Ultraviolet Repellent and Lethal Action on the American Cockroach[1,2]

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Adult *Periplaneta americana* (L.) is repelled by ultraviolet (UV) radiation and suceptible to its lethal action. Fertility may be reduced. Although adults and older nymphs are relatively resistant to UV irradiation, young nymphs are highly susceptible, so a single exposure of only 1 minute to a moderate dose results in over 50% mortality and retards growth among the survivors.

The action of UV radiation has been widely studied with bacteria and the lower organisms, with which lethal and mutagenic effects are observed (Giese 1964, Zelle and Hollaender 1955). In higher animals interest has been directed principally on superficial effects, such as sunburn, and the more profound and sometimes lethal consequences of exposure to UV light in animals following ingestion of foods containing certain fluorescent compounds (Blum 1941, 1955, Clare 1956). However, it has been shown that mice may succumb to whole-body UV irradiation (Rieck and Carlson 1955). Studies of the action of UV light on insects have been concerned with mutations resulting from irradiation of the egg in vitro or in situ and only rarely or incidentally with lethality (Swanson and Stadler 1955, Henzlik 1964), and some interest has focused on UV attraction for certain insects (Morgan 1966).

In this article we demonstrate the repellent and lethal effects of UV radiation on the American cockroach, *Periplaneta americana* (L.), and discuss their relevance to insect control. Since light of about 2537A is particularly lethal (bactericidal), lamps emitting light predominantly of this wavelength have been used. However, the 200-w super-pressure mercury lamp used in certain of these experiments produces a spectrum that is blank in this area but gives an intense beam at longer and shorter wavelengths that are more penetrating and may cause important reactions (Blum 1955, Buttolph 1955).

REPELLENCE OR ATTRACTION.—*Materials and Methods.*—A 12×75-cm glass cylinder was lined for ½ its circumference with a rough-surfaced black paper, which afforded a suitable footing for the insect. The cylinder was divided in the middle by a cardboard diaphragm covered with black paper, a small section of which was cut from the periphery to permit access by the cockroach from one side to the other. A removable cuff of 1-mm-wire gauze was used to close each end. One-half of the whole length of the cylinder was covered with black paper loosely held with tape that could be readily removed for viewing the insects. The cylinder was kept in a ventilating hood, the windows of which were covered with black paper and kept closed except during periods of observation. The insects were thus subjected to a minimum of ambient light. The experiments were performed with the same insects in a continuous sequence of time interrupted only for necessary manipulations.

Adult male cockroaches or young nymphs of mixed sexes were placed in the cylinder and exposed to the irradiation from a lamp placed at one or the other end of the cylinder. Most of the insects clung to the diaphragm and were therefore ca. 37.5-cm from the light source much of the time. Counts of insects in the 2 sections of the cylinder were made after different periods of exposure. Food consisted of a single pellet of Purina Laboratory Chow, and water was provided in a small test tube plugged with cotton.

The experiments shown in Table 1 were performed with a General Electric "Germicidal" lamp consisting of two 15-w tubes 18 in. long, 85% of the emission of which was at 2537A. Because the cylinder containing the insects was only 6 in. diam, the effective radiance directed into it was only ⅓ of the lamp power. Since these lamps emit about 15% of light of higher wavelength than 2537A, which could affect the insects' behavior, we also used a 9-w 2537A "Mineralite" hand lamp of such size that its entire output could be directed into the cylinder. In this series the cylinder was covered for its entire length, and the procedure also differed from that of the first in that the insects were left

[1] Orthoptera: Blattidae.

[2] Endorsed and communicated by Louis M. Roth, U. S. Army Laboratories. Received for publication June 10, 1970.

undisturbed from experiment to experiment; the position of the light only was changed (Table 2).

Results.—Experiments 1 and 3 of Table 1 were conducted overnight with terminal counts made at about 7:15 AM, while Experiments 2 and 4 were done during daylight hours. It is evident from Table 1 that the cockroaches were repelled by the light, and that the position of food and water, or their absence, did not influence its effect. Assuming the positions of the insects at the time they were counted to have resulted from a unidirectional response to the light, the results give little or no evidence of having been affected by the circadian rhythm of the insect. Although ⅔ of the light source extended beyond the border of the cylinder and flooded a large area surrounding it, the reflected light was apparently too diffuse and its angle of incidence too sharp for the higher wavelengths to affect the results materially by shining through the uncovered wall of the cylinder.

Exposure of the insects to the light from the 2537Å Mineralite lamp also consistently repelled the cockroaches regardless of the position of the food and water (Table 2). It is especially notable that under continuous exposure the insects could be made to reverse their positions in the cylinder repeatedly with a change in the position of the light at various time intervals. Although observations were made from time to time before those recorded, and no counts were then made, it can be said that no mass migration from one side to the other occurred. Repellence apparently reflected individual susceptibility among the insects and occurred over a period of hours, as indicated in Table 2. There was no evidence of a variance in sensitivity that could be ascribed to circadian rhythm. The data give no evidence that the cockroaches were attracted by light of the wavelengths used. This phenomenon contrasts with the attractance shown by longer wavelengths for certain insects (Morgan 1966, Zhigal'tseva and Chernobrovina 1966).

LETHAL EFFECT.—*Materials and Methods.*—The lethal effect of UV radiation was examined with insects at different stages of growth and therefore with different absorptive barriers to the light. So little had the probability of a significant lethal effect by anything less than an intense beam been entertained, that the first experiments, as shown in Table 3, were performed with a 200-w super-pressure mercury arc lamp. This lamp is specified as giving

Table 1.—Distribution of adult male cockroaches following exposure to UV radiation with the light source two 15-w General Electric Germicidal lamp 18 in. long. All insects initially at lamp side (L) in each experiment.

Experiment	Exposure, hr	No. in each side of cylinder[a]
1	19	FW U C L 9 5
2	6	C U L; FW 13 1
3	16	FW U C L 11 3
4	4	C U L 12 2

[a] U, uncovered cylinder; C, covered cylinder; L, lamp side; FW, food and water placed on side indicated.

Table 2.—Distribution of adult male cockroaches in covered cylinder following continuous exposure to UV radiation of 2537A (9-w mineralite hand lamp), interrupted only by change in position of lamp.

Experimental sequence	Exposure, hr[a]	Distribution in relation to position of light source (L), food and water (FW); (line represents cylinder)
1	16	L — FW 2 17
2	9	FW — L 14 5
3	15	FW — L 16 3
4	5	L — FW 11 8
5	19	L — FW 4 15
6	23	FW — L 18 1

[a] Experiments 2 and 4 were conducted during the daytime; the other experiments were carried overnight, with 5 and 6 extending into the daytime. They are all part of a continuous exposure.

a fairly uniform intensity spectrum covering the UV, visible, and IR, except for an energy void in the vicinity of the mercury resonance line (2537A) extending from about 253 nm to 275 nm, and as having an average luminance of 25,000 candles/cm² and a luminous efficiency of 47.5 lumens/watt at a real power of 200 w. At a distance of 23 in. this lamp was found to yield 3620 ergs/cm² per sec. In other experiments the Germicidal or Mineralite lamp was used.

Results.—Sixty-nine 2nd-stage nymphs together with fifteen 7th- and 8th-stage nymphs, and 10 adults 1 month old and presumed to be mated, were placed in a 6×8-in. Pyrex battery jar which was coated with Vaseline® on the inside and wrapped in aluminum foil. To illuminate the entire bottom area of the jar occupied by the insects the lamp was raised to a height of 23 in. Irradiation was performed during the daytime and was thus not continuous. Food and water were provided at night only. A jar of similar insects served as unirradiated controls (Table 3).

The essentially acute lethal effect of the radiation on the young nymphs is in sharp contrast with the prolonged resistance shown by the adults and older nymphs. It no doubt results principally from the relative thinness of the cuticle and low density of pigmentation, but all ages showed visible signs of injury soon after exposure began. When the light was first turned on the cockroaches became excited and moved about the jar attempting to avoid the most intense area of the beam by moving to the periphery. After a while they dispersed themselves in the full beam and became quiet. After some hours the adult insects were seemingly insensitive to a tap on the head, whereas the controls shied away. The cuticle of the irradiated insects acquired

Table 3.—Lethal effect, and effect on oöthecal production by females, of discontinuous high intensity UV irradiation (3620 ergs/cm² per sec at other than 2530A to 2750A) on cockroaches of different ages.

Cumulative irradiation time (hr)	No. dead cockroaches following indicated irradiation time				Adults oöthecal production	
	Nymphs					
	2nd instar	7th–8th instar	♂♂	♀♀	Irradiated	Control
2½	0					
5¼	2					
7¾	2					
11	22					
13¾	20					
15	8					3
19¾	15					
27¾		0	0	0		2
33¾		3		2	1	
39¾		1				
47¾		3		1		
51		3		1		
58½		4	2	1	1 aborted	2
67½		1	1 (1 survivor)	1		
Totals[a]	69	15	4	6	2	7

[a] Totals of insects used or of oöthecae produced.

a highly varnished appearance which became dull after a day or two, and the insects became increasingly lethargic. The youngest nymphs appeared moribund many radiation hours before their death, and the adults also suffered a prolonged decline. The possibility of a high temperature influencing the results was found improbable, inasmuch as the temperature at the bottom of the jar among the cockroaches was 23°C as compared with 21°C in the control jar. Nor was ozone a plausible factor, since there was rapid clearance of the air in the hood. In view of the higher wavelengths of light given off by this lamp, and the intermittent radiation procedure, photoreactivation may have played a significant part in prolonging the survival of the insects. This possibility was obviated with the use of other lamp sources.

The table shows that the irradiation caused a marked delay and reduction in egg production at a considerable period of radiation time before the 1st adult died. It thus seems probable that appreciably less than a lethal dose of radiation should have a sterilizing effect on the cockroach.

The demonstration of a lethal effect with rays of high intensity prompted examination of effects of lamps of lower intensity but emitting preponderantly or almost exclusively in the region of 2537A. Table 4 shows the results obtained with 7th- to 9th-stage nymphs exposed to the illumination of the same Germicidal lamps as used in Table 1. The twin lamps were placed 12 in. above the bottom of a 6×8-in. battery jar and they thus irradiated the insects with 255 ergs/cm² per sec. Irradiation was performed during part of each successive day. The effect was again lethal, and, as in Table 3, considerable differences in resistance to the radiation are shown. This table also distinguishes between deaths

Table 4.—Mortality of 7th- to 9th-stage nymphs resulting from exposure on successive days to UV radiation of moderate intensity (two 15-w Germicidal Lamps; 255 ergs/cm² per sec, 85% at 2537A).

Cumulative rad. time (hr)	Mortality		
	At end of rad time	Overnight	Total
5¼	0		
13¼	0	1	1
21¾	3		3
30¾	6	10	16
39¾	11	5	16
Totals[a]	20	16	36

[a] 100% of insects.

that occurred during exposure and deaths that occurred subsequently, overnight, and shows that the lethal action of the radiation may not be evident for a considerable time after exposure. It is to be noted that mortality resulted sooner from exposure to 255 ergs/cm² per sec of radiation from this lamp (85% 2537A) than from 3620 ergs/cm² per sec of radiation outside the 2530A–2750A range. In this experiment the quality of the light and the intermittence of the radiation were probably conducive to considerable photoreactivation (Jagger 1958), and hence to delaying death. These effects were avoided in the following experiment (Table 5) by using a 2537A Mineralite lamp (as in Table 2), providing continuous illumination, at a distance of 8 in. The results show clearly that even the adult cockroach is susceptible to moderate doses of irradiation with 2537A.

There was no mortality in a similar group of male cockroaches similarly exposed to a beam provided by a Mineralite 3660A lamp.

The lethal effect of moderate doses of UV radiation on the adult cockroach and other nymphs indicated that young nymphs should be highly susceptible. When 2nd-stage nymphs were exposed to intermittent radiation from two 15-w G. E. Germicidal lamps placed 12 in. above the floor of a 6×8-in. battery jar the effects were acutely lethal. Approximately 40% of the insects were dead at the end of 14½ hr of cumulative radiation resulting from 9

Table 5.—Mortality of adult male cockroaches resulting from continuous exposure to UV radiation (2537A).

Radiation time (days)	Mortality (no.)	
	At end of rad. time	Controls
3	0	
4	2	
5	2	
6	2	
7	3	
9	1	
10	4	
11	2	
12	2	
Total	18[a]	0 (No.=20)

[a] 100% of insects.

Table 6.—Mortality of 2nd-stage nymphs resulting from short-term exposure to UV radiation of moderate intensity (2537A, two 15-w General Electric Germicidal lamps).[a]

Radiation time	% mortality at days indicated									
	2	3	4	5	5⅓	6	8	12	19	26
5 hr	100									
1 hr	22	63	100							
30 min	5			84	96	98	100			
5 min	0			56	67	74	94	99	100	
1 min	0			23	36	42	47	50	52	52
Controls										0 (N=100)

[a] 100 nymphs used for each exposure.

and 5½ hr of exposure on 2 successive days, and the mortality was 100% by the following morning. The surprisingly drastic effect of this irradiation suggested that the insect might be susceptible to much lower doses, and this proved to be the case (Table 6). The procedure here was to expose different groups of nymphs for different lengths of time and then to observe their response over a period of days. In this way it was found that exposure for as little as 5 min produced 100% mortality in 19 days. An exposure of only 1 min was eventually lethal for more than 50% of the nymphs. Growth of the survivors was retarded and uneven, averaging 23.8 mg compared with 40.0 mg for the controls on the 41st day. In view of the reduction in oöthecal production observed in Table 3, it is probable that the fertility of these nymphs was greatly reduced if not eliminated.

DISCUSSION.—Considering the optically dense structure of the cockroach, the susceptibility of the insect, particularly the young nymph, to UV radiation is somewhat surprising and indicates that other insects may also be susceptible to comparatively small doses. From the standpoint of control, the indication that sterility may be achieved with low doses offers the attractive prospect of a simple and inexpensive procedure. Such a procedure might require no more than placing a constant radiant source a few inches above the runways of the cockroach, where they would be subject to repeated exposure. Experience with the Germicidal and the 2537A Mineralite lamps to which the insects were repeatedly exposed gave evidence that repellence was not immediate but rather became effective only after some hours of exposure. Since in their natural habitats cockroaches are nocturnal, they would be subject only to periodic exposure and therefore susceptible to sterilizing doses before being repelled.

The application of the sterilizing and lethal properties of UV radiation to the control of certain insects has a special appeal where avoidance of the use of toxic insecticides is advisable, as for instance with cockroaches, or for those species of mosquitoes whose eggs are exposed on the surface of water. Here the scanning of littoral areas with a suitable flood lamp should be effective.

REFERENCES CITED

Blum, H. F. 1941. Photodynamic Action and Diseases Caused by Light. Reinhold Publishing Corp., New York, N. Y. 309 p.

1955. Chap. 13, Sunburn; Chapter 14, Ultraviolet radiation and cancer. *In* A. Hollaender [ed.] Radiation Biology, Vol. II. McGraw-Hill Book Co., Inc., New York.

Buttolph, L. J. 1955. Chapter 2. Practical applications and sources of ultraviolet energy. Ibid.

Clare, N. T. 1956. Chap. 15, Photodynamic action and its pathological effects. Ibid. Vol. III.

Giese, A. C. 1964. Photophysiology, vol. II, Academic Press, New York. 441 p.

Henzlik, R. E. 1964. Studies on ultraviolet radiation and photoreactivation in *Tribolium confusum* Duval. Amer. Midland Natur. 72: 374–8.

Jagger, J. 1958. Photoreactivation. Bacteriol. Rev. 22: 99–142.

Morgan, M. O. 1966. Ultraviolet radiation as an attractant for adult horn flies. J. Econ. Entomol. 59: 1416–9.

Rieck, A. F., and S. Carlson. 1955. Photorecovery from the effects of ultraviolet radiation in the albino mouse. J. Cell. Comp. Physiol. 46: 301–5.

Swanson, C. P., and L. J. Stadler. 1955. Chapter 7. The effect of ultraviolet radiation on the genes and chromosomes of higher organisms. *In* A. Hollaender Radiation Biology, Vol. II. McGraw-Hill Book Co., Inc., New York.

Zelle, M R., and A. Hollaender. 1955. Chapter 10. Effects of radiation on bacteria. Ibid.

Zhigal'tseva, M. L., and S. M. Chernobrovina. 1966. Use of ultraviolet ray sources to control insect pests. Zool. Zh. 45 (3) : 375–82. [Authors' Abstr., Biol. Abstr. 1966.]

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