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## The A.M.L. Spectrum Intensity Recorder

## III. Final Results

ES5/027

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# THE A.M.L. SPECTRUM INTENSITY RECORDER

## PART III

THERMAL EFFECTS GROUP

Report No. A.M.L. (External) No. SA/40 (M)

ADMIRALTY MATERIALS LABORATORY,
HOLTON HEATH, POOLE, DORSET

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# THE A.M.L. SPECTRUM INTENSITY RECORDER

See T101/54 for description of instrument

## PART III

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## 1. INTRODUCTION

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Previous reports under this title (Parts I and II) were A.M.L. (External) Report Nos. SA/31 (M) and SA/36 (M) respectively. Part I. was a description of the principle, design and construction of the Spectrum Intensity Recorder whilst Part II gave details of the employment of the instrument during the "Hurricane" trial on 3. 10. 52. and included some preliminary details of results.

Part III here presented continues the record of experimental work and gives quantitative figures shewing the variation of absolute intensity with time in nine regions of the visible spectrum during the flash of the explosion as recorded at a known range.

## 2. EXPERIMENTAL

The methods used for the processing and densitometry of the films were fully described in Part II. Experimental details concerned with the standardisation of the films and the derivation of absolute intensities are described here.

### (a) Standard Light Source

A "sub-standard" lamp was obtained from Messrs. The General Electric Company, Wembley. This lamp, a 12 v, 36 watt, gas filled head-light type, was mounted on a small table so that with an accumulator of adequate capacity and the necessary accessories the assembly formed a compact movable unit. A low voltage lamp was chosen because of the increased difficulty in providing economically a controllable supply of higher voltage.

### (b) Photographic Process Control

All film records made during this series of experiments were passed through the Calibration Pattern Printer (mentioned in Part II) before processing. Final densities were read on the Zeiss microdensitometer. The roller blind speed of the Recorder, photographic details, processing and settings of the microdensitometer were maintained precisely as for the actual "Hurricane" trial recordings.

Densities obtained from the patterns shewed that in every accepted film development had been carried to a similar gamma to that previously obtained and that the sensitivity of the photographic emulsion had not materially deteriorated.

### (c) Intensity Calibration

Relative intensity calibration of the Recorder was effected by the inverse square law method. Repeat runs of the instrument were made at distances of 10.0, 7.08, 5.00 ..... 0.31 feet from the filter assembly of the Recorder to the filament of the sub-standard lamp. Details are given in Table 1.

Although several films were used in a 'pack' during this series of experiments only the first film in each 'pack' was employed for the density/relative intensity calibration. Each (first) film corresponded to a definite relative intensity, i.e., with a distance of one foot (30.5 cm.) from the lamp to the instrument the relative intensity equalled unity.

/Densities.....

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Densities of the nine spectrum ranges were read from the record tracks on each film and density/relative intensity curves were drawn for each spectrum range (colour). A table of the densities obtained is given in Table 1 and a typical curve is shewn in Figure 1.

Reverting to the set of films comprising the 'pack' of Recorder "B" exposed during the "Hurricane" trial. A complete series of density measurements had been tabulated whilst traversing in the microdensitometer the record tracks of each of the first four films (Nos. 1, 2, 3 and 4). By means of the curves just made these density figures were converted to relative intensities.

(d) Film Factors

Studying the relative intensities obtained along the record tracks of two adjacent films it was found that at certain identical traverse distances corresponding relative intensities were both on the straight line portion of the appropriate characteristic (density/relative intensity) curve and so could be most usefully compared.

For example, on the orange record tracks of films 1 and 2 the relative intensity at 16.50 mm. traverse on film 1 was 3.2 whilst in a similar position on film 2 the relative intensity was 0.16. Both these relative intensities are on the linear portion of the orange characteristic curve; there is therefore a factor of x 20 from film 2 to film 1.

To visualise this, it should be borne in mind that the pencil of light rays which passed through the slit in the roller blind when in position 16.50 mm., traversed the orange filter and continued through the emulsion of film 1 on into film 2 ... etc. The passage of this pencil of rays through films 1 and 2 produced photographic densities corresponding to relative intensities of 3.2 and 0.16. Thus we have a direct measure of the orange light absorption of film 1 obtained under working conditions on the actual film expressed in a form most suitable for the present purpose.

As a result of averaging many readings, taken at appropriate positions in the record tracks on films 1, 2 and 3, the film factors given in Table 2 were obtained.

(e) Relative Intensities

The final relative intensity values corresponding to distances along the record tracks (time) were accepted from film 1 up to the limit of linearity of the characteristic curve. Beyond this point relative intensities were taken from film 2 and multiplied by the appropriate factor. Similarly, when the limit of linearity was again reached, relative intensities were taken from film 3 and multiplied by two appropriate factors. In this way a complete record of variation of intensity with time was compiled.

(f) Intensity of Standard Lamp

After the calibration of Recorder "B" the "sub-standard" lamp was sent to the National Physical Laboratory for intensity and colour temperature measurements. The transmission characteristics of the set of Spectrum filters were also obtained. Details are presented in Table 3 and Figure 2.

Taking the given constants of the "sub-standard" lamp the energy distribution over the visible region of the spectrum was calculated in 0.01$\mu$ intervals using the formula:-

/E = ...

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$$E_{\theta\lambda} = \frac{I}{M.r^2}\left[\frac{kE_{\theta\lambda}}{\sum_{0.38\mu}^{0.78\mu} kE_{\theta\lambda}.V_\lambda \, d\lambda}\right] \text{ watts per sq.cm., per } 0.01\,\mu \text{ waveband,}$$

where $E_{\theta\lambda}$ = energy at colour temperature $\theta(^{o}K)$ and wavelength $\lambda$,

$I$ = luminous intensity in candelas,

$M$ = number of lumens per watt,

$r$ = distance in cm.,

$V_\lambda$ = relative luminous efficiency factor at wavelength $\lambda$,

and $k$ = a constant.

The values obtained are given in Table 4.

## 3. EVALUATION OF SPECTRAL ENERGY

From an examination of the transmissions of the set of nine Spectrum Filters employed, given in Figure 2, it will be seen that although the main transmission bands are distinct each filter allows the passage of some light of adjacent colour. Taking all nine filters together the overlap is considerable; further, the spectral width of individual filters varies.

In order to simplify the procedure of assessing final energies (and so to expedite progress) each filter was regarded as a distinct channel of 300 angstroms width. By this assumption there are no overlaps and only one narrow gap of 100 angstroms in the visible spectrum up to 6650 A. Details of the spectral channels chosen and the energies associated with them are given in Table 5.

Let us consider the sub-standard lamp set up at unit (30.5 cm.) distance from the Recorder, and incident light of wavelengths included in one of the selected channels - for instance orange. At 30.5 cm., this orange light has an absolute intensity of $326 \times 10^{-7}$ watts per sq.cm., and after passing the orange filter produces a photographic density equivalent (on the orange characteristic curve) to a relative intensity of unity. Another light source at any distance which produces unit relative intensity after the orange filter of the Recorder will have the same absolute intensity of $326 \times 10^{-7}$ watts per sq.cm., in the orange channel. This applies to each spectrum channel and, by the standardisation made, relative intensity values from 0.1 to more than 1000 can be converted directly into absolute units.

The results so obtained from the Trial films are presented graphically in Figure 3.

## 4. TOTAL ENERGY IN THE VISIBLE SPECTRUM UP TO 6650 A.

In the first evaluations attempted the full spectral width of each of the nine spectrum ranges was taken and plotted against time. With

/this....

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this method comparison of energies in different ranges and integration of total energy proved to be difficult.

An alternative method of calculation of energy in individual ranges (channels) each uniformly 300 angstroms wide allows the energies found in these individual ranges to be directly added. Their sum being the total energy in the visible spectrum from 3850 to 6650 A., due allowance being made for the gap of 100 angstroms.

Because the roller blind had a speed of 16.45 mm., per second and the slit width was 0.25 mm., the resolution of the Recorder is only 15 milliseconds. Bearing this in mind the following estimate is possible:-

> In the visible region of the spectrum from 3850 to 6650 A., the energy of the initial flash at the range employed, integrated over 15 milliseconds, was of the order of 0.050 watts per sq.cm. (500 watts per sq. metre).

## 5. OBSERVATIONS

### (a) Accuracy of Results

The results obtained for absolute energy values are considered to be accurate within ± 25%. Maxima of assessible errors in the Recorder during both recording and standardisation runs have been regarded as cumulative in arriving at this figure.

### (b) Film Factor

It was intended originally to obtain the film factors during standardisation, but it was found that each factor varied in the successive films used in the actual "Hurricane" trial. This variation is probably associated with differences in emulsion thickness, which would result in variable loss of energy due to absorption and scattering. By the method of determination used, however, film factors were obtained from the emulsions at the positions where they were applied in calculating final relative intensities.

### (c) Energy Peak

From a comparison of energies emitted in the individual spectral ranges as shewn in Figure 3, it will be observed that most of the energy is concentrated in the blue-green, green, yellow-green and yellow regions, 4750 - 5950 A, with a peak in the yellow-green at 5500 A.

That the wavelength of this intensity maximum should coincide with the wavelength of maximum visual luminous efficiency is unfortunate in that it increases the difficulty of providing efficient eye protection by the employment of orthodox welding filters.

## 6. ACKNOWLEDGEMENT

The co-operation of the National Physical Laboratory, Light Division, in calibrating the "sub-standard" lamp and filters and in giving guidance in the calculation of spectral energy distribution is gratefully acknowledged.

[redacted]

[redacted]

L. G. Young, S.E.O.,
B.E.J. Spreadborough, Asst.(Sc.).

September, 1953.

ADMIRALTY MATERIALS LABORATORY

(Sgd.) H. GOLLOP

SUPERINTENDENT.

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TABLE 1

Densities from Standardisation Films

| Distance feet | Relative intensity | Spectrum Range | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Red | Orange | Yellow | Yellow green | Green | Blue Green | Blue | Violet | Deep violet |
| 10.0 | 0.010 | - | 0.03 | - | - | - | - | - | - | - |
| 7.08 | 0.020 | - | 0.10 | 0.03 | - | - | - | 0.03 | 0.03 | - |
| 5.00 | 0.040 | 0.01 | 0.25 | 0.10 | 0.03 | 0.02 | 0.02 | 0.09 | 0.09 | - |
| 3.16 | 0.100 | 0.05 | 0.48 | 0.23 | 0.06 | 0.05 | 0.05 | 0.25 | 0.27 | 0.02 |
| 2.28 | 0.200 | 0.13 | 0.74 | 0.43 | 0.16 | 0.15 | 0.13 | 0.45 | 0.45 | 0.03 |
| 1.58 | 0.400 | 0.28 | 0.95 | 0.68 | 0.32 | 0.35 | 0.32 | 0.70 | 0.66 | 0.08 |
| 1.00 | 1.000 | 0.64 | 1.45 | 1.15 | 0.70 | 0.80 | 0.67 | 1.05 | 1.05 | 0.28 |
| 0.708 | 2.00 | 0.90 | 1.68 | 1.50 | 1.07 | 1.17 | 1.03 | 1.35 | 1.35 | 0.49 |
| 0.500 | 4.00 | 1.21 | 2.00 | 1.74 | 1.37 | 1.50 | 1.27 | 1.65 | 1.64 | 0.81 |
| 0.316 | 10.00 | 1.41 | 2.26 | 1.98 | 1.66 | 1.77 | 1.56 | 1.92 | 1.86 | 1.05 |

Each density shewn is the average of readings from four (first) films.

TABLE 2

Film Factors

| | Films 1 - 2 | Films 2 - 3 |
|---|---|---|
| Red | x 11.4 | x 8.6 |
| Orange | 21.6 | (14.2) |
| Yellow | 86.4 | (55.0) |
| Yellow green | 113.8 | - |
| Green | 38.8 | (26.0) |
| Blue green | 23.6 | 13.8 |
| Blue | 20.0 | 11.5 |
| Violet | 55.4 | (29.3) |
| Deep Violet | 140. | - |

It was found unnecessary to use the factors in brackets.



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TABLE 3

Details of "Sub-standard" Lamp

| | |
|---|---|
| Manufacture:- | Messrs. The General Electric Company, Wembley. |
| Mark on lamp:- | R 169 A 52 |
| N.P.L. mark on lamp:- | 78 A 1953 |
| Rating:- | 12v. 36w. |
| Volts:- | 11.50 |
| Luminous Intensity:- | 54.5 Candelas. |
| Amperes:- | 2.97 |

When operating at the above voltage the lamp had a mean Colour Temperature of 2856 $^{o}$K.



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TABLE 4

| $\lambda$ | Relative Energy Values $kE_{\phi\lambda}$ $\phi$=2856 °K | Relative luminous efficiency factors $V_\lambda$ | $kE_{\phi\lambda} \times V_\lambda$ | $E_{\phi\lambda}$ Watts per sq. cm. at 30.5 cm. per 0.01 $\mu$ wavelength interval |
|---|---|---|---|---|
| 0.38 | 9.825 | .00004 | .000 | $7.844 \times 10^{-7}$ |
| 0.39 | 12.11 | .00012 | .001 | 9.667 " |
| 0.40 | 14.74 | .0004 | .006 | 11.77 " |
| 0.41 | 17.71 | .0012 | .021 | 14.14 " |
| 0.42 | 21.04 | .0040 | .084 | 16.79 " |
| 0.43 | 24.71 | .0116 | .286 | 19.73 " |
| 0.44 | 28.75 | .023 | .660 | 22.93 " |
| 0.45 | 33.13 | .038 | 1.257 | 26.45 " |
| 0.46 | 37.86 | .060 | 2.271 | 30.23 " |
| 0.47 | 42.92 | .091 | 3.906 | 34.27 " |
| 0.48 | 48.29 | .139 | 6.712 | 38.54 " |
| 0.49 | 53.96 | .208 | 11.223 | 43.08 " |
| 0.50 | 59.90 | .323 | 19.348 | 47.82 " |
| 0.51 | 66.10 | .503 | 33.248 | 52.77 " |
| 0.52 | 72.53 | .710 | 51.496 | 57.90 " |
| 0.53 | 79.16 | .862 | 68.236 | 63.20 " |
| 0.54 | 85.96 | .954 | 82.006 | 68.63 " |
| 0.55 | 92.92 | .995 | 92.455 | 74.19 " |
| 0.56 | 100.00 | .995 | 99.500 | 79.83 " |
| 0.57 | 107.17 | .952 | 102.026 | 85.58 " |
| 0.58 | 114.41 | .870 | 99.537 | 91.33 " |
| 0.59 | 121.69 | .757 | 92.119 | 97.30 " |
| 0.60 | 128.98 | .631 | 81.386 | 103.0 " |
| 0.61 | 136.27 | .503 | 68.544 | 108.8 " |
| 0.62 | 143.52 | .381 | 54.681 | 114.6 " |
| 0.63 | 150.72 | .265 | 39.941 | 120.3 " |
| 0.64 | 157.85 | .175 | 27.624 | 126.1 " |
| 0.65 | 164.88 | .107 | 17.642 | 131.6 " |
| 0.66 | 171.79 | .061 | 10.479 | 137.2 " |
| 0.67 | 178.57 | .032 | 5.714 | 142.6 " |
| 0.68 | 185.21 | .017 | 3.149 | 147.9 " |
| 0.69 | 191.69 | .0082 | 1.572 | 153.0 " |
| 0.70 | 198.00 | .0041 | .812 | 158.1 " |
| 0.71 | 204.13 | .0021 | .428 | 162.9 " |
| 0.72 | 210.06 | .00105 | .220 | 167.7 " |
| 0.73 | 215.79 | .00052 | .112 | 172.3 " |
| 0.74 | 221.32 | .00025 | .055 | 176.7 " |
| 0.75 | 226.63 | .00012 | .027 | 180.9 " |
| 0.76 | 231.72 | .00006 | .014 | 185.0 " |
| 0.77 | 236.59 | .00003 | .007 | 188.9 " |
| | | | 1078.805 | |



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TABLE 5

Selected Spectral Ranges

| Spectral Range | | E $\Delta\lambda$ | Total energy incident at 30.5 cm. from "sub-standard" lamp. Watts/sq. cm. |
|---|---|---|---|
| Deep Violet<br>3850-4150 A. | .39<br>.40<br>.41 | $9.67 \times 10^{-7}$<br>11.77<br>14.14 | $35.6 \times 10^{-7}$ |
| Violet<br>4150-4450 A. | .42<br>.43<br>.44 | 16.79<br>19.73<br>22.93 | 59.5 |
| Blue<br>4450-4750 A. | .45<br>.46<br>.47 | 26.45<br>30.23<br>34.27 | 90.9 |
| Blue Green<br>4750-5050 A. | .48<br>.49<br>.50 | 38.54<br>43.08<br>47.82 | 129.4 |
| Green<br>5050-5350 A. | .51<br>.52<br>.53 | 52.77<br>57.90<br>63.20 | 173.9 |
| Yellow Green<br>5350-5650 A. | .54<br>.55<br>.56 | 68.63<br>74.19<br>79.83 | 222.7 |
| Yellow<br>5650-5950 A. | .57<br>.58<br>.59 | 85.58<br>91.32<br>97.30 | 274.2 |
| Orange<br>5950-6250 A. | .60<br>.61<br>.62 | 103.0<br>108.8<br>114.6 | 326.4 |
| Red<br>6350-6650 A. | .64<br>.65<br>.66 | 126.1<br>131.6<br>137.2 | 394.9 |



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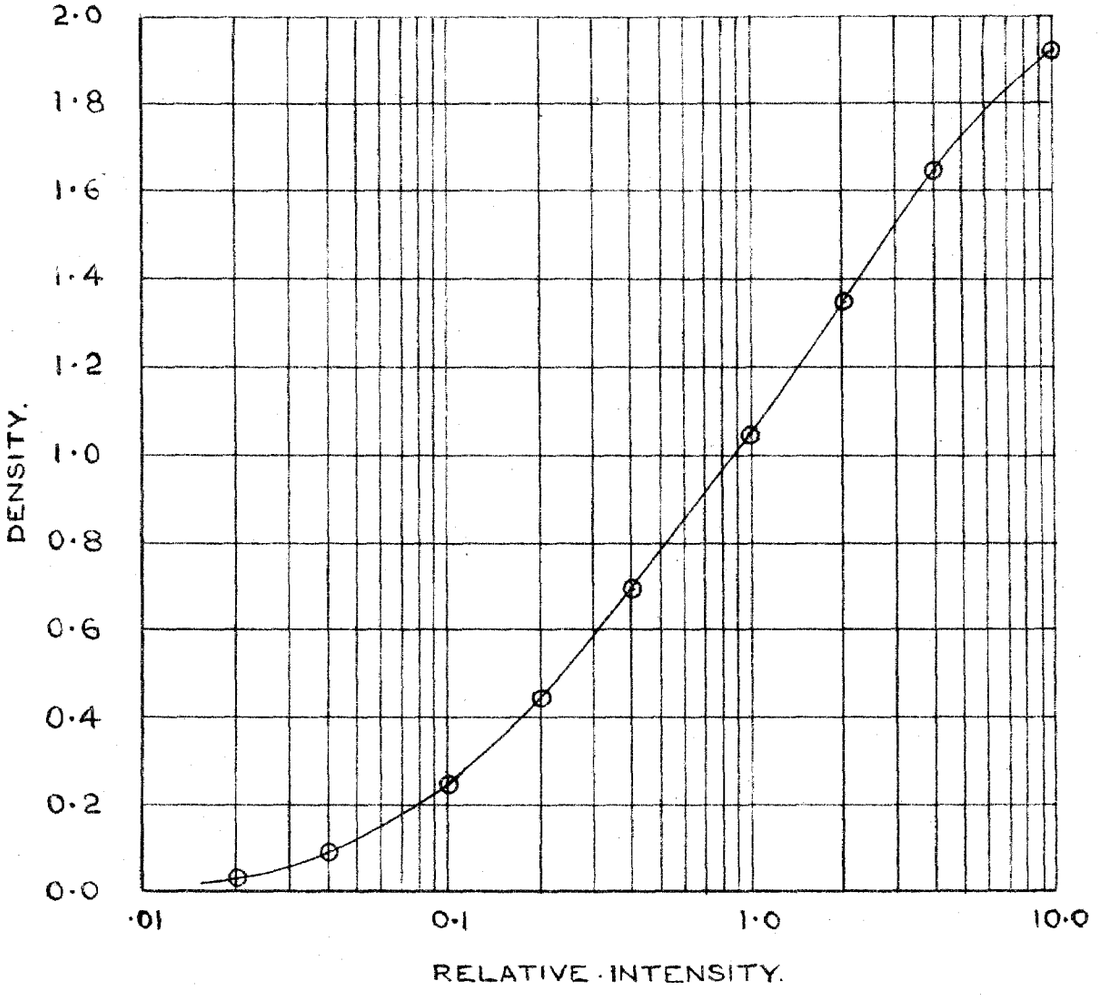


RECORDER "B" BLUE.

Fig. 1. CHARACTERISTIC CURVE.

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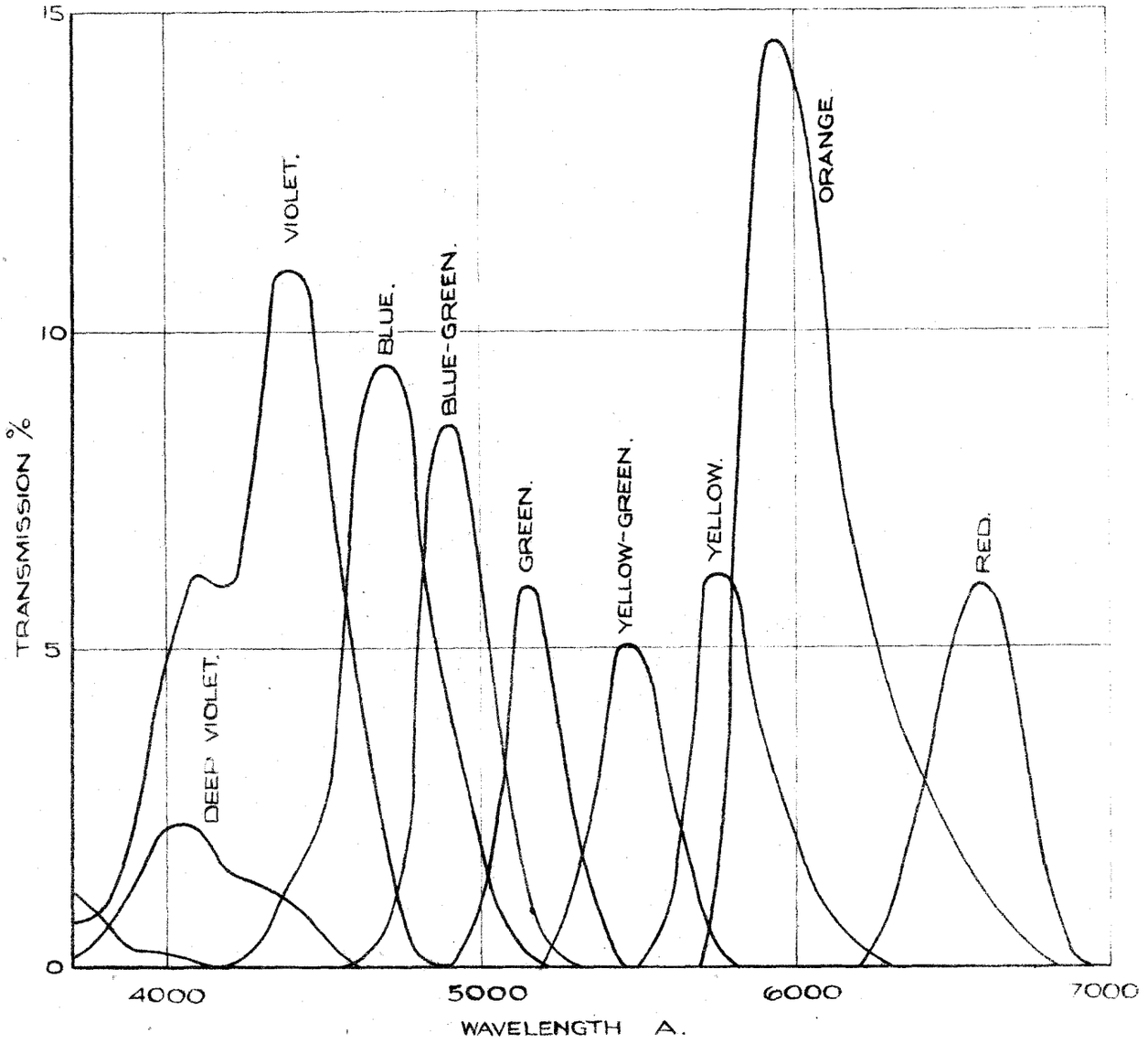


THE TRANSMISSION CURVES OF THE ORANGE AND RED FILTERS HAVE BEEN MODIFIED TO COMPENSATE FOR THE FALLING OFF IN SENSITIVITY OF THE PHOTOGRAPHIC EMULSION EMPLOYED (FP 3).

Fig. 2 SPECTRUM FILTERS.

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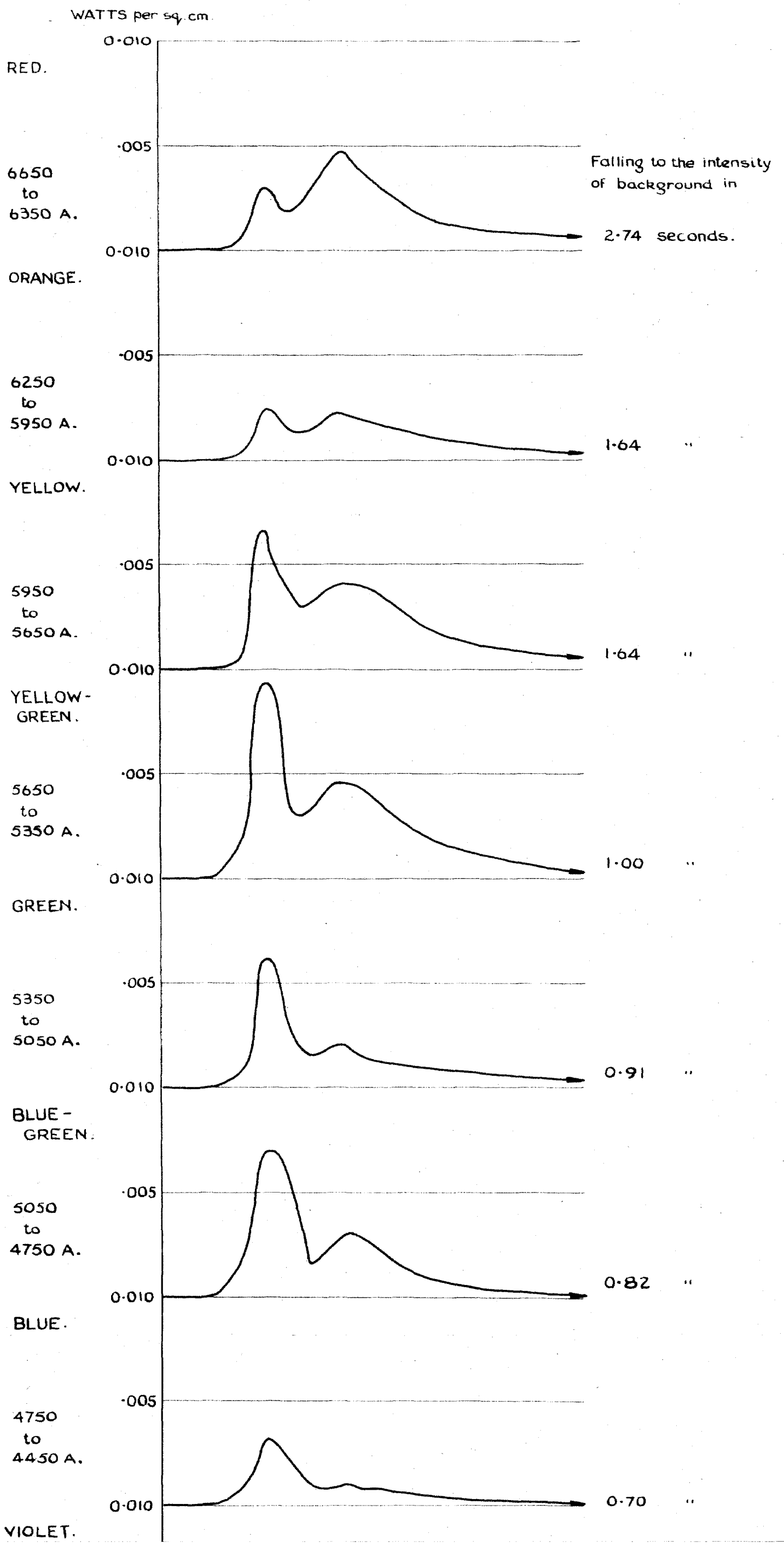


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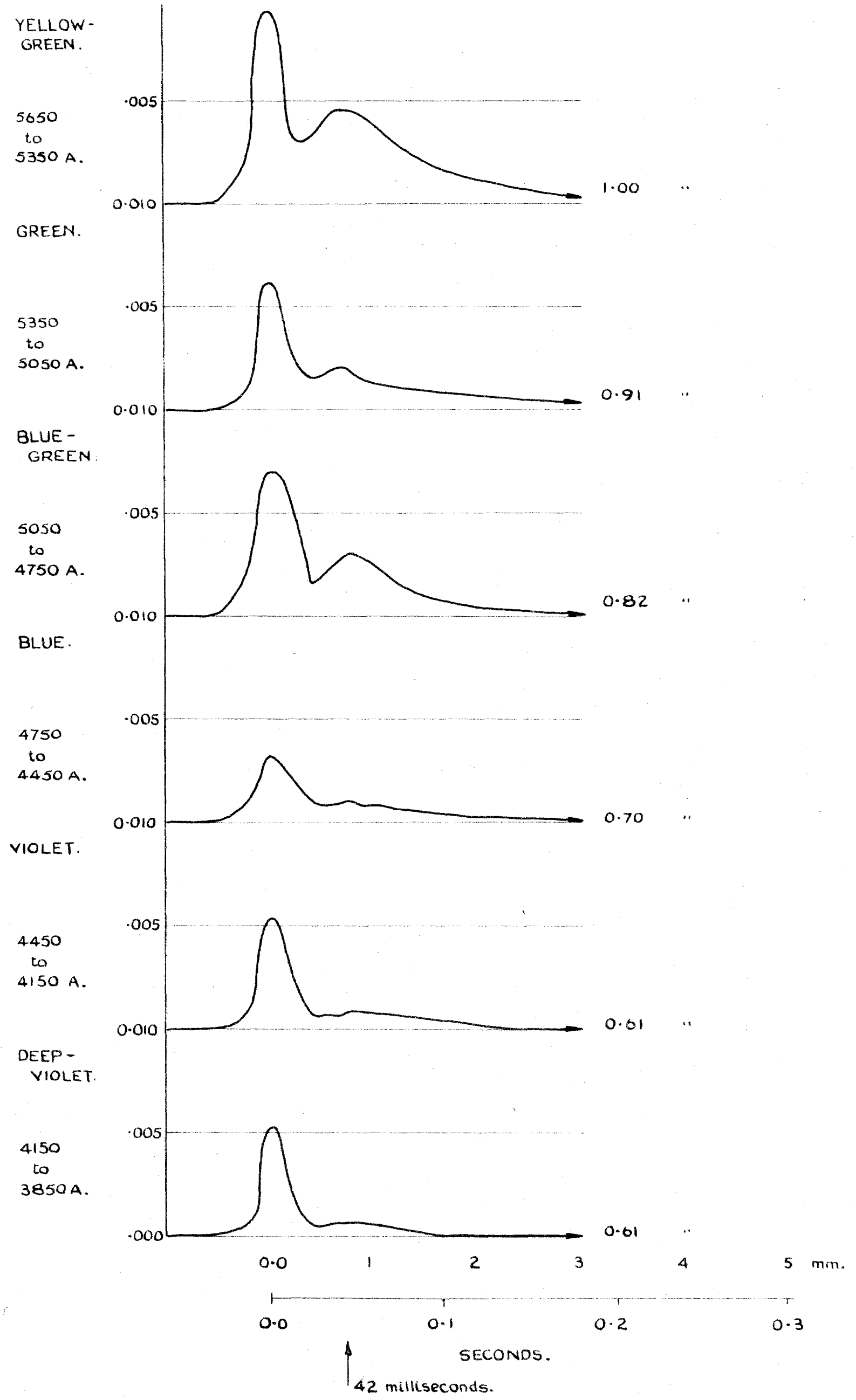


Fig. 3. VARIATION OF ABSOLUTE INTENSITIES WITH TIME.

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