[Chem. Pharm. Bull. 36(4)1483—1490(1988)]

A New Approach to Evaluating Photo-Stability of Nifedipine and Its Derivatives in Solution by Actinometry

KOICHI AKIMOTO,* KAORI KUROSAKA, HIROSHI NAKAGAWA and ISAO SUGIMOTO[1)]

Pharmaceuticals Research Center, Kanebo Ltd., 1–5–90, Tomobuchi-cho, Miyakojima-ku, Osaka 534, Japan

(Received August 12, 1987)

The photo-stability of nifedipine and its 4- or 1,4-substituted derivatives in methanol was studied. A ferrioxalate actinometer was used to measure cumulative number of photons as an index of light intensity. Under irradiation with a high-pressure mercury lamp, the photo-stability decreased in the order: 1-hydroxy-4-(*m*-nitrophenyl) compound, 4-(*p*-nitrophenyl) compound, 4-(*m*-nitrophenyl) compound, 1-methyl-4-(*o*-nitrophenyl) compound and nifedipine itself. The 4-phenyl compound and 4-(*o*-chlorophenyl) compound did not decompose in the range to 4×10^{21} quanta. Further, the photo-stability of nifedipine was quantitatively examined under sunlight, a fluorescent lamp and a high-pressure mercury lamp. The slopes of the linear plots of residual percent against cumulative number of photons irradiated through a UV-D33S colored glass filter were essentially the same for all three light sources. On the other hand, the slopes did not agree in the case of direct exposure without a filter. A good correlation between extent of photo-degradation and integrated illumination (lux × h) was not observed with or without the filter. By means of this actinometry with a UV-D33S colored glass filter, the 1-hydroxy-4-(*m*-nitrophenyl) compound and 4-(*m*-nitrophenyl) compound were quantitatively estimated to be more photo-stable than nifedipine by factors of 270 and 76, respectively, under a given light source.

Keywords——photo-stability; nifedipine; actinometry; sunlight; illumination; ferrioxalate; nifedipine derivative; fluorescent lamp; high-pressure mercury lamp

The properties of a candidate drug have to be fully examined from many physicochemical viewpoints at the development stage. Although many drugs are photo-sensitive, no general experimental methods for evaluating photo-stability have been established. Therefore, some experimental methods and standards for evaluating photo-stability of medicaments are needed. Several investigations on the photo-stability of drugs have been reported, in which light intensity was measured with illumination meter and represented as "illumination."[2–5)] A value measured with a selenium photoelectric cell type illumination meter is an index relating to "brightness" for human eyes, and such a meter hardly detects UV light intensity. Thus, "illumination" is not suitable as a measure for evaluating the photo-stability of drugs which decompose under ultraviolet (UV) light. Measurement of UV light intensity with a UV-intensity meter was described in some reports, in which light intensity was calculated from data relating to the spectral irradiance of the light source and represented in physical units, such as erg/cm^2 or μW/cm^2.[6,7)] However, it is difficult to obtain accurate data without corrections for the drift of intensity with time, because this meter measures instantaneous light intensity, similarly to an illumination meter.

Thus, we used a chemical actinometer for measurement of light intensity. A chemical actinometer is more convenient in handling than a UV-intensity meter or an illumination meter in the following respects. (a) Since a fresh actinometer can be easily prepared as required, there is no problem such as the fatigue effect in photoelectric devices. (b) Because this actinometry is based on measurement of cumulative number of photons during exposure,

accuracy of the data is not influenced by changes of light intensity during exposure. (c) Nonuniformity of beam intensity and beam size has no influence on the data because the form of the vessel for the actinometer can be arbitrarily selected.

Ferrioxalate and uranyl oxalate actinometers are well known chemical actinometers. The former, which was developed by Hatchard and Parker, is applicable to a wide range of wavelength and light intensity.[8] Further, it has so high a photo-sensitivity and is so easy to handle that it has been used widely in the field of organic photochemistry.

The principle of this method is as follows. Potassium ferrioxalate is subjected to photo-reduction to afford Fe(II) ion, which complexes 1,10-phenanthroline.

$$[Fe^{III}(C_2O_4)_3]^{3-} \xrightarrow{h\nu} C_2O_4^{-\cdot} + [Fe^{II}(C_2O_4)_2]^{2-}$$

$$C_2O_4^{-\cdot} + [Fe^{III}(C_2O_4)_3]^{3-} \longrightarrow C_2O_4^{2-} + [Fe^{III}(C_2O_4)_3]^{2-\cdot}$$

$$[Fe^{III}(C_2O_4)_3]^{2-\cdot} \longrightarrow [Fe^{II}(C_2O_4)_2]^{2-} + 2CO_2$$

The resulting complex is detectable spectrophotometrically. Further, the quantum yield of this photo-reduction by UV light in the range of 250 to 450 nm is constant, approximately 1.2. "Quantum yield" here means the probability of occurrence of the photo-reduction when one photon is absorbed by one molecule of potassium ferrioxalate. Consequently, the cumulative number of photons absorbed by the chemical actinometer can be calculated on the basis of the already reported quantum yield value.

In this study, we examined the relation between light intensity and photo-stability of nifedipine and six 4- or 1,4-substituted derivatives in methanol under sunlight, a fluorescent lamp and a high-pressure mercury lamp with a potassium ferrioxalate actinometer.

The mechanism of photo-degradation of nifedipine was proposed to be an intramolecular redox reaction.[9,10] The nitro group on the aromatic ring is considered to absorb light energy to afford its n–π^* excited state, which has radical-like reactivity. Little photo-degradation of nifedipine in solution was observed under light with a wavelength of more than 400 nm.[9] On the other hand, the energy distribution of the three light sources is different. A high-pressure mercury lamp shows the excitation spectrum of mercury vapor, which is mainly in the ultraviolet region. A fluorescent lamp radiates mainly in the visible region. The spectral distribution of sunlight is wide, covering the ultraviolet, visible and infrared regions.[11] Thus, we studied the effect of a colored glass filter on the photo-degradation as well.

Experimental

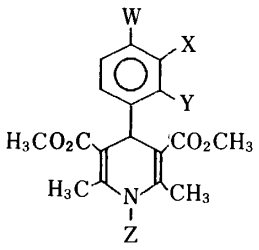
Materials——Nifedipine (JP XI) was used without further purification. Other chemicals were of reagent grade.

Preparation of Nifedipine Derivatives——The chemical structures of prepared nifedipine derivatives are shown in Chart 1. Compound II was prepared according to the procedure reported by Iwanami *et al.*[12] Compound III and compounds IV—VII were prepared according to the procedures described in the Japanese patents.[13,14] Absorption spectra of nifedipine and compounds II—VII were measured in methanol, and their absorption maxima and molar absorption coefficients are listed in Table I.

Preparation of Potassium Ferrioxalate[15]——Three parts of 1.5 M potassium oxalate were added to one part of 1.5 M ferric chloride, then the whole was stirred vigorously to afford a green precipitate of potassium ferrioxalate trihydrate. The precipitate was recrystallized three times from hot water, then air-dried at 45°C. These all procedures were carried out under a dark-red safety lamp.

Preparation of Acetate Buffer——Six hundred milliliters of 1 M sodium acetate was added to 360 ml of 0.5 M sulfuric acid. Further, water was added to make 1000 ml.

Exposure Test——Methanol solutions of nifedipine and its derivatives (2.9×10^{-4} M) were prepared and shielded from light. The exposure test under the light of a high-pressure mercury lamp (300 W) was carried out with a merry-go-round apparatus, shown in Fig. 1. The solutions of the actinometer and sample were rotated around the high-pressure mercury lamp at a constant speed (approximately 45 rpm) in order to ensure equalized photo-



Compound	W	X	Y	Z
nifedipine	H	H	NO_2	H
II	H	H	NO_2	CH_3
III	H	NO_2	H	OH
IV	H	NO_2	H	H
V	H	H	Cl	H
VI	H	H	H	H
VII	NO_2	H	H	H

Chart 1

TABLE I. Absorption Maxima (λ_{max}) and Molar Absorption Coefficients (ε) of Nifedipine and Its Derivatives in Methanol

Compound	λ_{max} (nm)	ε ($M^{-1}cm^{-1}$)
Nifedipine	326.0	4.65×10^3
	234.8	1.98×10^4
II	334.8	4.93×10^3
	240.8	1.73×10^4
III	353.8	5.36×10^3
	237.8	2.15×10^4
IV	350.8	5.89×10^3
	235.8	2.37×10^4
V	358.0	6.72×10^3
	237.0	1.90×10^4
VI	351.6	6.88×10^3
	235.8	1.71×10^4
VII	281.0	1.30×10^4
	233.0	1.98×10^4

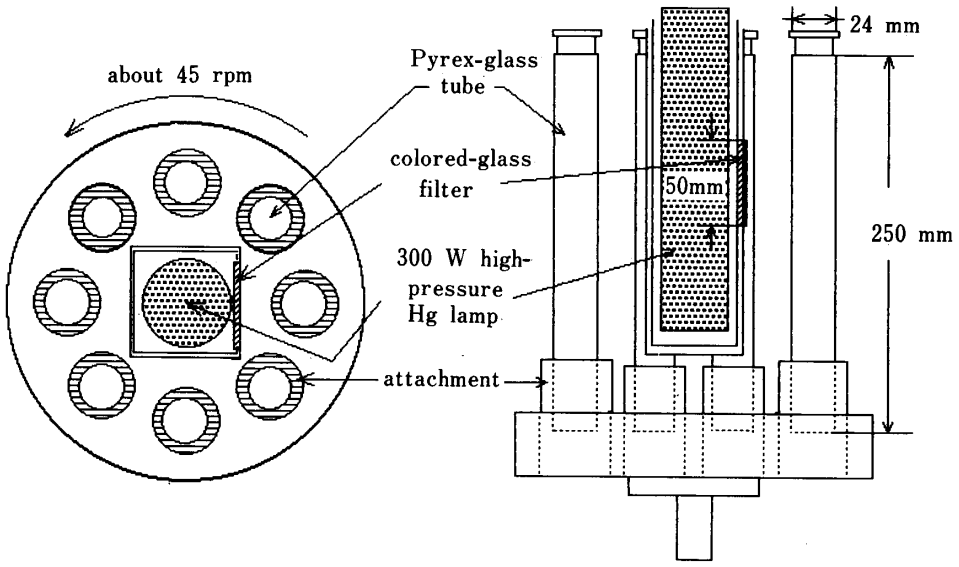


Fig. 1. Merry-go-round Apparatus for Exposure Test

irradiation. Fifty or fifteen milliliters of the methanol solution of nifedipine or a derivative was poured into test tube of Pyrex glass with a stopper. The distance between the high-pressure mercury lamp and the test tube was approximately 70 mm. When the light source was a fluorescent lamp (15W white light, Type FL15W, Toshiba Electric Co., Ltd., Tokyo) or sunlight, the test tube of 15 ml volume was irradiated through a window (40 mm square) attached to the test box, as shown in Fig. 2. All exposure tests were carried out at room temperature. Irradiation of the sample solution and actinometer solution was simultaneously carried out in the test box. Further, illumination at the spot where the sample solution was located was measured with an illumination meter (Tokyo Optical Instruments Co., Ltd., photoelectric cell illumination meter, model SPI-5).

Determination of Light Intensity by Actinometry[15]——Potassium ferrioxalate was dissolved in 0.05 M sulfuric acid to prepare a 0.006 M solution. V_2 ml of this solution was poured into test tube of Pyrex glass and was irradiated under UV light for t seconds. V_1 ml of the irradiated solution was added to 2 ml of 0.1% 1,10-phenanthroline aqueous solution. Further, V_1 ml of acetate buffer described above was added, then the whole was diluted with water to make V_3 ml. A solution without irradiation was treated in the same manner as a blank test. Each treated solution was allowed to stand for 30 min, then the absorbance was determined at 550 nm.

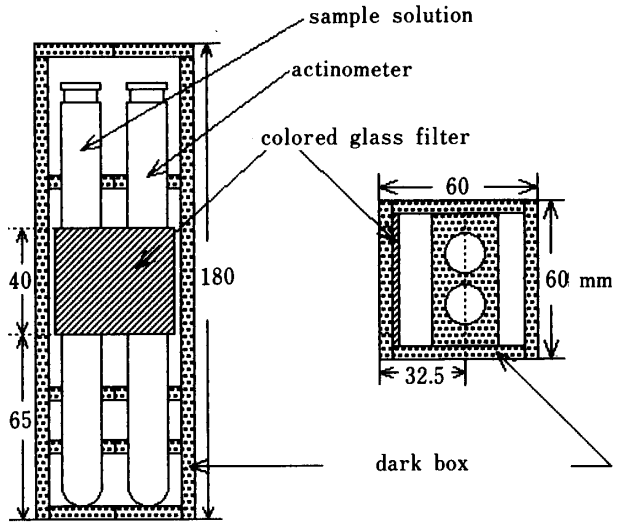


Fig. 2. Test Box Used for Exposure Test under Light of a Fluorescent Lamp and under Sunlight

The value of light quanta (I) was calculated from Eq. 1.

$$I=\frac{(A-A_0)V_2V_3}{\varepsilon t V_1 \phi}\times N_A \text{ (quanta/s)} \quad (1)$$

ε: molar absorption coefficient of Fe(II)–phenanthroline complex at 550 nm (1.11×10^4)
ϕ: quantum yield of the photo-reduction (1.2)
A: absorbance of irradiated sample solution at 550 nm
A_0: absorbance of blank test solution at 550 nm
N_A: Avogadro's number (6.02×10^{23})
t: exposure time (s)

In this experiment, V_1 was 1 or 2 ml, V_2 was 50 ml, and V_3 was 20 ml in the case of irradiation using a 50 ml test tube. On the other hand, V_1 was 1 ml, V_2 was 15 ml, and V_3 was 20 ml in the case of irradiation using a 15 ml test tube.

Analysis of Nifedipine and its Derivatives by High Performance Liquid Chromatography——The mobile phase was 0.05 M potassium dihydrogenphosphate (pH = 3.0)–methanol (36 : 64), which had been filtered through a 0.45 μm membrane filter and degassed under vacuum. Isopropyl benzoate (0.05 mg/ml with mobile phase) was used as an internal standard. The chromatographic system consisted of a model 6000A solvent delivery system, a model U6K injector, a model 440 ultraviolet detector (Waters Assoc.), and a Chromatopack CR-1B integrator (Shimadzu Co., Ltd.). UV absorption was measured at 254 nm. Samples were chromatographed at room temperature on a UNISILPACK 5C18-150A (4.6 mm i.d. × 150 mm, Gasukuro Kogyo Inc.). The flow rate was 0.9 ml/min (1500 psi).

We made calibration curves of the peak area ratio (nifedipine or its derivative to the internal standard) *versus* injected amount. They were all linear in the range of 0.01—0.07 μg injected, and all the correlation coefficients were more than 0.999.

Results and Discussion

Photolysis of Nifedipine and Its Derivatives

The time courses of residual percent of nifedipine and its 4- or 1,4-substituted derivatives in methanol under the light of a high-pressure mercury lamp are shown in Fig. 3. The value of light quanta was determined to be 6×10^{15} quanta/s by actinometry. Whereas nifedipine and the 1-methyl-4-(*o*-nitrophenyl) compound [compound II] were decomposed, no decomposition of the other compounds [compound III—VII] was observed in the range of cumulative number of photons up to 1.5×10^{19} quanta. Thus, a photo-stability test was carried out under more intense light, that is 8.0×10^{17} quanta/s, by removing the enclosure of the light source illustrated in Fig. 1. In this case, the 1-hydroxy-4-(*m*-nitrophenyl) compound [compound III], 4-(*m*-nitrophenyl) compound [compound IV] and 4-(*p*-nitrophenyl) compound [compound VII] decomposed. In contrast, no degradation of the 4-(*o*-chlorophenyl)

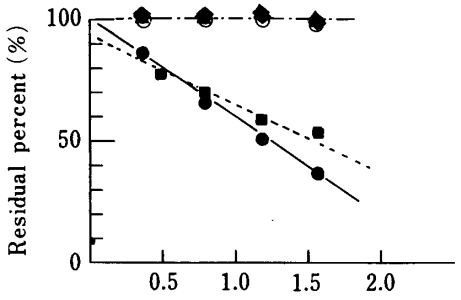


Fig. 3. Change of Residual Percent of Nifedipine and Its Derivatives in Methanol under a High-Pressure Mercury Lamp

Initial concentration: 2.9×10^{-4} M. Light quanta: 6.1×10^{15} quanta/s.
●, nifedipine; ■, compound II; △, compound III; ◆, compound IV; ◇, compound V; ▲, compound VI; ○, compound VII.

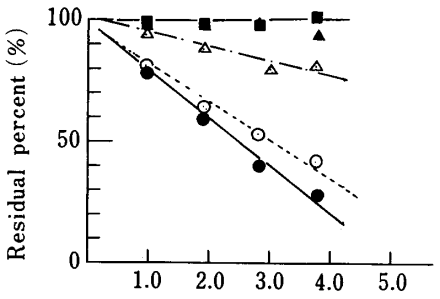


Fig. 4. Change of Residual Percent of Nifedipine Derivatives in Methanol under a High-Pressure Mercury Lamp

Initial concentration: 2.9×10^{-4} M. Light quanta: 8.0×10^{17} quanta/s.
△, compound III; ●, compound IV; ■, compound V; ▲, compound VI; ○, compound VII.

compound [compound V] or 4-phenyl compound [compound VI] was observed (Fig. 4).

In the case of nifedipine and compound II, the *o*-nitro group is located so close to the hydrogen atom at the 4-position that the intramolecular redox reaction was expected to occur easily. Compound II and compound III were more photo-stable than nifedipine and compound IV, respectively. For this reason, substitution at the 1-position of 1,4-dihydropyridine ring by a hydroxyl group and methyl group was considered to prevent aromatization of the 1,4-dihydropyridine ring.

As shown in Figs. 3 and 4, the plots of residual percent of intact nifedipine and the 4- or 1,4-substituted derivatives against cumulative number of photons all gave straight lines. Consequently, the residual percent of nifedipine and the 4- or 1,4-substituted compounds in methanol under the high-pressure mercury lamp was found to be a linear function of the cumulative number of photons. Exposure time is easily calculated by dividing the cumulative number of photons by the value of average light quanta. Therefore, a plot of residual percent against exposure time (for investigation of shelf-life) would show an apparently zero-order reaction as a matter of course.

Photolysis of Nifedipine under Three Light Sources

Comparison of the photo-stability of nifedipine under sunlight, a fluorescent lamp and a high-pressure mercury lamp was carried out. Figure 5 shows the plots of residual percent against cumulative number of photons under direct irradiation without a colored glass filter by the three light sources. The plots show good linear relationships. However, the slopes of the three lines were different. Thus, the photo-degradations under the three light sources were found to differ from one another in rate, even though each sample was exposed to the same cumulative number of photons.

The absorption spectral data in Table I show that λ_{max} of the n–π^* absorption bands of nifedipine in methanol is near 326 nm. On the other hand, the ferrioxalate actinometer has high sensitivity to light in the wavelength range of 250 to 450 nm, which is wider than the wevelength range contributing to the photo-degradation of nifedipine. That is to say, the photo-degradation rates under the three light sources seem not to agree because the three light sources differ from one another in energy distribution at 400—450 nm, which does not affect the degradation of nifedipine.

Thus, a photo-stability test with light passed through a UV-D33S colored glass filter (Toshiba Garasu Kogyo Co., Ltd.) was carried out in the same manner as described above.

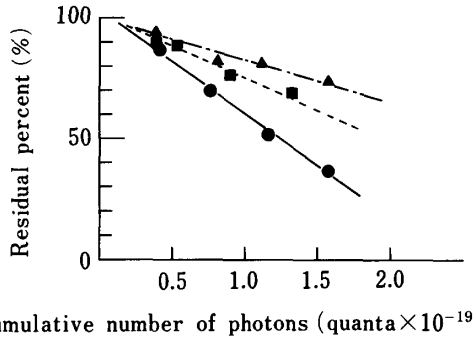


Fig. 5. Change of Residual Percent of Nifedipine in Methanol under a High-Pressure Mercury Lamp, Sunlight and a Fluorescent Lamp

Initial concentration: 2.9×10^{-4} M. Light quanta: 6.1×10^{15} quanta/s (high-pressure mercury lamp); 2.0×10^{17} quanta/s (sunlight); 3.1×10^{15} quanta/s (fluorescent lamp).

●, high-pressure mercury lamp; ■, sunlight; ▲, fluorescent lamp.

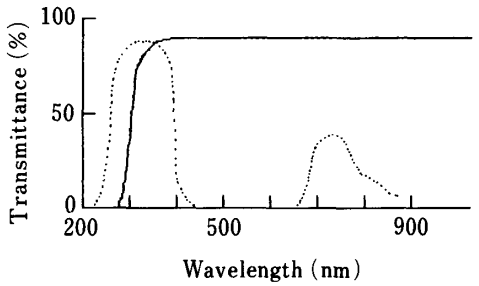


Fig. 6. The Spectral Transmittance of Pyrex Glass and the UV-D33S Colored Glass Filter

----, UV-D33S colored glass filter; ——, Pyrex glass.

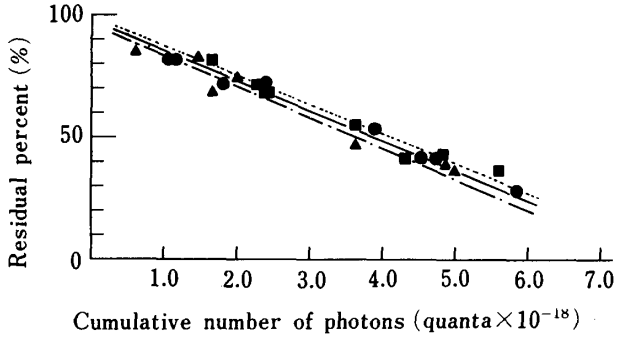


Fig. 7. Change of Residual Percent of Nifedipine in Methanol under a High-Pressure Mercury Lamp, Sunlight and a Fluorescent Lamp Transmitted through a UV-D33S Colored Glass Filter

Initial concentration: 2.9×10^{-4} M. Light quanta: 3.9×10^{15} quanta/s (high-pressure mercury lamp); 9.1×10^{15} quanta/s (sunlight); 7.0×10^{13} quanta/s (fluorescent lamp).

●, high-pressure mercury lamp; ■, sunlight; ▲, fluorescent lamp.

The light transmittance characteristics of this filter are shown in Fig. 6.

Plots of residual percent of nifedipine *versus* cumulative number of photons gave good linearity with the three light sources, as shown in Fig. 7. The slopes of the plots under the three light sources shown in Figs. 5 and 7 are summarized in Table II, together with the light intensity, that is illumination [lux] and light quanta [quanta/s]. Further, as described in Table II, the photo-degradation rate of nifedipine was calculated in terms of rate per integrated illumination [/lux/h] and per photon [/quanta]. The photo-degradation rates relating to integrated illumination under the light sources were found to differ remarkably from one another in the case of direct exposure. The photo-degradation rates relating to photons also differed under direct exposure, as shown in Fig. 5. On the other hand, the photo-degradation rates relating to photons under the three light sources agreed well in the case of irradiation through the UV-D33S colored glass filter.

Insertion of the UV-D33S colored glass filter between the light sources and exposed sample seemed to minimize the difference between wavelength bands contributing to photoreduction of the actinometer and photo-degradation of nifedipine.

Therefore, estimation of the photo-degradation rate in mol/h at a given location is considered possible by measuring mean light quanta at that location with a ferrioxalate actinometer to which a UV-D33S colored glass filter is attached.

On the other hand, even though photo-degradation of nifedipine occurred, the value of illumination determined by the illumination meter was zero in this case, so an illumination meter is not considered to be suitable for the estimation of photo-degradation.

TABLE II. Photo-Degradation Rate of Nifedipine in Methanol under Three Light Sources

	Light source		
	High-pressure Mercury lamp	Sunlight	Fluorescent lamp
Direct expqsure			
Light quanta[a] (quanta/s)	6.1×10^{15}	2.0×10^{17}	3.1×10^{15}
Illumination[b] (lux)	3300	14000	1650
Degradation rate (1)[c] (mol/quanta)	6.0×10^{-25}	3.4×10^{-25}	2.4×10^{-25}
Degradation rate (2)[d] (mol/[lux·h])	3.9×10^{-10}	1.7×10^{-9}	1.6×10^{-9}
Correlation coefficient[e]	0.998	0.988	0.969
Through filter[f]			
Light quanta[a] (quanta/s)	3.9×10^{15}	9.1×10^{15}	7.0×10^{13}
Illumination[b] (lux)	0	0	0
Degradation rate (1)[c] (mol/quanta)	5.2×10^{-25}	5.1×10^{-25}	5.4×10^{-25}
Correlation coefficient[g]	0.992	0.992	0.966

a) Measurement with ferrioxalate actinometer. *b*) Measurement with illumination meter. *c*) Number of mol decomposed per one irradiated photon. *d*) Number of mol decomposed per unit of integrated illumination. *e*) Linear relationship of plots shown in Fig. 5. *f*) UV-D33S colored glass filter. *g*) Linear relationship of plots shown in Fig. 7.

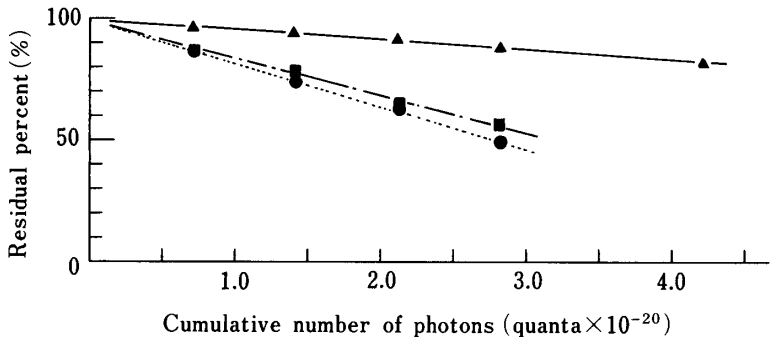


Fig. 8. Change of Residual Percent of Nifedipine Derivatives in Methanol under a High-Pressure Mercury Lamp Transmitted through a UV-D33S Colored Glass Filter

Initial concentration: 2.9×10^{-4} M. Light quanta: 3.9×10^{15} quanta/s.
▲, compound III [correlation coefficient = 0.999]; ■, compound IV [correlation coefficient = 0.999]; ●, compound VII [correlation coefficient = 0.998].

Among the nifedipine derivatives investigated in this report, compounds III, IV, and VII were more photo-stable than nifedipine and decomposed only under much more intense UV light.

As shown in Fig. 8, residual percent of intact compounds III, IV and VII was plotted against cumulative number of photons irradiated through the UV-D33S colored glass filter, in analogy with Fig. 7. The residual percent decreased linearly for all three compounds. The slopes are summarized in Table III in terms of decomposed mole per photon, together with the data for nifedipine already shown in Table II. The wavelength bands which contribute to the photo-degradation of compounds III and IV seem to be the same as in the case of nifedipine because the absorption spectra of compounds III and IV are both very similar to that of nifedipine, as shown in Table I. From the difference of the slopes, therefore, compounds III and IV were quantitatively estimated to be more photo-stable than nifedipine in methanol under a given light source by factors of 270 and 76, respectively.

Thus, it was found that the photo-stability on storage in solution for a long period of

TABLE III. Photo-Degradation Rates of Nifedipine and Its Derivatives under Light Transmitted through a UV-D33S Filter[a]

Compound	Photo-degradation rate[b] (mol/quanta)	Ratio of shelf-life[c]
Nifedipine	5.1×10^{-25}	1
III	1.9×10^{-27}	270
IV	6.7×10^{-27}	76
VII	7.8×10^{-27}	—[d]

a) Light source was a 300W high-pressure mercury lamp. *b*) Number of mol decomposed per one photon absorbed by the actinometer. *c*) Reciprocal of ratio of photo-degradation rate *versus* that of nifedipine. *d*) Difficult to estimate (see text).

time under a weak light source could be quantitatively estimated from experiments carried out under the same storage conditions (*e.g.*, temperature and container) under an intense UV-light source such as a high-pressure mercury lamp for a short period of time.

As shown in Fig. 8, compound VII was more photo-labile than compound IV, as shown in Table III, in contrast to the results obtained from Fig. 4. The difference of compound VII in absorption spectra from the other derivatives seemed to be the reason for this. Therefore, quantitative comparison of photo-stability between compound VII and the other derivatives seemed to be difficult.

In conclusion, the method described in this report has the following advantages for validation of light source, light intensity and wavelength bands in photo-stability study.

(1) The chemical actinometer is very easily available in the laboratory. (2) Wavelength bands detectable with the actinometer cover the region contributing to photo-degradation of many medicaments. (3) Experimental error in the measurement of light intensity which drifts with time is small because the cumulative amount for a given period is determined. (4) The use of an appropriate colored glass filter enables the determination of the light intensity of only wavelength bands contributing to the photo-degradation of medicaments.

References and Notes

1) Present address: *Department of Pharmacy, Kitano Hospital, 13–3, Kamiyama-cho, Kita-ku, Osaka 530, Japan.*
2) T. Saito, *Yakuzaigaku, Separate Ed.*, **36**, 3 (1976).
3) Y. Matsuda and M. Mihara, *Chem. Pharm. Bull.*, **26**, 2649 (1978).
4) K. Terui, R. Shimoyama, K. Sone and K. Fujita, *Byoin Yakugaku*, **10**, 224 (1984).
5) K. Inoue, A. Washihama, K. Kimura and T. Kuroda, *Byoin Yakugaku*, **11**, 267 (1985).
6) Y. Matsuda, H. Inoue and R. Nakanishi, *J. Pharm. Sci.*, **67**, 196 (1978).
7) Y. Matsuda, I. Itooka and Y. Murakami, *Chem. Pharm. Bull.*, **28**, 2665 (1980).
8) C. G. Hatchard and C. A. Parker, *Proc. R. Soc. London*, **A235**, 518 (1956).
9) K. Thoma and E. Klimek, *Pharm. Ind.*, **47**, 207 (1985).
10) J. A. Berson and E. Brown, *J. Am. Chem. Soc.*, **77**, 447 (1955).
11) Tokyo Astronomical Observatory (ed.) "Rikanenpyo, Showa 60 Nendo," (Chronological Scientific Tables, 1985), Maruzen Co., Ltd., Tokyo, 1984. The energy distribution of the three light sources in the photo-stability study is described in this report.
12) M. Iwanami, T. Shibanuma, M. Fujimoto, R. Kawai, K. Tamazawa, T. Takenaka, K. Takahashi and M. Murakami, *Chem. Pharm. Bull.*, **27**, 1426 (1979).
13) Kyowa Hakko Kogyo Co., Ltd., Japan Patent 83-2082718 (1983) [*Chem. Abstr.*, **100**, 120893*y* (1984)].
14) Kanebo, Ltd., Japan Patent 80-124760 (1980) [*Chem. Abstr.*, **95**, 24815*g* (1981)].
15) H. Kokubun, "Shin-zikkenkagaku Koza, Vol. 4, Kisogijyutu-3 Hikari (I)," Nihon Kagakukai (ed.), Maruzen Co., Ltd., Tokyo, 1976, pp. 239—308.