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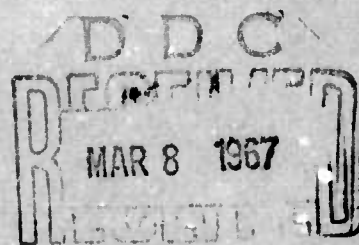
Stable Fluorescent Converter Solutions
Enhancing Optical Pumping in the Visible Region

Prepared by
Stig Claesson
W.W. Wladimiroff

Final Report
December 1966

Prepared Under Contract Nonr 4654(00)
Project Code No. 4730, ARPA Order No. 306

Institute of Physical Chemistry
University of Uppsala
Uppsala Sweden



INSTITUTE OF PHYSICAL CHEMISTRY
UNIVERSITY OF UPPSALA
Uppsala, Sweden

Final Report under
Contract Nonr 4654(00)
October 1, 1964 through September 30, 1966

Project Title: Stable Fluorescent Converter Solutions
Enhancing Optical Pumping in the
Visible Region

Name of Contractor: Uppsala University, Uppsala, Sweden
Project Code No 4730
ARPA Order No. 306

This research is part of project DEFENDER under the joint sponsorship of the Advanced Research Projects Agency, the Office of Naval Research, and the Department of Defense.

Reported By:

Stig Claesson

Stig Claesson
Professor of physical chemistry

Wladimiroff

W.W. Wladimiroff
Senior Research Assistant

Date: December 31, 1966

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Final Report under Contract Nonr 4654(00)
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Final Report under Contract NoNr 4654(00)
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Stable Fluorescent Converter Solutions

Enhancing Optical Pumping in the Visible Region

ARPA Order No. 306, Project Code No. 4730

Summary

In the contract period covered by this report a series of photochemically stable fluorescent converter solutions has been composed. At the beginning of the contract period some new stable u.v. transmitting solution filters were developed and with these the photo-stability of the converter solutions could be studied under irradiation with high intensity u.v. light only. The results of the investigation concerning the u.v. transmitting filters has been reported earlier and is now available in print⁽⁴⁾.

Applying the converter solutions in combination with large energy linear flash lamps the relative increase R_λ of the intensity of the incident light on the irradiated system has proved to be of the order 1.5 - 3 in the region 4000 - 6000 Å, when a total electrical energy of 5.6 kJ was discharged through the lamps. By filling the inner tube of a double jacket quartz cell with 0.3 % Ludox suspension and placing the cell between two linear flash lamps, the R_λ values were determined measuring the intensities I_{λ, H_2O} and $I_{\lambda, conv}$ of the scattered light coming from the inner tube, while the annular space was filled with water and converter solution respectively. R_λ was defined as $\frac{I_{\lambda, conv}}{I_{\lambda, H_2O}}$ and measured with and without the use of a reflector.

The applicability of the idea of mixing fluorescent solutes A, B, C, in the same solvent, such that the emission band of A covers the absorption band of B, etc., thus pumping all light absorbed by the solution into the "last" component

of the mixture, has been investigated. It has turned out that this idea has no promising aspects in connection with the work undertaken here.

In the last section of this report the effect of a reflector on the R_λ values is analysed and a new method of coating a reflector surface with MgO is reported.

Introduction

The light output of most light sources used for optical pumping is quite uniform over a large wavelength region, but in general the relative intensity of the emitted radiation in the u.v. is much higher than in the vis. When the irradiated system (receiver) has an absorption band in the vis. only, the u.v. emission of the light source is wasted. The same holds true for the more common case of a system with absorption bands in both the u.v. and the vis., where excitation with only vis. light is obtained by means of an u.v. cut-off filter. The ruby laser rod is a good example: since it was found that intense u.v. radiation damages the crystal, laser rods are clad with a u.v. cut-off envelope.

Fluorescent converters can be very useful in this connection, as they can be applied both as cut-off filters and to increase the light intensity of the light source in the region of the fluorescence emission of the converter. Preliminary data have been published illustrating the potential use of fluorescent converter solutions to increase the radiation intensity of flash lamps in the vis. region (1).

Fluorescent converters which are to be used in combination with flash lamps, must have the added property of good photostability, otherwise frequent changing of the converter solution will be necessary.

The photo-stability and the fluorescence quantum yield of a fluorescent compound in solution depends often on the solvent used. A large number of fluorescent compounds in different solvents were tested to obtain a series of stable converters covering the region 4000 - 6000 Å. Moreover practical considerations make it undesirable to develop fluorescent converters which would need degassing to secure their photo-stability and therefore only systems which were in equilibrium with air have been investigated. This observation becomes even more clear when one thinks of the application of the described converters as cooling or thermostating solutions.

Applying fluorescent converters in such a way that the receiver is irradiated with photons which have either passed through the converter solution or which have originated in the converter solution by a fluorescence mechanism, the relative increase R_λ of the intensity at a wavelength λ of the incident light on the receiver is defined as

$$R_\lambda = \frac{I_{\lambda, \text{conv}}}{I_{\lambda, \text{H}_2\text{O}}} .$$

$I_{\lambda, \text{conv}}$ is the intensity of a wavelength λ of the incident light on the receiver, when a converter solution with an optical light pass of 1 cm is placed between the light source and the receiver.

$I_{\lambda, \text{H}_2\text{O}}$ is the intensity of a wavelength λ of the incident light on the receiver, when an H_2O filter with an optical light pass of 1 cm is placed between the light source and the receiver.

Applying fluorescent converters in the above mentioned way, the optimum concentration of the solute is the concentration for which the maximum values of R_λ are obtained. For each converter the optimum concentration has been found by determining

R_λ for different concentrations of the solute. The optimum concentration is directly dependent on the relation between the following quantities: (a) the absorption of the exciting light, (b) the emission of the fluorescent light, (c) the self-absorption of the converter solution, (d) the concentration quenching, (e) the transmission of the radiation from the light source at the wavelengths of the fluorescence emission of the converter.

Although the study of the relation between these quantities is of great interest, the purpose of the present investigation does not justify a further treatment of this subject here.

Experimental

A 0.3 % Ludox suspension (see Materials) was poured into the inner tube of a 20 cm long double jacket quartz cuvette with a 1 cm thick annular space. The annular space was filled with water and the relative intensities I_{λ, H_2O} of the incident light on the receiver were measured by placing the cuvette between the two linear flash lamps of flash apparatus VI (2) and focussing the scattered light from the Ludox suspension through one plane end window of the inner tube onto the slit of a Zeiss monochromator MM 12, forming the first element of the experimental arrangement normally used in kinetic spectroscopy.

The I_{λ, H_2O} values were determined at 50 Å intervals in the region 4000 - 6500 Å at a band width of 10 Å by photographing the oscilloscope trace of the photomultiplier signal on a Tektronix 533 with an operational amplifier plug-in unit type 0, displaying directly the integrated form of the flash intensity (at wavelength λ) versus time curve.

The I_{λ} values were measured using 5.4 kJ flashes - from 12 μF and 30 kV - with a $10 \mu\text{sec} \frac{1}{6}$ time (at 4000 \AA) throughout the investigation; air at a pressure of 20 mm Hg was applied as lamp filling. Replacing the water in the annular space of the cuvette with a particular fluorescent converter, the $I_{\lambda, \text{conv}}$ values were determined at 50 \AA intervals for the whole fluorescence emission band of the converter and at a band width of 10 \AA .

The accuracy of this method for the determination of the R_{λ} values depends mainly on two factors: the amount of stray-light from the flash lamps entering the monochromator slit and the reproducibility of the 5.4 kJ flashes.

Using an optical system consisting of two lenses and four diaphragms, the scattered light from the Ludox suspension passing through one end window of the cuvette was focussed onto the monochromator slit in such a way that, with the same sensitivity of the detection system as used for the determination of the I_{λ} values, no stray-light was detected when the Ludox suspension was poured out of the inner tube.

The reproducibility of the flashes produced by flash apparatus VI is such that photographing the oscilloscope trace displaying photomultiplier signal versus time gives curves of exactly the same height. It is for this reason that no use has been made of a reflector to focus the light from the flash lamps onto the cuvette, as the aging of the reflector material would have caused a certain change in the intensity of the incident light on the cuvette. $\text{\textcircled{x}}$)

$\text{\textcircled{x}}$) It has to be pointed out here that when a reflector is used, other R_{λ} values are obtained - see last section.

The advantages of this method for the determination of the R_λ values are evident: factors such as the spectral sensitivity of the photomultiplier and other properties of the detection system, or the aging of a fluorescent receiver as used by Holmström and Stening ⁽¹⁾, do not enter the determination of R_λ . At the same time one can test the photo-stability of a particular fluorescent converter simply by repetitively measuring the $I_{\lambda, \text{conv}}$ value at the fluorescence emission maximum of the converter, exposing the converter solution to a series of 5.4 kJ flashes. [The photo-stability of a 0.3 % Ludox suspension was tested by determining the light scattering intensities of the newly prepared suspension and of the same suspension exposed to onehundred 5.4 kJ flashes. These measurements were performed on a recording light scattering instrument described elsewhere ⁽³⁾. The suspension appeared to be completely stable under high intensity irradiation with u.v. and vis. light.

The concentration of 0.3 % was chosen, since with a 20 cm cuvette the contribution to I_λ of the scattered light coming from that half of the cuvette which faces away from the monochromator slit is still 30 % at this concentration. This was determined simply by screening one half of the cuvette with Al foil and measuring the change in I_λ .

Materials

Solvents. Alcohol (Vin och Spritcentralen), spectrographic grade, 99.5 %. Dimethylformamide [DMF] (Baker), pro analysi. Cyclohexane (Merck), for chromatography and cyclohexane (Mallinckrodt), spectrographic grade. Concentrated H_2SO_4

(Merck), pro analysi, 95-98 %. The solvents were used without further purification. No difference in fluorescence emission intensity was observed when either cyclohexane for chromatography, containing max. 0.03 % benzene, or spectrographic grade cyclohexane was used to prepare converters No. 1 and No. 4.

Solutes. Acridine (BDH), pro analysi, 9-oxo-9,10 dihydro-acridine [acridone] (Schuchardt) and 9-aminoacridine hydrochloride monohydrate (Merck), pro analysi, were used without further purification. 9,10-Diphenyl anthracene (Schuchardt), 2- α -naphthyl-5-phenyl-oxazole [α -NPO] (Schuchardt) and perylene (Schuchardt) were scintillator quality. Eosin (Merck), pro analysi, fluorescein (Riedel - de Häen), pro analysi, 2,7-dichlorofluorescein (Eastman Kodak), rhodamine B extra and rhodamine 6 GL (du Pont de Nemours) were dissolved in alcohol, containing 10^{-2} M NaOH, and chromatographically purified on an aluminium oxide column.

Ludox, HS, (du Pont de Nemours) is a colloidal silica suspension, containing 30 % colloidal silica as SiO_2 . Approximate particle diameter: 15 μ . Stable diluted suspensions are obtained when water, containing 2 g/l NaCl, is added.

The Converters

The composition of the converter solutions is given in Table 1. The concentrations of the fluorescent solutes are the previously mentioned optimum concentrations.

For some solutes the maximum fluorescence quantum yield is obtained in slightly acid or alkaline solution in alcohol; to keep the water content of the alcohol low, the H_2SO_4 or NaOH aliquot was added to the solution as 2 M H_2SO_4 or 2 M NaOH respectively. The starred converters have a lower value for

R_λ max. than the corresponding converters with R_λ max. at nearly the same wavelength λ . The starred converters are added to the table because of their different transmission spectra, which may make these converters appropriate for irradiation experiments where some part of the u.v. radiation has to be cut off, which is transmitted by the converters with the higher value for R_λ max.

In many irradiation experiments complete cut-off of the u.v. radiation coming from the light source is necessary. The described converters could still be applied with full efficiency if a 1 cm layer of converter No. 3 or some other filter, cutting off the u.v., could be placed between the annular space containing the appropriate converter and the receiver. In flash photolysis work this is difficult to realize, since the double jacket cuvettes generally used have only one annular space and cuvettes with two annular spaces are difficult to make or may not be applicable, when the distance between the two flash lamps is too small. For this reason one would like to add a stable solute, cutting off the u.v. radiation from the flash lamps completely, to the appropriate converter solution.

A suitable solute is α -NPO, which can be dissolved to a concentration of $5 \cdot 10^{-4}$ M in all solvents used to compose the described converters and it has the necessary photo-stability. The result of adding α -NPO to the converter solution, however, is a decrease in the R_λ values, partly as a result of concentration quenching, partly because of the overlapping u.v. absorptions of the fluorescent solute and α -NPO (see Mixed Fluorescent Converters). The decrease in the R_λ values is illustrated by converter No. 10.

Table 2 gives the R_λ values of the converters measured at 18° C. For the convenience of the reader the transmission spectra and the fluorescence emission spectra are given in Figs 1-11. The

transmission spectra were obtained by means of a Bausch and Lomb recording spectrophotometer, type Spectronic 505. The fluorescence emission spectra were obtained with a Zeiss spectrofluorometer set, consisting of xenon arc LX 501, fluorescence attachment ZFM 4, monochromator M 4 Q III, and detection amplifier PMQ II. The emission spectra were measured with a constant monochromator slit width, are drawn at an arbitrary scale and not corrected for self absorption or photomultiplier sensitivity.

The photo-stability of the converters is such that the solutions can be irradiated with at least twenty five 5.4 kJ flashes, without this causing a significant change in the R_λ values or the transmission spectra.

It has been found that the fluorescence emission of converter No. 12 decreases slowly when the solution has been standing longer than a week at room temperature. The other converters can be kept at room temperature for a much longer period without any noticeable change in fluorescence emission.

Some of the described converters can undoubtedly be improved and some gaps in the converter series be filled up by a more extended investigation covering more solutes. The aim of the work presented here, however, is to show that a series of stable fluorescent converters can be composed, increasing the radiation intensity of flash lamps in the vis. region to a considerable extent.

Other Fluorescent Solutes Tested

The relation between fluorescence quantum yield, emission band width and the R_λ values of a converter solution is such that the quantum yield must be high and the emission band width narrow to get good R_λ values; even when the fluorescence quantum yield of

a solute is nearly 1, the emission band can be too broad to give proper R_{λ} values.

In the search for other converter solutions the following fluorescent solutes were tested and rejected, either because of insufficient photo-stability, insufficient fluorescence emission, or both. Acriflavine, alloxazine, m-nitrodimethylaniline, anthracene, anthranilic acid, auramine, rose bengale, benzidine, biphenyl, carbazole, o-coumaric acid, erythrocin, fluorene, lumazine, α - and β -naphthol, 2,5-dibiphenyloxazole (BBO), phenanthrene, phenosafranine, primuline, 3-aminophthalimide, pyrene, quinine sulfate, 5,6-benzoquinoline, magdala red, riboflavine and umbelliferone.

The above mentioned solutes were tested in one or more of the following solvents: water, alcohol, DMF, cyclohexane, benzene and conc. sulfuric acid. When the solute could be forced into an ionic state by dissolving in conc. sulfuric acid, different proton concentrations were tried for the aqueous and the alcohol solution, to obtain the ionic state in a less viscous medium. (Perylene and 9-aminoacridine e.g., when dissolved in conc. sulfuric acid, show absorption and emission spectra which are quite different from the spectra obtained with the pure alcohol solutions.) However none of the tested solutions gave a new useful converter.

Mixed Fluorescent Converters

The applicability of the idea of mixing fluorescent compounds A, B, C, ... in the same solvent, such that the emission band of A covers the absorption band of B, etc., thus pumping all light absorbed by the solution into the "last" component of the mixture, has been investigated. It has turned out that this

idea has no promising aspects in connection with the work undertaken here. As the two compounds A and B, of which the emission band of A covers the absorption band of B, are generally quite alike in a chemical sense, the u.v. absorptions almost completely overlap, even when the absorption bands in the vis. region lie approx.

200 Å apart. In a mixture of two fluorescent compounds, where the concentration effects have been taken care of, using half the optimum concentration for both A and B, the finite number of photons coming from the light source is either absorbed by A or by B in a competitive way, as the absorption spectra of A and B not only overlap almost completely in the u.v., but even to a considerable extent in the vis. at the concentration used.

It has turned out that to obtain a proper transfer between A and B in a mixture, the concentration of both compounds has generally to be so much lower than the optimum concentration of solutions of A and B separately, that the increase in the intensity of the fluorescence emission of B, when pumping from A to B, does not result in the amount of fluorescent light which is obtained when B alone is used at optimum concentration.

The Effect of a Reflector

It is evident that the R_λ values are dependent on the geometry of the system and on the type of flash lamps used in combination with the fluorescent converters. The first condition necessary to obtain good R_λ values is a very high colour temperature of the applied lamps. The higher the discharged voltage the higher the colour temperature becomes. In this connection can be mentioned that even the colour temperature of a high pressure xenon arc is too low to give a detectable increase in light intensity when this light source is used in combination with any of the converters.

In most flash lamp applications a MgO coated or aluminium reflector is used to "focus" all available light onto the receiver. However, particularly the reflectance for the u.v. of such reflectors decreases distinctly with use. The R_λ values have therefore been determined without the use of a reflector, as only in this way could the R_λ values be correlated.

It has to be pointed out that lower R_λ values are obtained, for the same converter, when a reflector is used. This can be illustrated in the following way - see Fig. 12.

First the case when no reflector is used.

I_{λ, H_2O} is measured, S is filled with water. A light wave α coming from the left lamp enters S at an angle α which sends a through S without hitting R. This holds for all light waves entering the unshaded part of S.

$I_{\lambda, conv}$ is measured, S is filled with converter solution. A light wave α coming from the right lamp enters S under the same angle α , is absorbed by a molecule of the fluorescent solute and a light wave e at wavelength λ is emitted. The fluorescent light of the excited molecules in S is emitted in all directions, but a certain fraction of the emitted light will hit R. As the unshaded part of S is about 50 % larger than the shaded part of S, the amount of fluorescent light hitting R coming from the unshaded part of S is considerably larger than the amount of light coming from the shaded part of S. The fluorescent converter acts to a certain extent as reflector.

Second, the case when a reflector is used.

I_{λ, H_2O} is measured, S is filled with water. "All" light coming from the flash lamps will hit R, as even those light waves entering the unshaded part of S and being transmitted

without hitting R directly, will fall on R after a number of reflections.

$I_{\lambda, \text{conv}}$ is measured, S is filled with converter solution. The amount of fluorescent light coming from the unshaded part of S is still larger than the amount of fluorescent light coming from the shaded part, but now it is easily seen that R_{λ} (with refl) must be smaller than R_{λ} (without refl) as the ratio

$$\text{ratio } \frac{I_{\lambda, \text{conv}} (\text{with refl})}{I_{\lambda, \text{conv}} (\text{without refl})} \text{ is considerably smaller than the } \frac{I_{\lambda, \text{H}_2\text{O}} (\text{with refl})}{I_{\lambda, \text{H}_2\text{O}} (\text{without refl})} .$$

To determine the decrease of the R_{λ} values when a reflector is used, a cylindrical MgO coated reflector *) with a diameter of 19 cm was placed around the experimental arrangement

*) The generally used method for coating reflector surfaces with MgO is to smoke on the oxide from burning Mg ribbon. For larger surfaces this is a tedious and time consuming procedure, but the main drawback of this method is the fact that the smoked-on MgO coating is so loosely bound to the base material that it easily falls off when the shock wave in the reflector, caused by high energy discharges, hits the MgO layer.

A better and quicker method is to suspend approx. 150 g/l MgO (pro analysi) in chloroform and with this suspension paint a sand-papered Perspex surface by means of an air-pressured paint-sprayer. With an air pressure of ~ 3 atm a smooth well bound MgO coating is obtained which stands strong mechanical shocks. As Perspex dissolves in chloroform the bond between the base material and the first MgO layer is very good and giving the coating a thickness of at least 1 mm the final surface consists of pure MgO.

shown in Fig. 12. The measurements performed with this set-up showed that the R_λ values > 1 given in Table 2 have to be decreased in the following way when a reflector is used:

$$R_\lambda \text{ (with refl)} \approx \frac{2(R_\lambda - 1)}{3} + 1 = \frac{2R_\lambda + 1}{3} .$$

Table 1. The converter solutions

No.	$\lambda(\text{\AA})^b$	$R_\lambda \text{ max.}^a$	Converter composition
1	4300	1.75	10^{-3} M 9,10-Diphenyl anthracene in cyclohexane
2	4400	1.65	$5 \cdot 10^{-4}$ M α -NPO in alcohol, containing 25 ml conc. $\text{H}_2\text{SO}_4/1$
3	4550	2.7	10^{-4} M 9-Aminoacridine in alcohol, containing 10^{-2} M H_2SO_4
4	4700	2.3	10^{-4} M Perylene in cyclohexane
5	4750	1.9	$5 \cdot 10^{-4}$ Acridone in alcohol, containing 10^{-2} M NaOH
6	4950	1.65	$2 \cdot 10^{-4}$ Acridine in alcohol, containing 10^{-2} M H_2SO_4
7	5350	3.35	$5 \cdot 10^{-5}$ M Fluorescein in alcohol, containing 10^{-3} M NaOH
8	5450	3.2	$5 \cdot 10^{-5}$ 2,7-Dichlorofluorescein in alcohol, containing 10^{-3} M NaOH
9	5700	3.25	$5 \cdot 10^{-5}$ M Rhodamine 6 GL in alcohol
10	5700	2.35	$5 \cdot 10^{-5}$ M Rhodamine 6 GL + $5 \cdot 10^{-4}$ α -NPO in alcohol
11	5750	2.95	$5 \cdot 10^{-5}$ M Rhodamine 6 GL in DMF
12	5750	2.1	$5 \cdot 10^{-5}$ M Eosin in DMF
13	5850	2.45	$5 \cdot 10^{-5}$ M Rhodamine B extra in alcohol, containing 10^{-3} M NaOH

^a Maximum value of R_λ for each converter. ^b Wavelength at which $R_\lambda \text{ max.}$ was found; for the majority of the converters this wavelength does not coincide with the fluorescence emission maximum, but lies at longer wavelength.

Table 2. The R_λ values of the converters when applied in combination with air filled linear flash lamps and without the use of a reflector. When a reflector is used the R_λ values > 1 in this table have to be decreased as follows:

$$R_\lambda (\text{with refl}) \approx \frac{2 R_\lambda + 1}{3}$$

Converter No. 1		Converter No. 3		Converter No. 5	
λ (Å)	R_λ	λ (Å)	R_λ	λ (Å)	R_λ
4150	0.95	4300	0.9	4500	0.6
4200	1.25	4350	1.6	4550	1.2
4250	1.45	4400	1.9	4600	1.3
4300	1.75	4450	1.75	4650	1.45
4350	1.55	4500	2.6	4700	1.7
4400	1.5	4550	2.7	4750	1.9
4450	1.4	4600	2.35	4800	1.6
4500	1.35	4650	2.15	4850	1.5
4550	1.3	4700	2.0	4900	1.4
4600	1.25	4750	2.0	4950	1.5
		4800	1.9	5000	1.1
		4850	1.45		
		4900	1.4		
		4950	1.25		
Converter No. 2		Converter No. 4		Converter No. 6	
λ (Å)	R_λ	λ (Å)	R_λ	λ (Å)	R_λ
4100	1.1	4450	0.8	4550	1.3
4150	1.25	4500	1.4	4600	1.3
4200	1.35	4550	1.4	4650	1.4
4250	1.45	4600	1.5	4700	1.45
4300	1.55	4650	2.1	4750	1.6
4350	1.55	4700	2.3	4800	1.5
4400	1.65	4750	2.25	4850	1.6
4450	1.5	4800	1.65	4900	1.55
4500	1.6	4850	1.45	4950	1.65
4550	1.4	4900	1.4	5000	1.2
4600	1.3	4950	1.55	5050	1.25
4650	1.3	5000	1.2	5100	1.4
4700	1.2				

Converter No. 7		Converter No. 9		Converter No. 11	
λ (Å)	R_λ	λ (Å)	R_λ	λ (Å)	R_λ
5200	1.1	5500	1.0	5600	1.45
5250	2.2	5550	2.15	5650	1.9
5300	3.15	5600	2.85	5700	2.25
5350	3.35	5650	3.2	5750	2.95
5400	3.3	5700	3.25	5800	2.8
5450	2.8	5750	3.2	5850	2.6
5500	2.6	5800	2.8	5900	2.3
5550	2.5	5850	2.75	5950	2.2
5600	2.3	5900	2.6	6000	2.1
5650	2.0	5950	2.3	6050	2.0
5700	1.9	6000	2.1	6100	1.9
5750	1.8	6050	2.0	6150	1.75
5800	1.7	6100	1.9	6200	1.65
		6150	1.7		
Converter No. 8		Converter No. 10		Converter No. 13	
λ (Å)	R_λ	λ (Å)	R_λ	λ (Å)	R_λ
5300	1.0	5550	1.35	5700	1.15
5350	1.85	5600	2.05	5750	1.8
5400	2.9	5650	2.25	5800	2.15
5450	3.2	5700	2.35	5850	2.45
5500	3.1	5750	2.3	5900	2.35
5550	3.0	5800	2.2	5950	2.2
5600	2.95	5850	2.2	6000	2.0
5650	2.55	5900	2.1	6050	1.9
5700	2.3	5950	1.9	6100	1.8
5750	2.2	6000	1.8	6150	1.65
5800	2.05	6050	1.7	6200	1.55
5850	2.0	6100	1.6		
5900	1.8	6150	1.45		
5950	1.6				

(Table 2 cont.)

Converter No. 12	
λ (Å)	R_λ
5600	1.15
5650	1.65
5700	1.85
5750	2.1
5800	2.05
5850	2.05
5900	2.05
5950	1.85
6000	1.8
6050	1.7
6100	1.6
6150	1.5
6200	1.4

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Legends to illustrations

Fig. 1. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 1, at 18° C; optical path 1 cm.

Fig. 2. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 2, at 18° C; optical path 1 cm.

Fig. 3. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 3, at 18° C; optical path 1 cm.

Fig. 4. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 4, at 18° C; optical path 1 cm.

Fig. 5. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 5, at 18° C; optical path 1 cm.

Fig. 6. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 6, at 18° C; optical path 1 cm.

Fig. 7. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 7, at 18° C; optical path 1 cm.

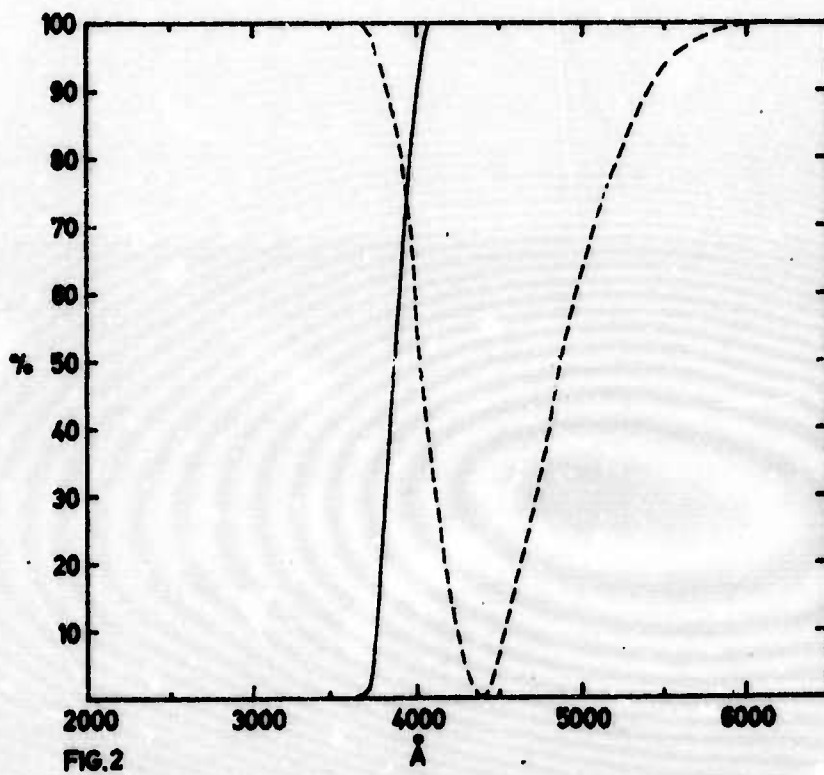
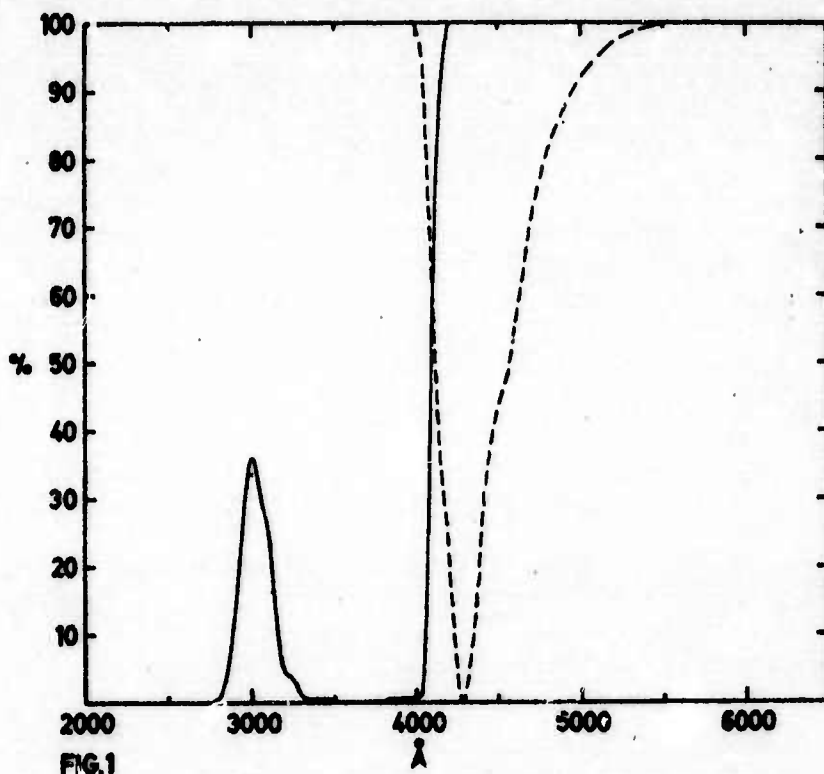
Fig. 8 - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 8, at 18° C; optical path 1 cm.

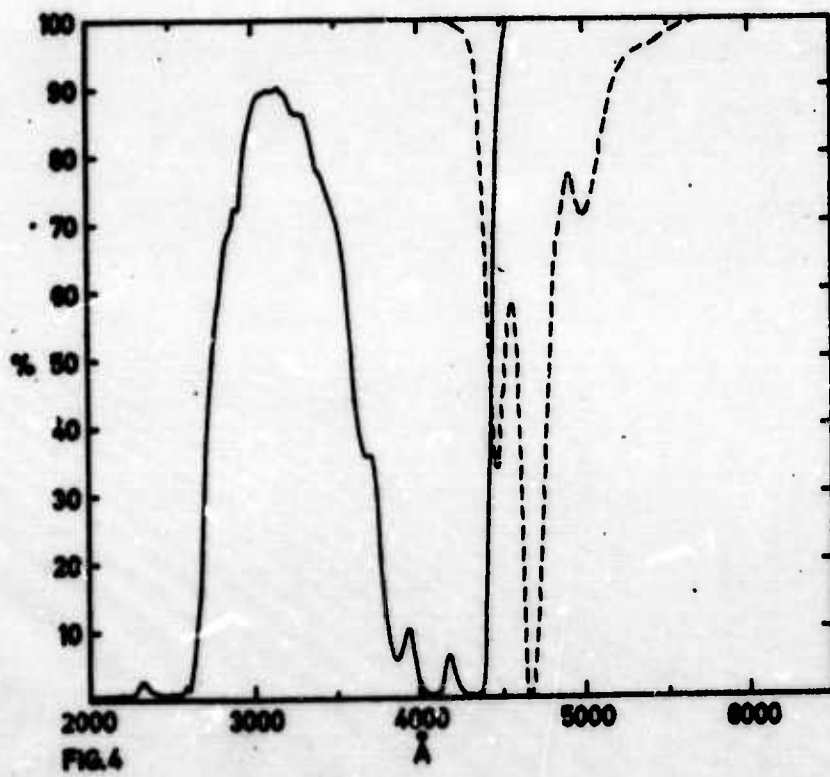
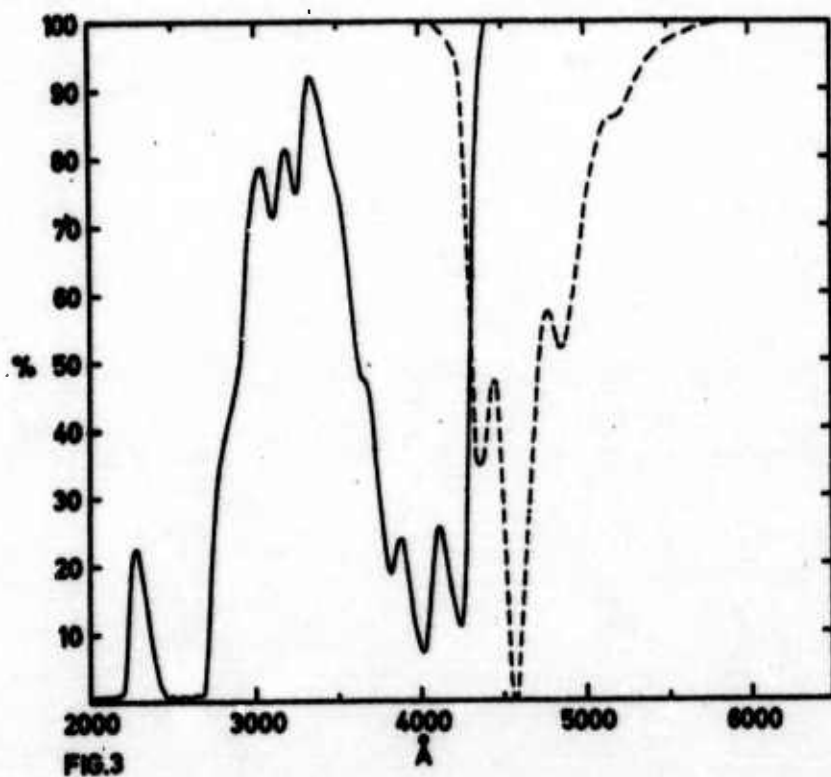
Fig. 9. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 9 (1) and converter No. 11 (2), at 18° C; optical path 1 cm.

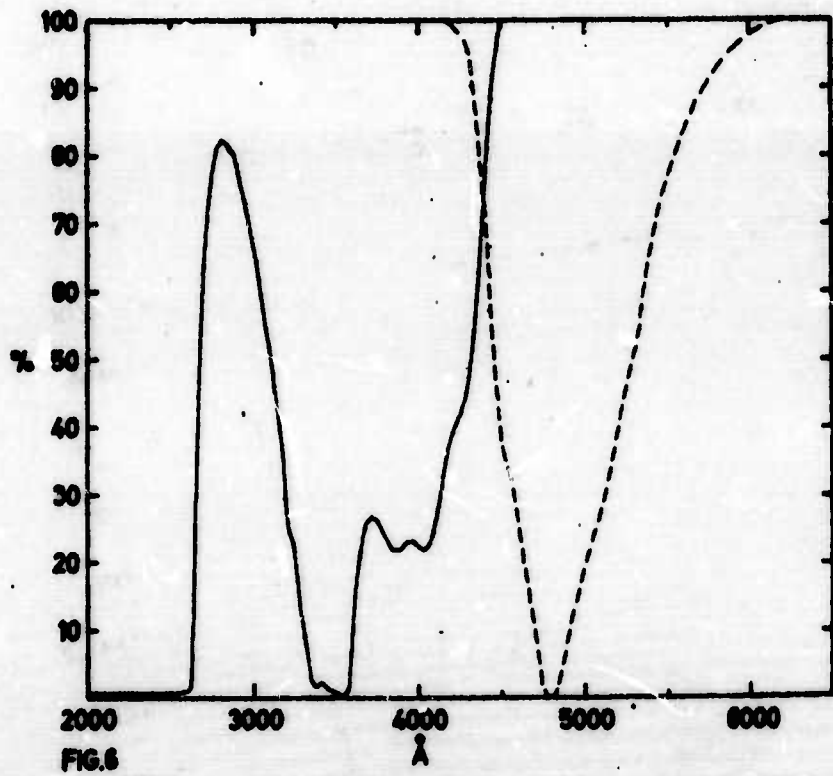
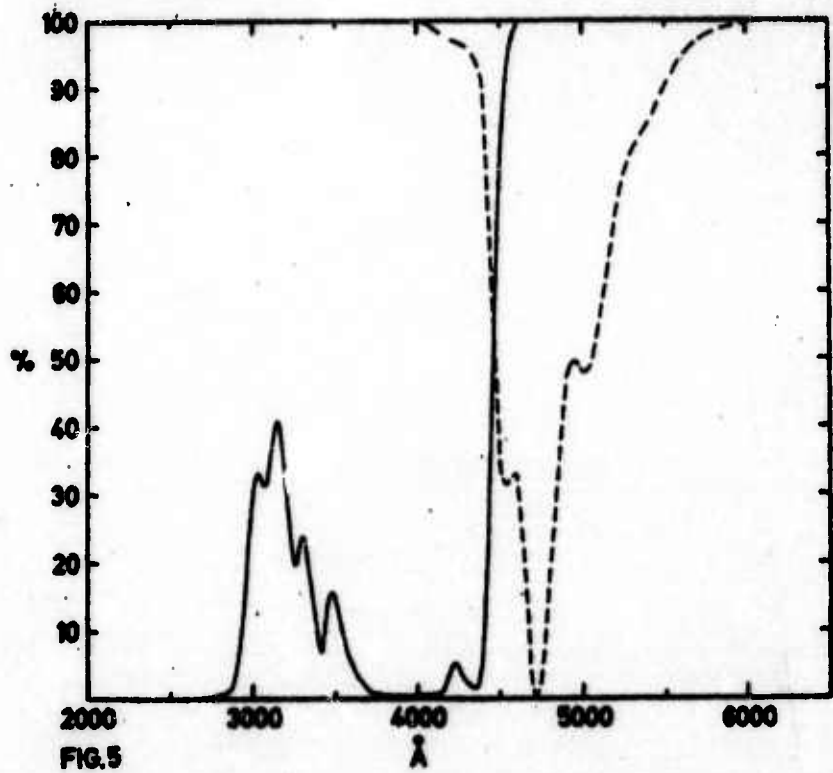
Fig. 10. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 12, at 18° C; optical path 1 cm.

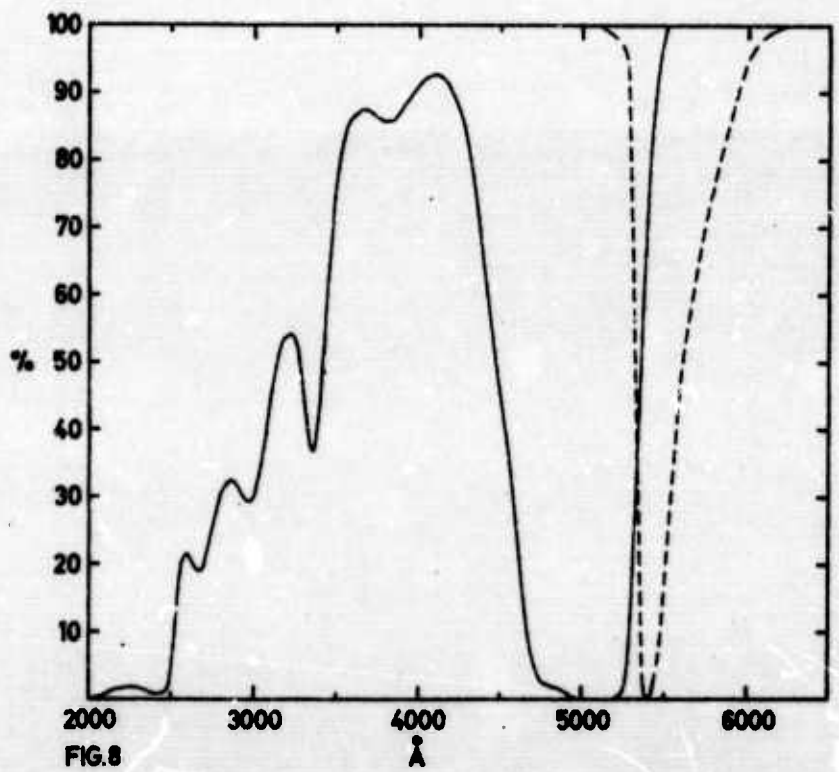
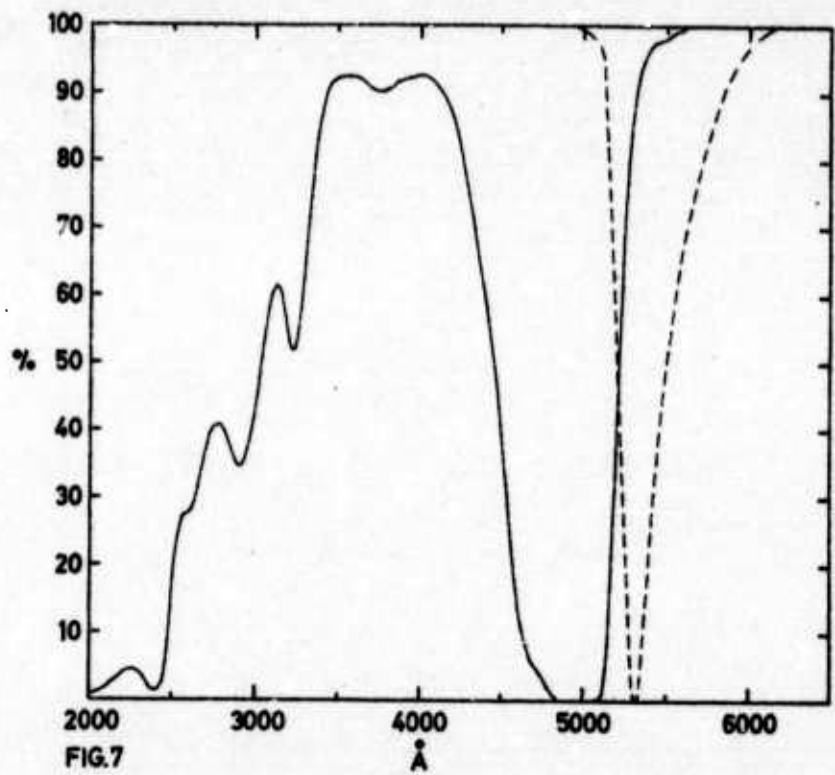
Fig. 11. - The transmission spectrum, measured against air, and the fluorescence emission spectrum of converter No. 13, at 18° C; optical path 1 cm.

Fig. 12. - Section of the experimental arrangement drawn to scale. L flash lamps; S annular space and R inner tube of quartz cuvette; shaded part of S: part of the annular space through which the flash lamps illuminate R directly.









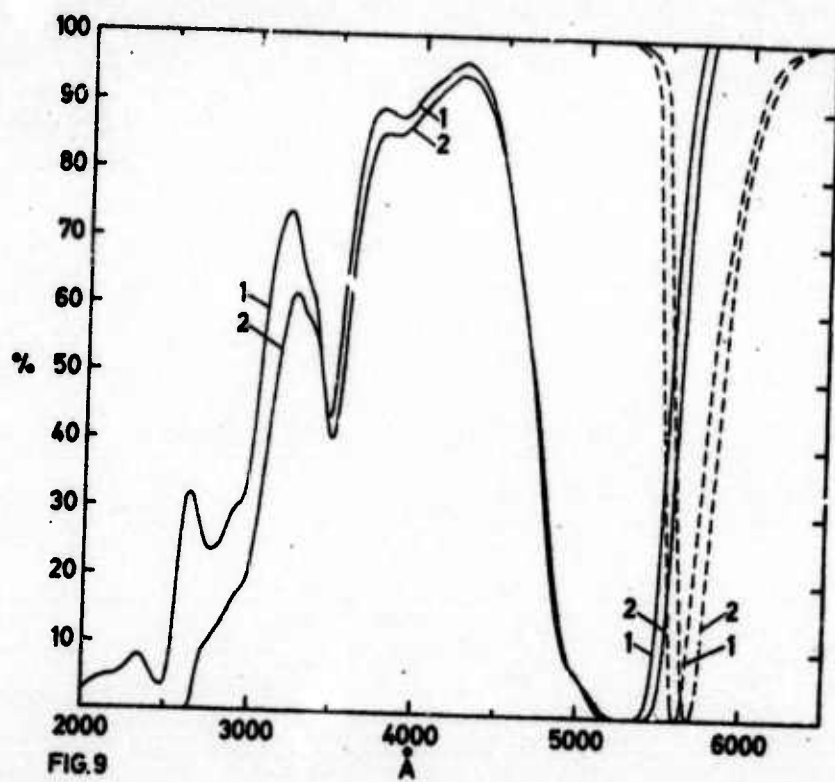


FIG. 9

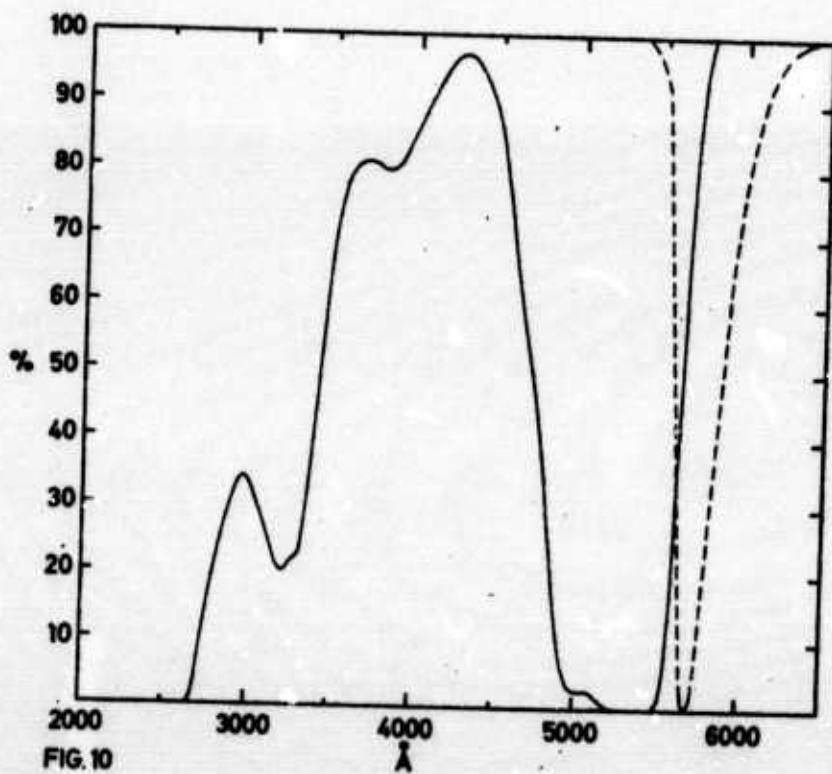
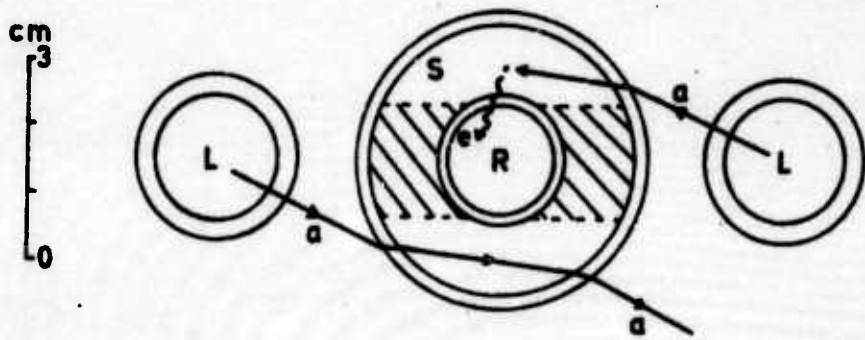
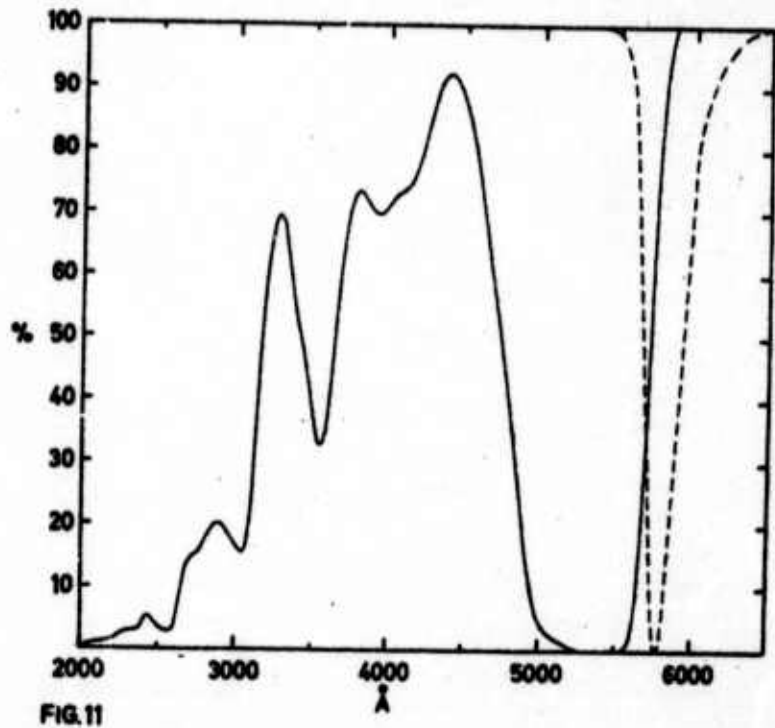


FIG. 10



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1. ORIGINATING ACTIVITY (Corporate author) Institute of Physical Chemistry University of Uppsala Uppsala Sweden		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE Stable Fluorescent Converter Solutions Enhancing Optical Pumping in the Visible Region			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report for the Period 1 October 1964 through 30 September 1966			
5. AUTHOR(S) (Last name, first name, initial) Claesson, Stig Wladimiroff, W.W.			
6. REPORT DATE December 31, 1966		7a. TOTAL NO. OF PAGES 39	7b. NO. OF REFS 4
8a. CONTRACT OR GRANT NO. Nonr 4654(00)		8b. ORIGINATOR'S REPORT NUMBER(S)	
a. PROJECT NO. ARPA Order No. 306 Program Code 4730		9. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. AVAILABILITY/LIMITATION NOTICES "Qualified requesters may obtain copies of this report from DDC"			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY ARPA, ONR, and DOD. Administered by Department of the Navy, Office of Naval Research, Washington, D.C. 20360	
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DD FORM 1473
1 JAN 64

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14. KEY WORDS	LINK A		LINK B		LINK C	
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