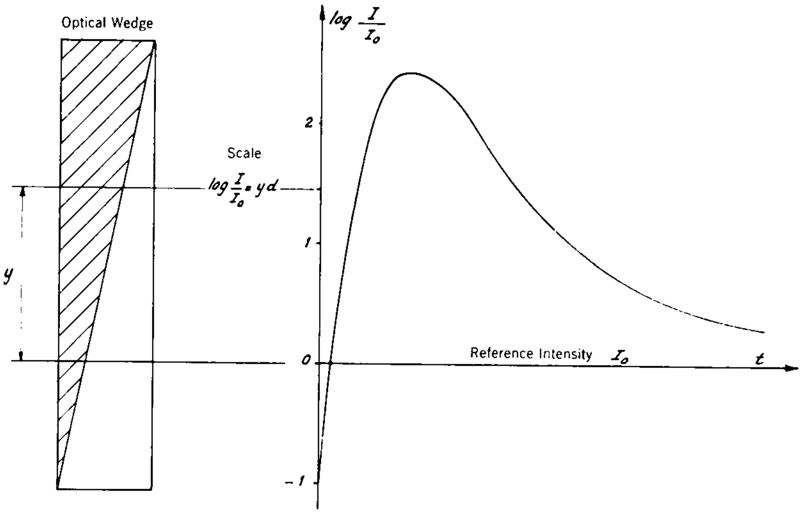


**Fig. 7. Relative intensity curve; $d$ is the slope of the wedge.**

The curve of equal darkening may be determined by microphotometric measurements on the negative. Generally, we preferred to make one or several copies of the record. This made it possible, by increasing the contrast, to make region 2 narrower and thus to leave only a narrow strip between regions 1 and 3. The relative intensity curve could then be drawn directly within this narrow strip.

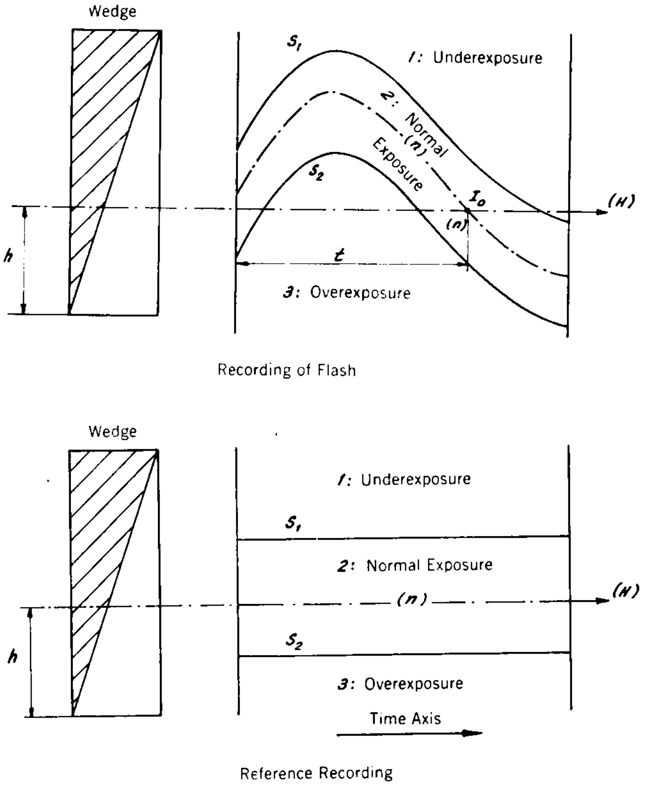
In the most general case, where the spectral composition of the emitted radiation varies during the discharge, the intensity curve is different for each emulsion. In fact, in general each wavelength is governed by a different law of variation and therefore the total response varies as a function of the inherent selectivity of the receptor.

In such a case, we no longer get a curve of relative intensity, but a curve of relative efficacy which is different for each emulsion used.

On the other hand, to the extent that it can be assumed that the composition of the radiation emitted by the entire source remains constant with respect to time, the selectivity of the emulsion no longer affects the response. In fact, the law of variation is then the same for any wavelength, and the relative efficacy curve remains the same for any emulsion.

*Comparison of Levels of Photographic Efficacy*

The curve of relative intensity can be defined independent of the receptor, but the comparison of the



Recording of Flash

Reference Recording

**Fig. 8. Determination of the reference level $I_0$.**

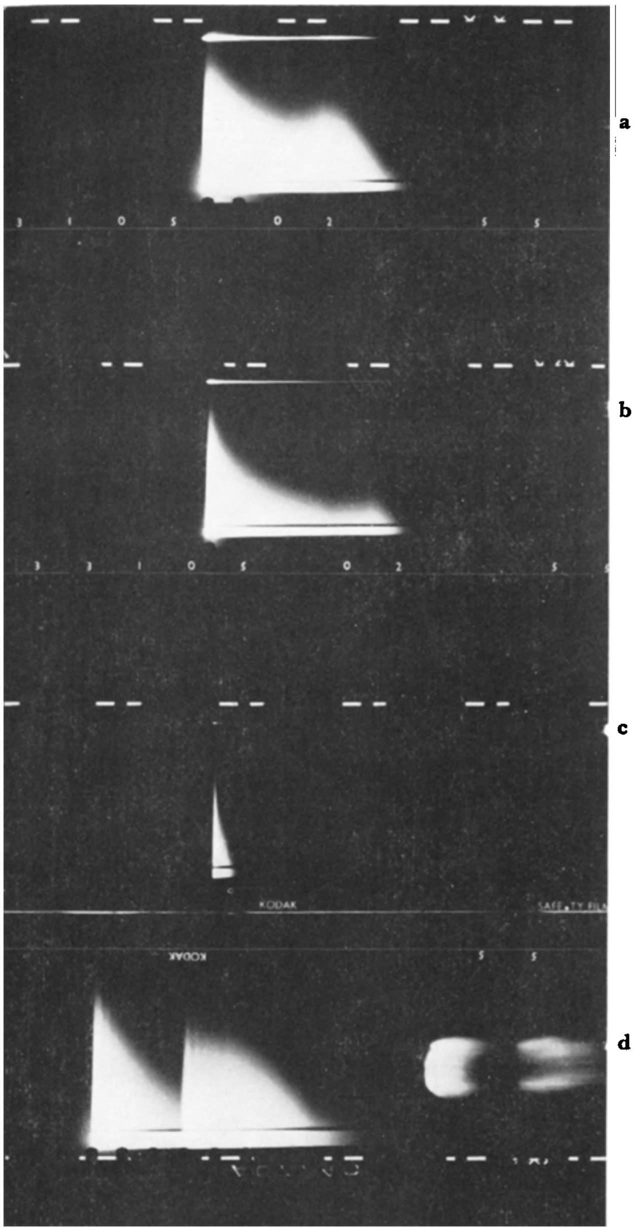


**Fig. 9. ONERA recordings. Flash unit, 6 kv; time base, 1 mm/$\mu$sec; slit width, 0.5 mm. (a) $C = 0.1\ \mu f$; (b) $C = 0.025\ \mu f$; (c) $C = 0.002\ \mu f$; (d) Two flash setup. (Reproduced 0.85 × original size.)**

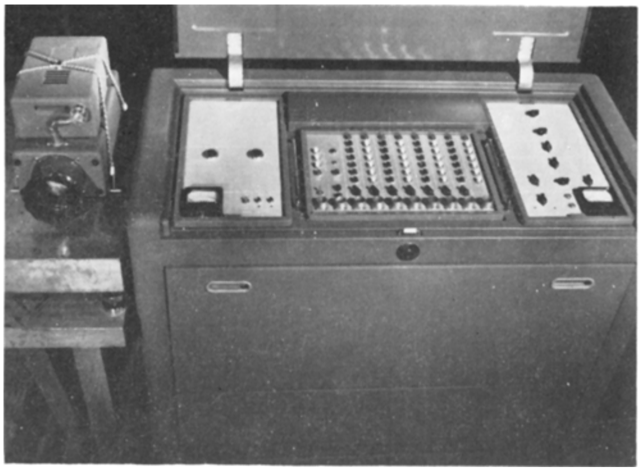


**Fig. 10. ONERA flash unit.**

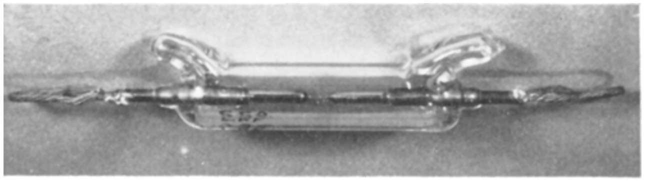


**Fig. 11. ONERA diode tube.**

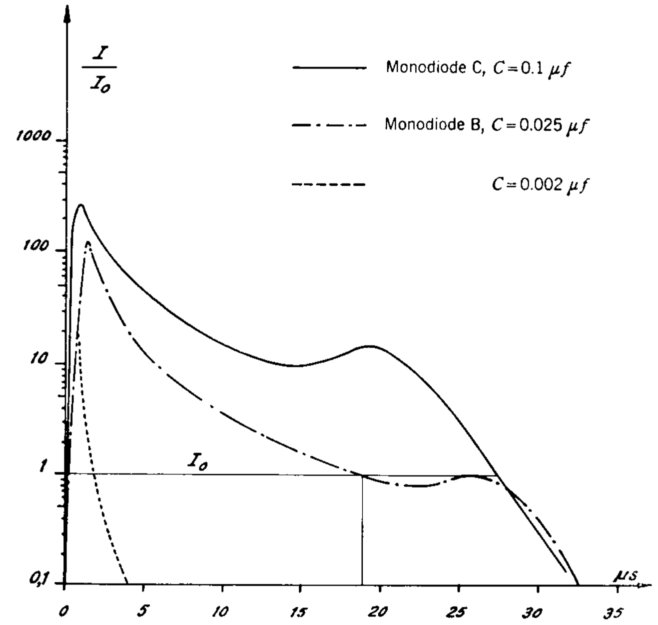


**Fig. 12. Intensity curves for ONERA flash unit.**

efficacy levels of the various flash sources must be made for each emulsion. To make this comparison, it is sufficient to relate the various curves to a given reference level $I_0$. This is done by comparing, at each instant of the discharge, the photographic efficacy of the flash with that of a continuous reference source.

The continuous source is recorded with experimental conditions identical to those adopted for the recording of the flashes. This means that there must be a simple substitution of the sources without any modification of the optical system. Furthermore, it is necessary to make sure, in both cases, that the image S′ of the source is completely inscribed within the useful contour of the mirror. In order that the times of exposure remain identical, the speed of rotation of the motor and the width of the slit must remain the same.

Finally, the film must be exposed only once. To assure this, a shutter is placed in front of the slit and is adjusted to a suitable speed, so that it unmasks the slit for a period slightly shorter than that required for one complete rotation of the mirror.

The films are developed simultaneously.

The determination of the reference level $I_0$ on the curve of relative intensity is made by a photometric comparison of the two negatives.

As shown in Fig. 8, one selects on the reference negative, by means of a microdensitometer, a horizontal line H with a photographic density $n$ which is included within the normal range of exposure. One then seeks on the corresponding horizontal line of the flash recording the point which has the same density. This point indicates the instant $t$ of the discharge where the luminous efficacy of the flash is equal to the efficacy of the reference source. It therefore determines the position of the level $I_0$ on the curve of relative intensity.

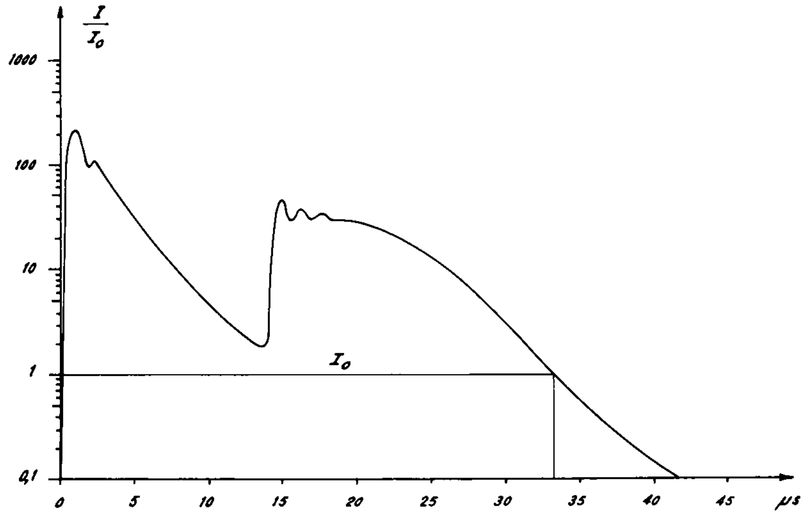


**Fig. 13. Intensity curve for ONERA flash unit: two-flash setup.**

In the event that the maximum efficacy of the flash should be smaller than the efficacy of the reference source, it would suffice to reduce the latter by means of a known, suitably selected density.

## Results and Conclusion

Figure 9 shows several recordings (positive prints) relating to the ONERA* flash unit.

This apparatus, which is shown in Fig. 10, can produce discharges in a diode tube containing krypton under a pressure of 15 atm. The tube is shown in Fig. 11. The supply voltage of the condensers is 6 kv. The first three recordings (Figs. 9a, 9b, 9c) correspond, respectively, to capacities of 0.1, 0.025 and 0.002 µf. The recording 9d corresponds to a special setup which makes it possible to produce in the same diode two flashes at an interval of 15 µsec.

The relative intensity curves are given in Figs. 12 and 13. The emulsion used for all recordings is the Tri-X Kodak emulsion. The reference lamp is an HBO 200 mercury-vapor lamp which has an intensity on the axis of approximately 1100 candles.

Figures 14 and 15 are from records made with the Früngel Superstroboscope for various values of the capacity. The supply voltage was 8 kv; and the gases used were argon at 1 kg/cm$^2$ and hydrogen at 1.5 kg/cm$^2$. The curves give the intensity variations in a range the extent of which is a function of the density interval actually used on the optical wedge. For the present results, the range of the wedge extends from 0 to 3. Accordingly, the curves represent the intensity variations in an interval with extreme limits in the ratio of 1000:1.

The utilization of a more extensive range of densities would permit increasing this ratio, provided sufficient light was directed on the slit to assure that the peak illumination caused some exposure of the emulsion throughout the entire range of the wedge. In fact, the range from 0 to 3 is sufficient in practice since it corre-

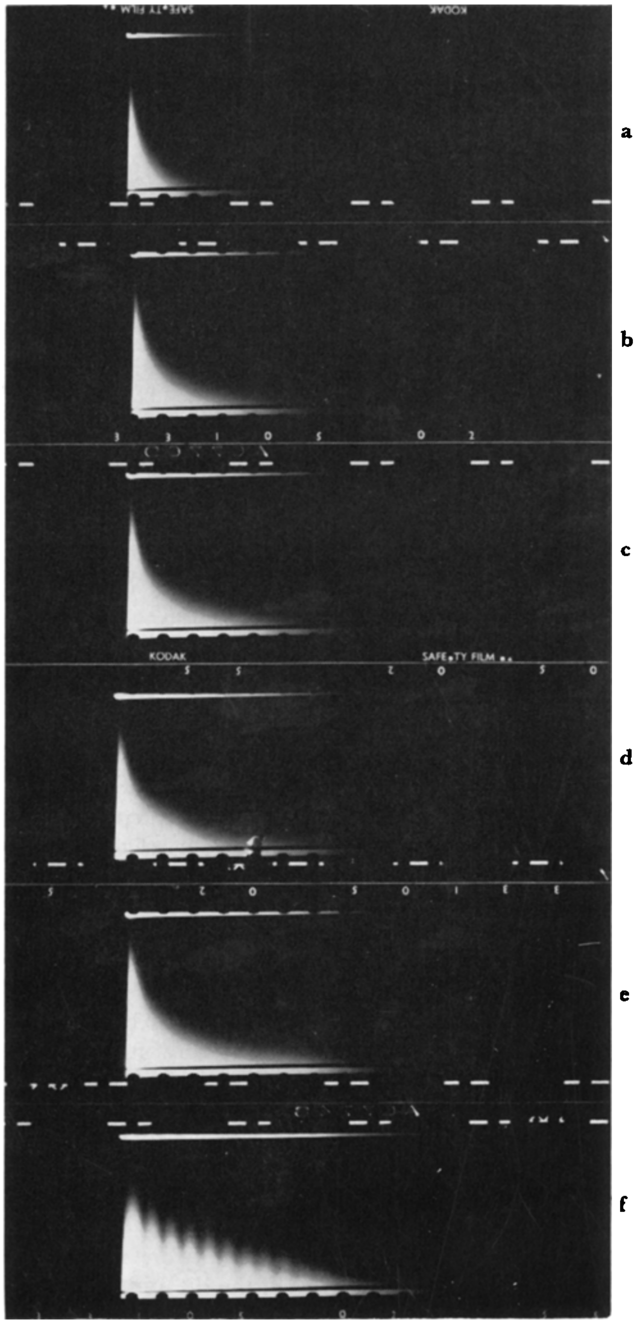


**Fig. 14. Recordings with Früngel Superstroboscope working at 8 kv. Time base, 1 mm/µsec; slit width, 0.5 mm. (Reproduced 0.85 × original size.) (a) $C$ = 0.04 µf; (b) $C$ = 0.08 µf; (c) $C$ = 0.12 µf; (d) $C$ = 0.16 µf; (e) $C$ = 0.2 µf; (f) $C$ = 2 µf. (The overall level of this last record should be raised by 7 mm.)**

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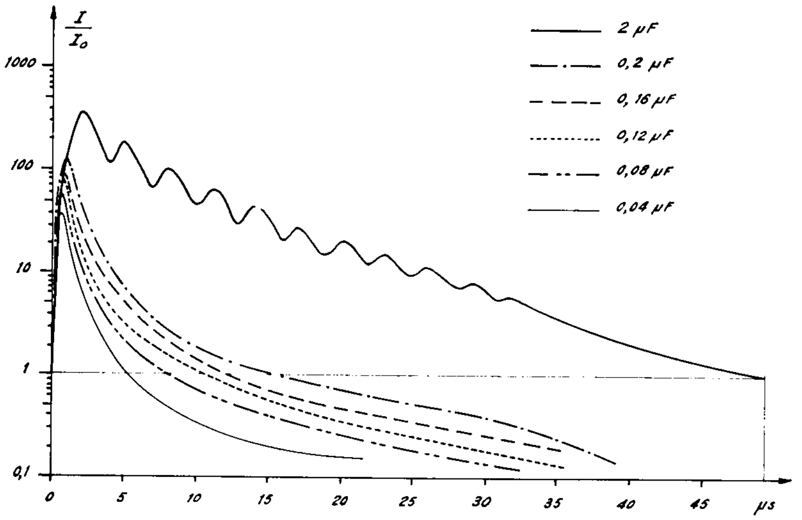

**Fig. 15. Intensity curves for Früngel Superstroboscope.**

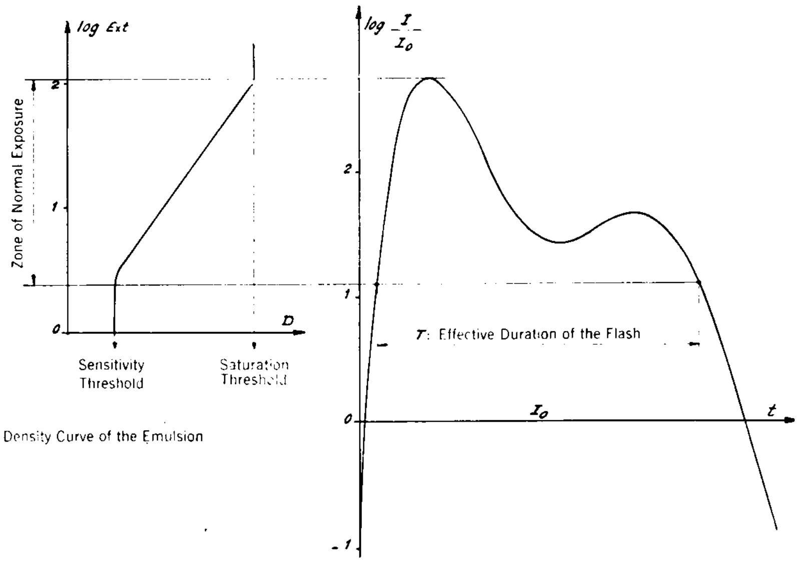

**Fig. 16. Effective duration of the flash as a function of the emulsion.**

sponds approximately to the normal latitude of standard emulsions.

The effective duration of the flash is actually determined partly by the type of receptor. In the case of a correctly exposed photographic emulsion, the duration $T$ of the flash is related to the range of the normal zone of exposure. See Fig. 16. If it is desired to obtain the entire gray scale which the emulsion can reproduce, the peak intensity must be adjusted to correspond with the saturation threshold.

It is evident that the use of underexposed emulsions or the use of high-contrast emulsions makes it possible to reduce the effective duration of a flash. However, this approach reduces the range of information which the negative may contain. Nevertheless, this method can be useful when the aim is not especially to make an analysis of the illumination levels in the image—for instance, in cases, when it is simply desired to define the silhouette of a ballistic projectile, or to record the position of a shock wave.

On the other hand, when it is desired to study phenomena presenting a wide range of illumination, it is necessary to use the emulsions throughout their entire normal range of exposure. As the range may be very extensive (luminous energy can easily vary 1000-fold), we must know the behavior of luminous phenomena over a very wide range.

Owing to its inherent logarithmic scale, it seems that the photographic method at present is the best choice, particularly as this method yields the results directly as a function of the commonly used receptor, the photographic emulsion.

This method can be very valuable to the users of flashlamps, in enabling them to make a selection to suit their particular problems; and to manufacturers by providing them with an effective means for the control and study of their equipments.

*Edit. Note:* Readers' attention is drawn to the paper, "Flash Light Source Measurement," presented by G. H. Lunn at the Fifth International Congress on High-Speed Photography; published as the preceding paper in these *Proceedings.*