SENSITIZATION TO HEAT DUE TO EXPOSURE TO LIGHT OF SHORT WAVE-LENGTHS.

By W. T. BOVIE and ALICE KLEIN.

(*From the Cancer Commission of Harvard University, Boston.*)

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This paper is a report of some experiments on the effect of heat upon organisms which have been exposed to fluorite rays. The experiments have yielded valuable information concerning the mechanism of the action of rays. They show that the exposed organisms (*Paramecium caudatum*) are made extremely sensitive to the influence of heat.

The experiments are of interest because they show the necessity of a careful control of the temperature of the radiated organisms both during and after the radiation. Heretofore investigators have paid but little, if any, attention to temperature control in their radiation experiments. They have, perhaps, considered the matter unimportant, since the rate of most photochemical reactions is independent of temperature. The effect of heat upon the organism which has been made sensitive to heat by radiation must be clearly distinguished from its effect upon the specific photochemical reaction, for in the former case the effect is upon a series of reactions initiated by the exposure and not upon the photochemical change itself.

The heat sensitization resulting from radiation appears to be of general occurrence. It has been found in *Laminaria* exposed to the rays from radium emanation[1] and in egg white exposed to the rays from a quartz mercury-vapor lamp.[2] In the case of the heat-sensitized egg white visible coagulation occurs at a lower temperature than in the non-radiated control. The degree of sensitization increases with the amount of radiation so that with sufficient expo-

[1] Unpublished experiments by the writer.

[2] Bovie, W. T., Temperature coefficient of the coagulation caused by ultraviolet light, *Science*, 1913, xxxvii, 373.

sure coagulation occurs at 0°C. Gelatin, on the other hand, when heat-sensitized by radiation liquefies at a lower temperature than non-radiated gelatin.[3]

The method of experimentation was as follows: By means of a method previously described[4] a single organism from a pedigreed culture of *Paramecium caudatum* was exposed in a small drop of tap water (always of the same size) to the rays emitted through the fluorite window of a hydrogen discharge tube. The drop of water containing the organism was maintained, unless otherwise stated, both before and during the radiation at a temperature of 16–17°C. After the exposure the organism was placed in a larger drop of tap water in the concavity of a microscope slide on the warm plate of an electric stove. The variable junction of a thermocouple (made with No. 30 B. and S. gauge copper and "ideal" wires) was placed in the drop with the organism. The thermocouple circuit contained a galvanometer from which deflections corresponding to 0.1°C. could be read. The temperatures of the dish from which the drop of tap water was taken and the warm plate of the electric stove were so controlled that no change of temperature, capable of being detected by the galvanometer, occurred in the drop containing the organism during the experiment.

No attempt was made to heat all the organisms used in any one experiment to precisely the same temperature. It was sufficient for these experiments to keep the temperature within a certain range. The organisms were exposed to the temperatures indicated below for a period of 60 ± 3 seconds and were then transferred to a culture drop and placed in the damp chamber with the controls for future observation. The experimental results are given below.

Control Experiments.

Experiment 1. Effect of Radiation Alone.—Organisms were radiated at 17–18°C., for 4 seconds and then transferred immediately to culture drops without being placed on a temperature slide.

[3] Unpublished experiments by the writer.

[4] Bovie, W. T., and Hughes, D. M., Rate of recovery from the action of fluorite rays, *J. Gen. Physiol.*, 1918–19, i, 323.

Total No. of organisms radiated	60
No. of deaths	0
Per cent of death	0

Experiment 1 shows that with the light intensities used, an exposure of 4 seconds to fluorite rays is not sufficient to cause death of the organism.

Experiment 2. Effect of Extra Manipulation of Placing on a Temperature Slide and Then Exposing to Heat.—Organisms were radiated for 4 seconds at 17–18°C., and then exposed on a temperature slide to 16–17°C. for 60 seconds.

Total No. of organisms radiated	30
No. of deaths	3
Per cent of death	10

We had observed that some of the radiated organisms appear to be sticky and it was thought that a certain per cent of the deaths in Experiment 5 might be due to accidental physical injury incurred during the transfer to and from the temperature slide. Experiment 2 gives the result of an investigation of this question.

Experiment 3. Effect of Heat Alone.—Unradiated organisms were exposed on a temperature slide to 24–28°C. for 60 seconds.

Total No. of organisms	21
No. of deaths	0
Per cent of death	0

The results obtained in Experiment 3 were to be expected. They are in agreement with those of Woodruff and Baitsell[5] on the temperature coefficient of the rate of reproduction of *Paramecium aurelia*. According to these authors the optimum temperature zone for reproduction is between 24° and 28.5° C.

Experiment 4. Effect of Heating First and Then Radiating.—Organisms were exposed on a temperature slide to 24–26°C., for 60 seconds, and then radiated for 4 seconds at 17–18°C.

Total No. of organisms radiated	52
No. of deaths	4
Per cent of death	8

[5] Woodruff, L. L., and Baitsell, G. A., The temperature coefficient of the rate of reproduction of *Paramæcium aurelia*, *Am. J. Physiol.*, 1911–12, xxix, 147.

Experiment 4 was made in order to determine whether or not we are dealing with an additive effect instead of heat sensitization.

Sensitization Experiment.

Experiment 5. Effect of Radiating First and Then Heating.—Organisms were radiated for 4 seconds at 17–18°C. and then exposed on a temperature slide to 24–26° C. for 60 seconds.

Total No. of organisms radiated	44
No. of deaths	29
Per cent of death	66

Summary.

Experiment No.	Treatment.	Deaths.
		per cent
1	Radiation alone	0
2	Extra manipulation	10
3	Heat alone	0
4	Heating first then radiating	8
5	Radiating first then heating	66

In a previous paper[4] it has been shown that *Paramecia* recover in 1 hour from the effects of a 4 second exposure to fluorite rays, so that an additional 4 second exposure does not increase the effects of the first.

We were interested to see whether the organisms would likewise recover from the heat sensitization caused by an exposure of 4 seconds to fluorite rays. In the following experiments the organisms were not exposed to the higher temperatures immediately after radiation, but in order to permit recovery to take place were kept at the radiation temperature for varying periods of time.

Recovery Experiments.

Experiment 6. Recovery Period ½ Hour.—Organisms were radiated for 4 seconds at 17–18°C., and after ½ hour at 17–18°C. were exposed on a temperature slide to 24–28°C. for 60 seconds.

Total No. of organisms radiated	20
No. of deaths	4
Per cent of death	20

Experiment 7. Recovery Period 1 Hour.—Organisms were radiated for 4 seconds at 17–18°C., and after 1 hour at 17–18°C. were exposed on a temperature slide to 24–28°C. for 60 seconds.

Total No. of organisms radiated	21
No. of deaths	1
Per cent of death	5

Experiment 8. Recovery Period 5 Hours.—Organisms were radiated for 4 seconds at 17–18°C., and after 5 hours at 17–18°C. were exposed on a temperature slide to 24–28°C. for 60 seconds.

Total No. of organisms radiated	24
No. of deaths	0
Per cent of death	0

The organisms had nearly recovered from the heat sensitization caused by the exposure to fluorite rays in 1 hour, and had completely recovered in 5 hours. In this ability to recover the heat-sensitized *Paramecium* differs from the heat-sensitized egg white, since the latter does not recover however long the interval of time between the radiation and the exposure to heat.

The results of these experiments are clear cut, and show that *Paramecia* which have been exposed to fluorite radiation are so sensitized to heat that they are unable to withstand, even for 60 seconds, temperatures which are optimum for non-radiated controls.

Woodruff and Baitsell[5] found normal *Paramecia* from a pedigreed culture able to withstand a temperature of 32° for about 2 days.

In the experiments on egg white, referred to above, it was shown that egg white which is maintained at 0°C., during the exposure to ultra-violet light, will, with the proper amount of exposure, coagulate when it is warmed to room temperature. On the other hand, egg white which is maintained at room temperature while receiving an equal amount of exposure coagulates during the radiation. Now in this case it might not be improper to say that the coagulation is in reality not photocoagulation but is heat coagulation. The egg white has been heat sensitized by the radiation so that it can no

longer withstand normal room temperatures. We might, perhaps, with equal propriety say that the death of *Paramecia* following fluorite radiation is in reality a destruction by heat. The organism, as a result of the exposure, has been sensitized to heat so that it is no longer able to withstand its normal optimum temperatures.

This statement is made in order to emphasize the importance of heat sensitization rather than to suggest an explanation of the nature of the action of rays. Nevertheless, no theory of the action of rays can be complete which does not take the results of such experiments into consideration.