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Photochemical study of para-substituted anilines

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Abstract

A study of the photochemical behaviour of three para-substituted anilines with low photoreactivity has been carried out.

The photoproducts formed via irradiation at $\lambda > 300$ nm of solutions of 4-aminobenzylidene camphor (ABC) diisobutyl 4-aminobenzal malonate (BMA) and 2-ethylhexyl-4-aminobenzoate (PAB) in methanol under aerated conditions have been identified.

In methanol the direct irreversible phototransformation quantum yields are very low ($(3–10) \times 10^{-5}$).

The three compounds have a similar photochemical behaviour leading to the formation of photoproducts with absorption spectra very similar to the spectra of the initial compounds. In an acidic environment or in an aqueous solution a very fast back reaction occurred. NMR, IR and mass spectroscopy were used to characterize the unsubstituted Schiff bases that were formed. These photoproducts can also be obtained indirectly from the irradiation of diacetyl with a quantum yield of $(1–4) \times 10^{-2}$.

It can be proposed that the first step of the direct photochemical process is the formation of an aminyl radical.

Keywords: Para-substituted anilines; Phototransformation

1. Introduction

Among the various photostable UV absorbers used as sunscreens, the para aminobenzoic acid (PABA) and benzylidene camphor derivatives are effective UV filters for cosmetic applications [1–4]. Benzylidene malonate derivatives are UV absorbers used in the photoprotection of automotive coatings [5]. When cosmetic applications are considered, a good photostability is a strict requirement for any development of new filters. Despite a very low phototransformation quantum yield, photoproducts appear during the irradiation. Analysis of these photoproducts is very important in order to estimate a potential phototoxicity.

Some PABA and benzylidene malonate derivative photoproducts have been analysed, but benzylidene camphor derivative photoproducts have never been studied; upon light exposure, benzylidene malonate derivatives are known to dimerize in substituted cyclobutane derivatives [6].

Photoproducts of PABA in aqueous solutions have been analysed by various authors, but no agreement on their nature has been obtained. From irradiated aqueous solutions of PABA (7×10^{-5} M) at 254 and 313 nm in the presence of oxygen, Gasparro [7] isolated two compounds found to be the two forms E and Z of azodibenzoic acid. These photoproducts may be responsible for the observed cases of photosensitization effects [8]. These results were contradicted by Shaw et al. [9], who have identified different photoproducts of PABA. The nature of these photoproducts was found to vary with pH and concentration and to be modified by the dissolved molecular oxygen: in deoxygenated solutions, between pH 7.5 and 11, 4-(4′-aminophenyl) aminobenzoic acid and 4-(2′-amino-5′-carboxyphenyl) aminobenzoic acid were detected, whereas in aerated solutions 4-amino-3-hydroxybenzoic acid, 4-aminophenol and 4-(4′-hydroxyphenyl) aminobenzoic acid were analysed. The quantum yields of the formation of 4-(4′-aminophenyl) aminobenzoic acid were highly pH dependent ($\phi \leq 10^{-4}$ at pH 7 and $\phi > 10^{-3}$ at pH 11). Rothman and Rubin [10] proposed that photo-oxidation of aromatic amines such as PABA led to the corresponding aromatic imine formation.

Detailed studies of the $E \leftrightarrows Z$ photoisomerization of some benzylidene camphor derivatives have been published [11–15]. Initial isomerization quantum yields ϕ° of these compounds have been determined: $\phi^{\circ} = 0.3$ in cyclohexane for benzylidene camphor at 365 nm [11]. The initial isomerization quantum yield depends neither on the concentration nor on the presence or absence of oxygen. The $E \leftrightarrows Z$ photoisomerization of benzylidene

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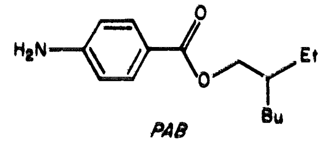
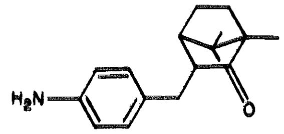
derivatives appears to be an important deactivation process occurring in these molecules. Benzylidene camphor derivatives are very slightly phototransformable ($\phi < 4 \times 10^{-4}$ in cyclohexane at 290 nm) [11]. Irreversible phototransformation products have not been identified.

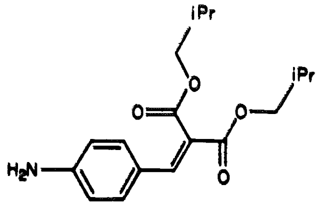
In the present paper three potential filters with an amino substituent in the para position on the aromatic ring will be examined: PAB, the ester of PABA; ABC, aminobenzylidene camphor; BMA, aminobenzylidene malonate.



PAB



ABC



BMA

The aim of this research is to determine the direct irreversible phototransformation quantum yields and to characterize the route of photoconversion from the analysis of the photoproducts. In order to study the behaviour of the compounds in the presence of radicals, diacetyl is added to the filter solutions and irradiated at 436 nm.

2. Materials and methods

The three compounds have been synthesized at the Centre de Recherche de l'Oréal [16–18]. ABC was supplied in the E form. Diacetyl was provided by Fluka (purissimum grade).

The studied filters were not hydrosoluble; all the solutions were made in methanol.

Irreversible phototransformation quantum yields were determined at room temperature (20 ± 2 °C) using a high pressure Osram 200 W mercury lamp coupled with a Bausch and Lomb monochromator. The light intensity was determined by actinometry based on the photoreduction of potassium ferrioxalate [19]. When necessary, the solutions were degassed by means of successive freeze–pump–thaw cycles.

In order to isolate the photoproducts, the solutions were irradiated in a cylindrical reactor equipped with a cooling jacket. For exposure of the compounds ABC and BMA, three MAW-Mazda 125 W lamps as a source of 365 nm radiation were located at about 10 cm around the tubular reactor. Solutions of the compound PAB were irradiated using a cylindrical reflector with an elliptical base. Three tubes (Philips 15 W TLD) whose emission was centred at 310 nm were located along the first focal axis and the cylindrical reactor along the second focal axis. Stirring was maintained during irradiation.

High performance liquid chromatography (HPLC) analyses were performed on a Waters 540 chromatograph equipped with a photodiode array detector 990. The Inertsil ODS2 column (5 μm, 250 × 4 mm^2) was used with a water–methanol mixture as eluent. The UV–visible measurements were carried out with a Cary 118C spectrophotometer (Varian).

IR spectra were obtained on an FTIR Nicolet 20SX spectrophotometer.

Mass spectra were provided by CNRS, Lyon (France) operating in the normal scan mode of 70 eV.

Photoproduct structures were determined by NMR spectroscopy using a Brucker MSL AC 400 spectrometer.

2.1. Determination of irreversible phototransformation quantum yield

The irreversible phototransformation quantum yield is defined as the ratio of the number of molecules disappearing through the photochemical processes to the total number of photons absorbed during the same period of time. Quantum yields were determined by two methods.

The first method is based on the HPLC determination of the variation in the concentration of the compound with the exposure time, which gives true values of the quantum yield.

The second method is based on UV spectrophotometry. The quantum yield is therefore determined from the slope of the tangent at the initial point of the curve which represents the variation in the compound absorbance vs. the exposure time. This technique only affords apparent quantum yields when the photoproducts are absorbing in the same range as the initial compound.

2.2. Induced phototransformation by radical attack

Radical species were provided by irradiation of diacetyl (7×10^{-3} M). This compound was chosen for its absorption at 436 nm (S1), a wavelength at which filters do not absorb.

In methanol a hemiacetal is formed (75% at 20 °C), but this does not interfere with the absorption at 436 nm. Diacetyl in aerated conditions is known to give radical species [20]. Induced phototransformation quantum yields were calculated from the variations in concentration of the initial compounds by HPLC measurements and light absorption of diacetyl at 436 nm.

3. Experimental results

3.1. UV spectra

The UV spectra of the three filters in methanol display two absorption bands. The positions and extinction coefficient values of the two bands are reported in Table 1.

3.2. Irreversible phototransformation quantum yield determination upon direct exposure

In the case of the compound ABC the UV irradiation induces a rapid photoisomerization leading to a photostationary state, from which the irreversible phototransformation can be observed. It was difficult to determine which one of the two isomers was degraded; only an upper limit of the quantum yield can be obtained using the lower value of the extinction coefficients of the two photoisomers (the Z form) for the determination of the variation in the concentration.

The irreversible phototransformation quantum yields ϕ_d have been measured using the two methods described previously: HPLC (Table 2) and UV determination (Table 3).

The results reported in Tables 2 and 3 prompt the following comments.

Table 1
Extinction coefficients at the maxima of the two bands of the filters (accuracy 5%)

	λ_{max} (nm)	ϵ (mol^{-1} l cm^{-1})
ABC	241	8600
	353	25300
BMA	240	9000
	355	27200
PAB	219	9300
	292	21400

Table 2
Irreversible phototransformation quantum yields in methanol determined by HPLC (accuracy 20%)

	λ_{irr} (nm)	[ ]$_o$ (mol l^{-1})	ϕ_d (true)
ABC	365	5.1×10^{-5}	2.9×10^{-5}
PAB	302	4.3×10^{-5}	1.1×10^{-4}
BMA	365	4.8×10^{-5}	Very low

Table 3
Irreversible phototransformation quantum yields in methanol determined by UV spectroscopy (accuracy 10%)

	λ_{irr} (nm)	[ ]$_o$ (mol l^{-1})	ϕ_d (apparent)
ABC	365	$51.\times10^{-5}$	2.1×10^{-5} max.
PAB	302	4.5×10^{-5}	4.2×10^{-5}
BMA	365	5.0×10^{-5}	Very low

Table 4
Induced irreversible phototransformation quantum yields in methanol (accuracy 20%); [diacetyl]$_o$ = 7×10^{-3} M, λ_{irr} = 436 nm

	[ ]$_o$ (mol l^{-1})	ϕ_d (induced)
ABC	4.1×10^{-5}	4×10^{-2}
PAB	4.9×10^{-5}	1×10^{-2}
BMA	5.6×10^{-5}	2×10^{-2}

(1) The chromatogram of a solution of BMA irradiated for 500 h in methanol and the initial one were identical. The irreversible phototransformation quantum yield was certainly very low but cannot be determined under our experimental conditions.

(2) Phototransformation quantum yields determined by UV spectroscopy are lower than quantum yields determined by chromatography, the photoproducts absorbing in the same range as the initial compounds.

(3) The three compounds ABC, PAB and BMA present particularly low direct phototransformation quantum yields in methanol, which is quite consistent with the use of these molecules as UV filters in cosmetic applications.

3.3. Irreversible phototransformation quantum yields photoinduced from the irradiation of diacetyl

Under visible exposure, diacetyl is known to give radicals with a high quantum yield [20].

Free-radical formation has been shown to occur in UV-irradiated skin and these agents may be responsible for the deleterious effects of UV upon skin [21]. This is why the behaviour of the three filters in the presence of radicals has been studied.

Induced irreversible phototransformation quantum yields are reported in Table 4.

The induced irreversible phototransformation quantum yields are about 100–1000 times higher than the direct phototransformation quantum yields.

3.4. Analysis of photoproducts

3.4.1. Irradiation and UV spectra

When solutions were degassed, no photoproducts appeared during irradiation. Thus the presence of oxygen is necessary for photoproduct formation.

During monochromatic irradiation and HPLC measurements, photoproducts have been detected for the compounds ABC and PAB. It is important to note that irradiation in the presence of diacetyl leads to the same photoproducts with an increased rate of formation.

In order to increase the quantity of photoproducts, concentrated solutions (about 10^{-4} M) in methanol have been irradiated in the devices previously described. Phototransformation has been studied by HPLC measurements. As shown in Figs. 1–3, a main photoproduct whose elution time is higher than the corresponding time of the initial compound was detected in each case. The two photoisomers E and Z of ABC appear on the chromatogram (Fig. 2).

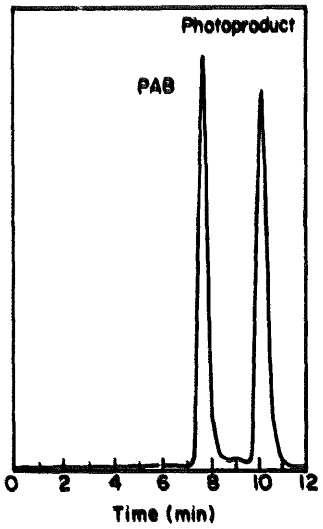


Fig. 1.

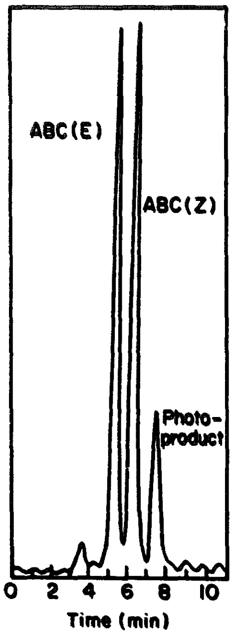


Fig. 2.

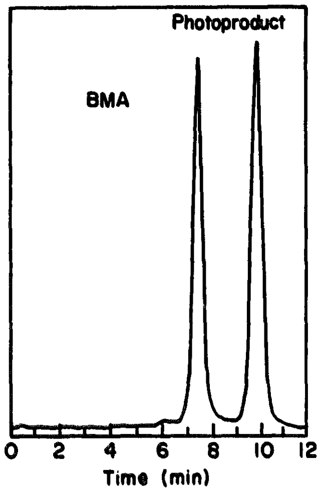


Fig. 3.

The waters 540 chromatograph equipped with a photodiode array detector allows the determination of the qualitative UV spectra of the photoproducts. As shown in Fig. 4, the UV spectra of the photoproducts and initial compounds are very similar: chromophore groups appear to be almost unchanged.

3.4.2. *Isolation and analysis of photoproducts*

In order to isolate the main photoproduct, a concentrated irradiated solution of PAB in methanol was eluted on semipreparative HPLC. The eluent was a mixture of methanol and water.

When collected fractions of photoproduct were analysed by HPLC, two peaks corresponding to the photoproduct and PAB respectively were detected. Indeed, this mixture was unstable: the proportion of PAB in the fractions increased with storage time and after a few minutes the photoproduct had disappeared. The same phenomena existed for ABC and BMA: a rapid back conversion of the photoproduct into the initial compound was observed in the presence of water or in an acidic environment.

When irradiated solutions were stored in methanol, no back reaction was observed. The most convenient procedure consisted of analysis of a mixture of an initial filter and its photoproduct. An irradiated solution of ABC was previously purified on a silica column (hexane–ethyl acetate as eluent) in order to get rid of ABC (E and Z forms) and to simplify the NMR spectrum. The resulting solution containing a majority of ABC photoproduct was maintained in the dark to avoid potential photoisomerization of the photoproduct.

To study the photoproducts, various analytical techniques were used.

IR spectroscopy. Analysis of the IR spectra in CCl_4 shows that the primary amine bands at 3505 and 3408 cm^{-1} present in the three filters disappear in the mixture

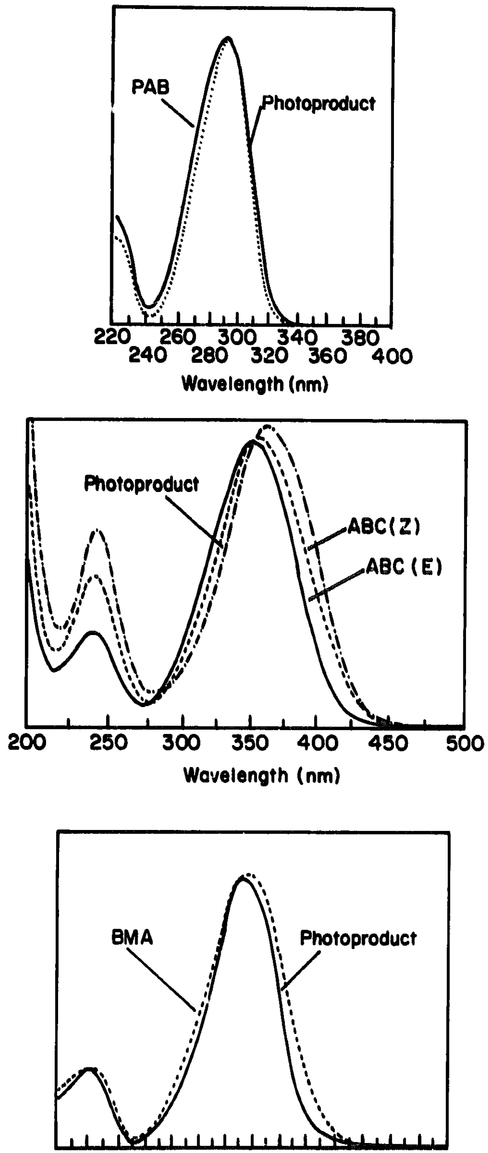


Fig. 4.

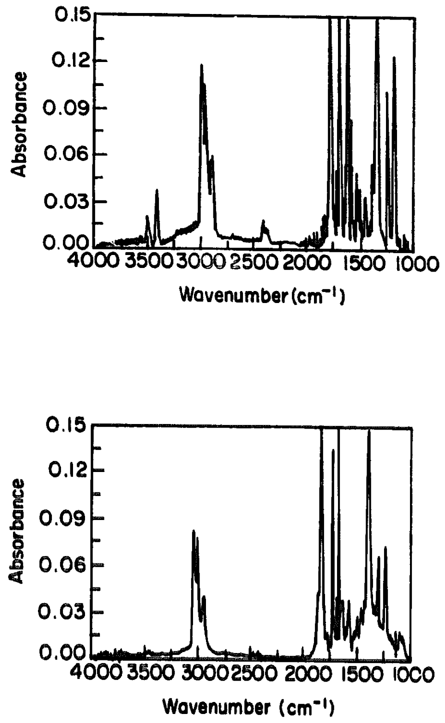


Fig. 5.

with photoproducts. In the range 1000–3000 cm^{-1} the two spectra were very similar. For example, the IR spectra of PAB and the mixture of PAB plus photoproduct are shown in Fig. 5. (The initial compound is present in the mixture in very low quantity.) Therefore the amino group is directly involved in the photochemical process.

NMR spectra. All the spectra were recorded in deuterated chloroform. From the NMR spectra of a mixture of filter plus photoproduct it can be noted that the values of chemical shifts of aromatic protons of the photoproduct are higher than those observed with the initial compound. Moreover, the typical structure of a para-substituted phenyl with two doublets is unchanged in the case of the photoproduct. Chemical shifts of aliphatic protons are identical for the initial compound and the photoproduct, so this part seems unchanged (Table 5). The amino group is probably replaced by another function which can increase the values of chemical shifts in the ortho position. Chemical shifts of aromatic protons in the meta position are almost unchanged.

Mass spectroscopy coupled with HPLC. Mass spectroscopy coupled with HPLC gives the following data: there is a difference of −12 g between the main fragments of the initial compound and the corresponding fragments of its photoproduct (Table 6).

UV spectrum evolution during irradiation of a solution of PAB in methanol. An irradiated solution of PAB at 302 nm exhibits an absorption beyond 330 nm (Fig. 6). Addition of water or acid can rapidly transform the photoproduct into PAB. By following the compound spectral changes of the solution, it was noted that the absorption beyond 300 nm remained constant. Thus this absorption is not due to the formation of the described photoproduct but to other minor compounds.

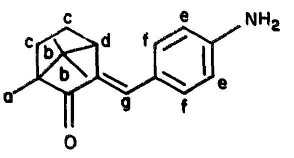
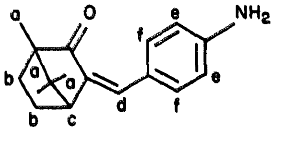
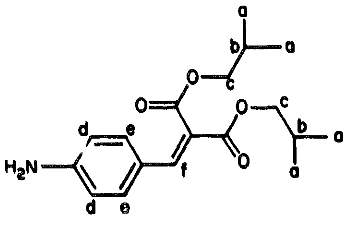
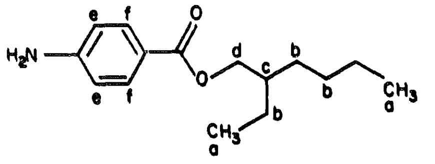
4. Discussion and conclusions

In brief, the following spectroscopic data have been obtained.

(1) The photoproducts did not include an amino group.

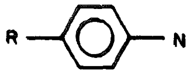
(2) The aromatic protons of the photoproducts had higher chemical shifts than the initial compounds.

Table 5
Chemical shifts of protons of the compounds ABC (E and Z), BMA and PAB and of their respective photoproducts in $CDCl_3$

	δ	Structure	Ident.	
ABC (E)	0.7		H_a	
	1		H_b	
	1.4–2.2		H_c	
	3.1		H_d	
	6.7	Doublet $J=8$ Hz	H_e	
	7.15	"	H_f	
	7.35	Singlet	H_g	
ABC (Z)	0.8–1		H_a	
	1.2–2.2		H_b	
	3.1		H_c	
	6.45	Singlet	H_d	
	6.7	Doublet $J=8$ Hz	H_e	
	7.9	"	H_f	
ABC photoproduct	0.8–1			
	1.2–2.2			
	3.1			
	6.5	Singlet		
	7.55	Doublet $J=8$ Hz		
	7.95	"		
BMA	1		H_a	
	2		H_b	
	4		H_c	
	6.6	Doublet $J=8$ Hz	H_d	
	7.3	"	H_e	
	7.6	Singlet	H_f	
BMA photoproduct	1			
	2			
	4			
	7.3	Doublet $J=8$ Hz		
	7.4	"		
	7.6	Singlet		
PAB	0.9		H_a	
	1.4		H_b	
	1.7		H_c	
	4.2		H_d	
	6.8	Doublet $J=8$ Hz	H_e	
	7.35	"	H_f	
PAB photoproduct	0.9			
	1.4			
	1.7			
	4.2			
	8.2	Doublet $J=8$ Hz		
	8.35	"		

(3) There was a difference of 12 g between the main fragments of the photoproducts and the initial compounds.

From all these analyses the main photoproduct is thought to be an unsubstituted Schiff base



(a) In fact, the mass difference between the imine function and the amino group is 12 g.

(b) The compounds with a $>C=N-$ group present an IR band of low intensity in the range 1650–1690 cm^{-1} [22,23]. This band does not appear in the IR spectra of photoproducts because it may be covered by the signal attributed to the ester function revealed at 1705 cm^{-1} or by the band at 1620 cm^{-1} attributed to $>C=C<$ bonds.

(c) Many compounds including the double bond $-N=C<$ have been studied by NMR spectroscopy [24]. The chemical shift in DMSO of the proton linked to

Table 6
Main fragments of mass spectra of PAB, ABC and BMA and their photoproducts

	Filter	Photoproduct
PAB	92	104
	120	132
	137	149
	249	261
ABC	77	77
	92	104
	106	118
	117	129
	171	183
	255	267
BMA	57	57
	117	129
	163	175
	190	202
	246	258
	263	275
	319	331

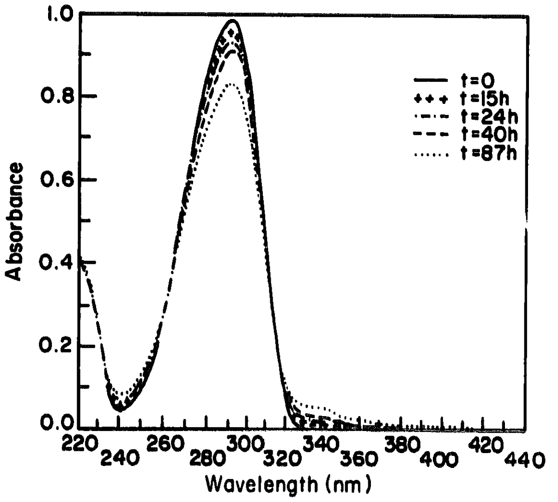
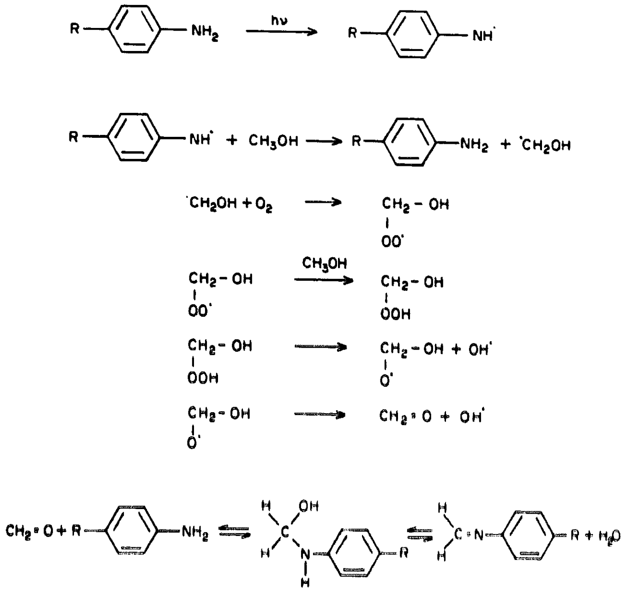


Fig. 6.

the carbon has been found to be in the range 7.22–7.25 ppm.

In our case the spectrum of PAB photoproduct shows a weak signal at 8 ppm which may be attributed to the two protons of the imino function. In the case of the compounds ABC and BMA the quantity of photoproduct analysed was very low, so the spectra were not well defined enough to detect a weak signal. Moreover, the imino group increases chemical shifts of aromatic protons in the ortho position without changing significantly chemical shifts of the meta position.

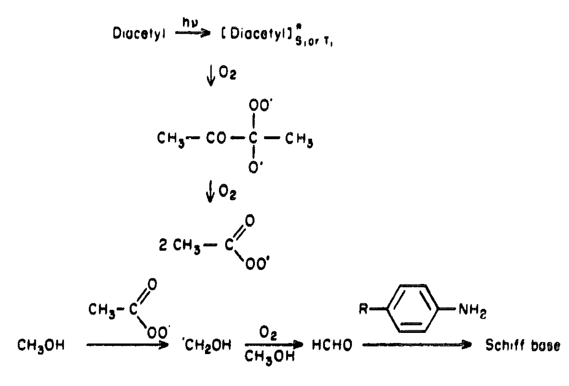
The formation of the photoproducts can be explained by a condensation of aldehyde or ketone with primary amine. These compounds are stable if there is at least one aryl group on the nitrogen or carbon [25]. In our experiments formaldehyde is formed by radical attack of aminyl on methanol, these radicals being unreactive with oxygen [26].



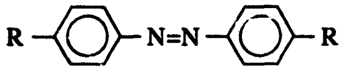
Schiff bases are known to hydrolyse easily, especially under acidic conditions, back to the original amine and carbonyl compound [27].

In order to confirm the structure of these photoproducts, the reaction between formaldehyde and the initial compounds has been studied. The reaction product analysed by HPLC had the same elution time and the same qualitative UV spectrum as the respective photoproduct described above. Moreover, the reaction product hydrolysed easily to give the initial compound.

The Schiff bases are also formed by induced phototransformation provoked by irradiation of diacetyl at 436 nm. This result allows us to think that the radicals obtained from diacetyl react with methanol to induce formaldehyde formation according to



As mentioned in Section 1, the formation of various compounds has been considered previously for PABA irradiated in aqueous solution. Under our conditions methanol orientates the reaction towards the formation of a Schiff base. Nevertheless, in the case of PAB the absorption beyond 330 nm of an irradiated solution may correspond to traces of a symmetrical azo compound



according to Gasparro [7].

It can be pointed out that irreversible phototransformation quantum yields in methanol are very low for the three compounds. A route of irreversible disappearance of filters through the analysis of photoproducts has been characterized: for the three compounds the amino group is involved in the photochemical process leading to the formation of Schiff bases, which are transformed into initial compounds in aqueous or acidic environments.

These photoproducts are obtained by direct irradiation with low quantum yield and by radical attack provided by irradiation of diacetyl at 436 nm with a higher quantum yield. The formation of an aminyl radical seems to be the first step in the direct photochemical process. In the photoinduced reaction the radicals issued from diacetyl react mainly with methanol.

References

[1] D.H. Liem and L.T.H. Hilderink, *Int. J. Cosmet. Sci.*, *1* (1979) 341–361.
[2] A. Langner and A.M. Kligman, *Arch. Dermatol.*, *105* (1972) 851–855.
[3] I. Willis and A.M. Kligman, *Arch. Dermatol.*, *102* (1970) 405–417.
[4] *J. Offic. Républ. Fr.*, (1989) 48.
[5] B.D. Gupta, L. Jirackova-Audouin and J. Verdu, *Eur. Polym. J.*, *24* (10) (1988) 947–951.
[6] M. Remmas, J.C. Soutif and J.C. Brosse, *Makromol. Chem.*, *192* (1991) 1849–1857.
[7] F.P. Gasparro, *Photodermatology*, *2* (1985) 151–157.
[8] J.C. Sutherland and K.P. Griffin, *Photochem. Photobiol.*, *40* (1984) 391–394.
[9] A. Shaw, L.A. Wainschel and M.D. Shetlar, *Photochem. Photobiol.*, *55* (1992) 647–656.
[10] S. Rothman and J. Rubin, *J. Invest. Dermatol.*, *5* (1942) 445–457.
[11] I. Beck, *Thesis (3ème cycle)*, University of Clermont-Ferrand, 1980.
[12] I. Beck, A. Deflandre, G. Lang, R. Arnaud and J. Lemaire, *Int. J. Cosmet. Sci.*, *3* (1981) 139.
[13] I. Beck, A. Deflandre, G. Lang, R. Arnaud and J. Lemaire, *J. Photochem.*, *30* (1985) 215–227.
[14] A. Deflandre and G. Lang, *Int. J. Cosmet. Sci.*, *10* (1988) 53–62.
[15] A. Deflandre and G. Lang, *Cosmet. Toiletries*, *103* (1988) 69–75.
[16] H. Richard, M. Leduc and A. Junino, *Eur. Patent 0 507 691 A1*, 1992.
[17] *Eur. Patent 2 151 503*, 1971.
[18] *Eur. Patent 2 385 685*, 1977.
[19] C.G. Hatchard and C.A. Parker, *Proc. R. Soc. Lond. A*, *235* (1956) 518.
[20] M. Bouchy, *Thesis*, University of Nancy, 1973.
[21] H.S. Black, *Photochem. Photobiol.*, *46*(2) (1987) 213–221.
[22] F.H. Snydam, *Anal. Chem.*, *35* (1963) 193.
[23] J. Fabian, M. Legrand and P. Poirier, *Bull. Soc. Chim. Fr.*, (1956) 1499.
[24] G. Slomp and J.G. Lindberg, *Anal. Chem.*, *39* (1967) 60.
[25] R.L. Reeves, in S. Pataï (ed.), *Chemistry of the Carbonyl Group*, Wiley, New York, 1966, pp. 608–614.
[26] J. Pospisil, in G. Scott (ed.), *Developments in Polymer Stabilisation*, Vol. 7, Elsevier Science, London, 1984, p. 24.
[27] D.J. Curran and S. Siggia, in S. Pataï (ed.), *Chemistry of the Amino Group*, Wiley, New York, 1968, p. 156.