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SELECTIVE HEAT PRODUCTION BY ULTRASHORT (HERTZIAN) WAVES *

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Several authors(1, 2) have reported a selective heat production of ultrashort waves according to the equation

$$\lambda = \frac{\epsilon \cdot c}{\epsilon \kappa}$$

where λ is the wavelength producing maximal heat, ϵ represents the dielectric constant, κ the electric conductivity of the substance, and c the velocity of light. According to this formula there is an optimal wavelength for heat production in any material, depending upon its dielectric constant and electrical conductivity. Experimental data obtained on inorganic substances and on biological tissues demonstrate the existence of a selective heat production.

Recently a number of papers in the American literature also discussed this problem. Krusen(3) doubts the correctness of Schliephake's claims *in toto,* but presents no new experimental data to substantiate his criticism.

Mortimer and Osborne(4) report extensive experimental work — *in vivo* and *in vitro* — on the problems of the "penetration of heat into the body," selective thermal action, specific biologic and bactericidal action. The authors find no evidence "that short wave diathermy possesses a more uniform penetration of heat into the body than the conventional diathermy." They consider "the possibility of special selective thermal action a very remote one." They are not "able to substantiate the claim of specific biologic action of short wave diathermy." They believe, however, that the claims of specific bactericidal action can be explained on the basis of "point heating" of the micro-organisms to a higher temperature than that of the medium.

Galê(5) has studied the "penetrative and selective heat effects of short and ultrashort waves." In this work, the two problems of selective heat production of various substances under otherwise identical experimental conditions, and of the heat distribution produced in a homogeneous medium, have not been separated. Therefore nothing further can be concluded than that "short and ultrashort waves have the power of *selective heat penetration*" and that "the cross sectional area of a substance plays an important rôle in its heating reaction — ." The destructive effects on paramecium and chilomonas is attributed to the heat effect.

In a paper, "Short Wave Therapy," by Turrell(6) the "theory of selectivity" is tied up with the permeability of all membranes to high frequency currents and the field distribution in a homogeneous tissue. The claim that certain wavelengths may have "specific selective properties for certain cells" is disposed of by a comparison with the "famous Schearer War Hoax."

It is evident that conclusions arrived at in these papers leave the problem of selective heat production by ultrashort waves unsettled. The following investigation was conducted for the purpose of deciding whether or not ultrashort waves produce selective heating in different biological substances. The problems of field distribution, conduction and convection of heat in the dead or live body are not considered here, in order to prevent clouding of the issue.

Before the problem of selective heat production could be studied experimentally, it was deemed necessary to examine the effect of the position of several objects in the condenser field. In case of high frequency currents it makes a great difference whether tw objects with different resistances are in parallel or in series. In the first case, the potential difference in both objects is the same, but the object with lower resistance will conduct most of the current and will be heated most. In the second case the same current will go through both objects, but at a greater potential difference in the object with higher resistance, and that one will be more heated. In the case of hertzian waves, conditions are so different from electric currents that it was necessary to

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study the influence of the relative position of two objects in the field.

Figure 1 illustrates the two positions used.

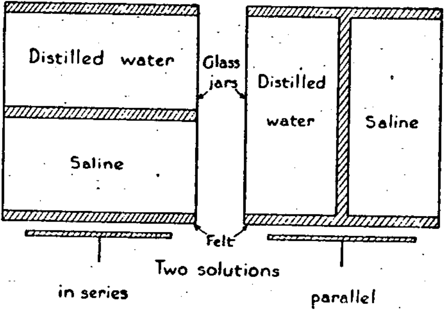

Fig. 1. — Two solutions in series, and parallel.

Two glass jars (5 x 4 x 2 inches) were employed, one filled with distilled water, one with saline solution. A piece of felt was used to insulate one from the other jar, and the jars from the electrodes, to prevent heat conduction. A 7 m. wave was applied. In both positions the saline heated up ten times as much as the distilled water. Neither did a reversal of the two vessels in the series arrangement between the two electrodes alter the result. Since the series arrangement appeared less sensitive to the position of the electrodes, experiments with different wavelengths were made in this setting. Table 1 gives the averages of the observations:

Table 1. — *Averages of Observations*

λ (m)	dt water (c°)	dt saline (c°)	dt saline / dt water
3.5	+ .2	+7.4	37
4.5	.1	2.9	29
5.5	.4	6.6	17
7.0	.5	5.1	10
15.0	3.8	3.7	1.1

(dt = temperature increase)

While the 15 m. wave heats both liquids at about the same rate, a selective heat production occurs with shorter waves in favor of the saline solution and increases with declining wavelength until with 3.5 m. the saline heats 37 times as much as the water. This relationship is illustrated in figure 2.

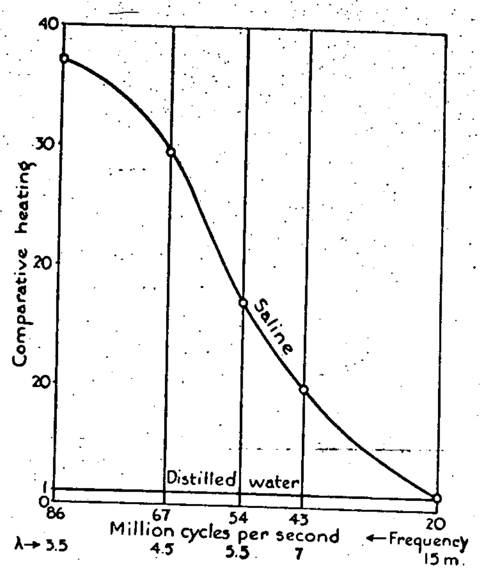

Fig. 2. — Heating of saline and distilled water through different wavelengths of ultrashort waves.

In order to study the selective heating of many substances under strictly identical physical conditions, the following arrangement was designed: The vertical metal rod of a kymograph was extended by a hard rubber rod, and on the upper end a round cardboard disc with 6 holes was fastened, in which 6 test tubes were held. Various electrolytes and body fluids or tissues could be placed in these tubes, and an alcohol thermometer, graded in fifths of a degree, could be inserted. This apparatus rotated between two condenser plates of 5 x 7 inches, at a speed low enough to allow temperature readings. By this arrangement a comparative study of six substances could be made in a short time. Temperature readings were made over ten to thirty minutes by inserting the thermometer for one minute in the alternate tubes, and the temperatures were interpolated for the times between the readings. The temperature time curves appeared straight over a certain range, but the steeper curves showed a tendency to flatten out after several minutes, indicating heat loss by air convection and heat radiation, while the flatter curves tended to bend upwards, suggesting indirect heating from the hotter tubes. Only points along the straight part of the curves were used for the evaluation of the results. Figure 3 illustrates a typical experiment. The following six substances were used:

Substance	Spec. Res. ohm . cm.	1 / ohm . cm.	Conductivity
Distilled water	220,000		.0000045
Coll. gold-solution dialized	10,300		.000097
Coll. gold-solution undialized	1,240	.00081	
Gelatin	250		.0040
½ physiologic saline	180	.0055	
Physiologic saline	71		.014

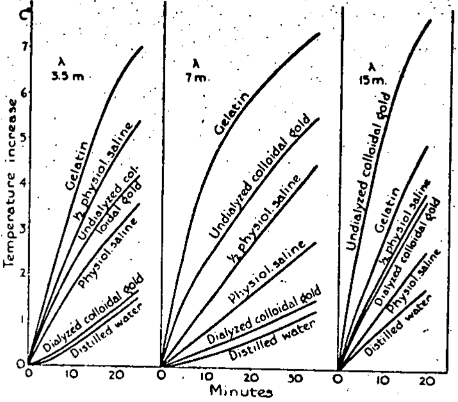

Fig. 3. — Observed temperature increase for different inorganic substances and various wavelengths of ultrashort waves.

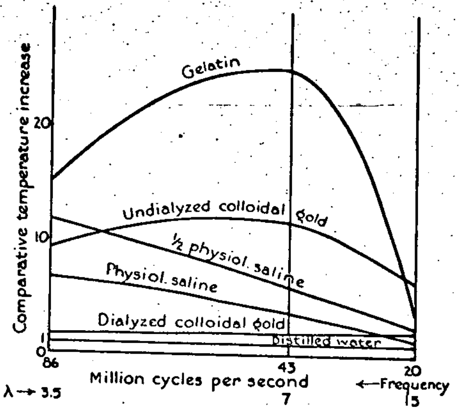

Fig. 4. — Selective heating of various electrolytes.

Equal volumes of these substances were exposed to the field of 3.5, 7, 15 meter wavelengths. The intensities were regulated so as to produce similar heating in the average; the exposure times were chosen so as to correct for still existing temperature differences. In spite of all this, decided differences occur for the various wavelengths, proving selective heating. Gelatin, for example, is predominantly affected by the 7 m. wave; undialized gold more by the 15 m. wave. The greatest differences in heating occur at the 3.5 and 7 m. waves, even to a degree that the distilled water and the dialized gold solution were indirectly heated by the hotter tubes.

In order to eliminate the influence of the variation of energy output in the field from one to another wavelength, all figures can be referred to one standard, for instance, the heating of distilled water. For the preparation of figure 4 the heat values at 5 minutes exposure have been selected, as representing the part of the curve which is not influenced by heat conductivity. In this curve (and the following ones) the abscissa is subdivided from the right to the left into frequency figures, and the corresponding wavelength figures are indicated below. The ordinate represents the ratio of the heating of each substance to that of water. Therefore, the water figures appear always as unity. Although the data are too incomplete for the exact determination of the shape and the position of the maxima of the curves, it is evident that for gelatin and the undialized colloidal gold solution wavelengths around 7 and 15 m. are optimal, while for the other substances wavelengths of less than 3.5 and more than 15 m. would be desirable for maximum heating.

Tissues Studied

In a similar way the following body tissues were studied: human skin (white, colored), (normal, cleaned); subcutaneous fat; mesenteric fat; muscle; spleen; liver; brain; lungs; bone (femur, vertebra); bone marrow; hair.

For the comparison of these biological materials with one another the skin was selected as a standard rather than distilled water as before. This was done for two reasons:

1. The heating of distilled water was very slight and was influenced by the nearby heated tubes.

2. The ratio of the heating of these tissues to the heating of the skin is of greater biological importance, since it is one of the factors which determine the heat distribution in the body.

Figure 5 is characteristic of the experimental findings.

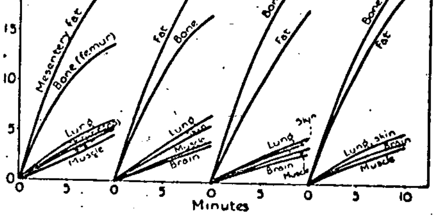

Fig. 5. — Observed temperature increase for various organic substances and various wavelengths of ultrashort waves.

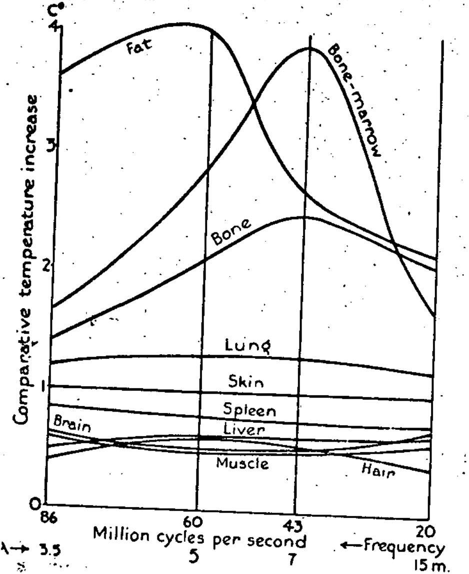

Fig. 6. — Selective heating of biological tissues.

The results are completed, averaged and compiled in figure 6.

Every curve represents the average of measurements on 2 to 6 specimens. As a rule each individual curve had sharper and more extreme maxima, sometimes at different wavelengths for the same or similar material. In some cases the individual curves were still ascending at the shortest or longest wavelength, indicating that the optimal wavelength fell outside the range studied.

The various tissues can be subdivided in two groups in their heating relation to the skin: Spleen, liver, muscle, brain and hair heat less than the skin; also skin well cleaned of fat and grease by boiling in ether, heated somewhat less than normal skin, from which the adipose layers were mechanically removed. On the other hand, lungs, bone marrow, fat and bone were heated much more than the skin. These observations may lead to the following conclusions:

1. Hair and fur on the skin will not increase the heating of the skin by these waves unless local heating occurs through the shafts of the hair.

2. The subcutaneous tissue is heated considerably more than the skin and will indirectly heat up the skin by conduction and convection.

3. Internal structures such as muscles, spleen, liver, brain, are primarily heated less than the skin. They may be heated secondarily from adjacent structures, which are more selectively heated, such as bone.

4. While the lungs cannot be heated by high frequency currents, due to their position and great resistance, they manifest selective heating in the hertzian wave field.

5. The bones are also heated selectively; for these experiments parts of the vertebrae and femur were used. The spinal cord and the bone marrow were removed. The thermometer was inserted into the cavity and the lower end closed by a cork. To test whether organic substances were responsible for this selective heating, the bones were boiled in water and tested again. The specific heating was not markedly altered by this procedure.

6. The strongest heating was observed in fat (mesenteric and subcutaneous) and in the bone marrow. The most pronounced heating of these substances occurred around the 6 m. wave (5 and 7 m.).

The observations by Pratt and Sheard,(7) that the knee joint of a live dog can be heated to a higher temperature than the superficial tissues of the exposed region, must be due to the selective heating of bone, cartilage and fat, to such an extent that tissue conduction and blood convection are unable to equalize the temperatures in the tissues in question.

These results, obtained under well defined physical conditions, substantiate in principle the results obtained by Schliephake under conditions less well defined. In detail, however, rather pronounced differences were noticeable. Such a strong relative heating of the liver as was claimed by Schliephake could not be observed by the author.

The selective heating of the blood and its constituents, the blood serum and the blood corpuscles, was studied in the same way and compared with human skin. The results are given in figure 7. Blood is heated about one-half as much as skin. The serum is heated 25 to 40 per cent less, and the corpuscles 10 to 45 per cent more than the whole blood; the actual heating of the whole blood is, therefore, the result of the direct heating of its two components.

In a similar way the heating of bacteria (B. prodigiosus) and yeast (sac. cerevisiae) was studied in comparison with the fluids from which they were centrifuged; this was the

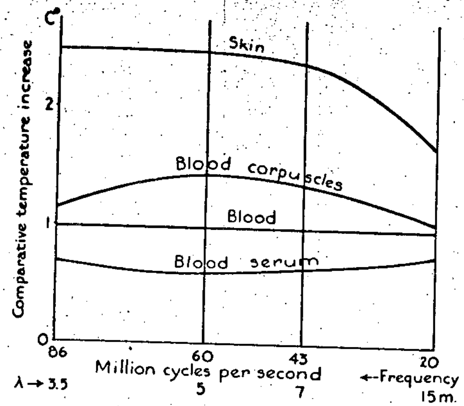

Fig. 7. — Selective heating of blood and its constituents.

broth in case of the bacteria, and the fluid in which the yeast was washed. The heating of these suspension fluids is arbitrarily set as unity for all wavelengths; thus the figures for bacteria and yeast give the heating in ratio to their respective suspension fluids. Figure 8 indicates that for most of the waves used the organisms were heated less than their suspension fluids. In case of yeast the ratio is reversed between 5 and 3.5 m. wavelengths; in case of the bacteria the reversal seems to occur at a wavelength shorter than 3.5 m.

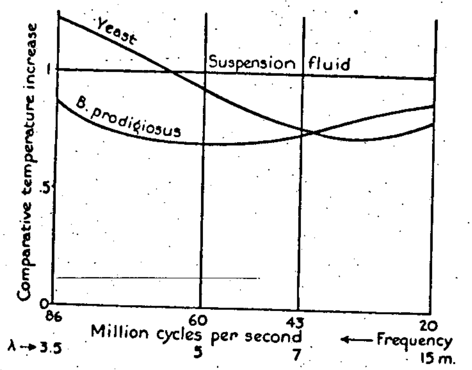

Fig. 8. — Selective heating of bacteria, yeast and their respective suspension fluids.

This experiment appears to show that a selective bactericidal effect of the high frequency waves is improbable. While several authors⑧ have claimed that bacteria are killed in the high frequency field at a temperature which normally does not destroy them, other investigators⑨ could not substantiate these findings.

Two kinds of experiments were designed for the purpose of studying the effect of the high frequency field on bacteria.

1. Two test tubes contained the bacterial (B. prodigiosus) suspension, one in distilled water, one in physiologic saline solution. Each tube contained a mercury thermometer graded in 1/5 degrees C. and was held in the center of a museum glass jar containing water of 40 degrees C. The jar was exposed to the ultrashort wave field for one hour, the intensity of the field was regulated so as to avoid an increase of the temperature of the bacterial suspension to more than 44 degrees C. The 3.5, 5, 7 and 15 m. wavelength was used. An identical jar was held at the same temperature by means of a water bath and a Bunsen burner, outside of the ultrashort wave field. Just before and after the one hour exposure a plate was made on which the bacterial population was later counted. The quotient of the resulting figures gave the growth rate of the bacteria per hour. The quotient: Growth rate of the control divided by growth rate of the exposed bacteria represents the bactericidal effect of the ultrashort wave field in relation to the normal behavior of the cultures, 1 indicating no noticeable effect, >1 indicating destructive effect of short wave, <1 indicating stronger growth than normal.

2. A similar experiment was conducted with a cooling system to keep the temperatures far away from destructive temperatures, close to 30 degrees C. Only saline suspensions were used. Table 2 gives the results of all these experiments.

At first glance the resultant figures seem to be scattered at random between 0 and 4, indicating no significant inhibitory or growth promoting effect. It is peculiar, however, that all the saline figures are decidedly higher than the corresponding figures for water. This seemed to correspond with the observation that during full exposure the saline heated up more than the water, with a difference of about ½ degree C., in the field; in most of the experiments the control was kept at the average of these temperatures. In order to decide upon the influence of this factor a different experiment (table 2) was conducted with the 7 m. wave, in which the water and the saline suspension were studied separately at exactly identical temperatures. Again there was a difference between the saline and the water figures in the same direction, al-

TABLE 2. — *Results of All Experiments*

	Exp. λ (m)	Media	Ultrashort waves Bef'e	Ultrashort waves After	Ultrashort waves Gr-rate	Control Bef'e	Control After	Control Gr-rate	Control U. Sh. W.
Bacteria Exp. Type I (high T°) H_2O, Saline. No cooling.	3.5	H_2O	176	106	.60	140	97	.69	1.1
		Sal.	138	115	.83	124	126	1.02	1.2
	4.5	H_2O	405	390	.96	411	0	0	0.
		Sal.	544	594	1.08	324	591	1.82	1.7
	4.5	H_2O	152	51	.35	183	0	0	0.
		Sal.	135	43	.32	160	54	.35	1.1
	5.0	H_2O	120	75	.63	107	40	.37	.6
		Sal.	231	94	.40	115	97	.84	2.1
	7.0	H_2O	104	8	.08	171	16	.09	1.1
		Sal.	146	41	.28	120	138	1.15	4.1
	* 7.0	H_2O	171	118	.69	414	77	.19	.3
		Sal.	315	506	1.6	480	469	.97	.6
	15.	H_2O	121	27	.22	88	4	.04	.2
		Sal.	129	99	.77	114	143	1.24	1.6
	Avge	H_2O							.5
	Avge	Sal.							1.8
Bacteria Exp. Type II (low T°) Saline. Cooling.	3.5	Sal.	520	350	.67	460	450	.97	1.4
			204	165	.80	189	170	.90	1.1
	5.0	Sal.	120	106	.58	166	149	.90	1.0
	7.0	Sal.	82	92	1.11	98	79	.81	.7
			96	104	1.08	123	81	.66	.6
	15.	Sal.	191	148	.78	216	124	.57	.7
	Avge	Sal.							.9

though not so pronounced as in the original experiment.

In the experiment at lower temperatures it seems that at the shorter wavelength a destructive effect takes place, that is not present with the longer wavelengths. All these bacteriological results should be regarded as preliminary. Further studies are required for the final settlement of these questions.

Summary

1. Identical results were obtained when two objects with different conductivities were exposed to ultrashort waves, once in series, once in a parallel circuit.

2. Different heating was observed if electrolytes of different conductivities and various biological materials were exposed to ultrashort waves under strictly identical conditions as to volume, shape, position, wavelength, intensity and time.

3. The wavelength at which maximal heating occurred was different for the various materials.

4. The ratio of heating of the various materials was different for various wavelengths.

5. For a 5 m. wave the relative heating in descending order is: fat, bone marrow, bone, lung, skin, spleen, liver, hair, brain, muscle. Blood corpuscles are heated more, blood serum is heated less than whole blood.

6. The results obtained upon selective heating and destruction of bacteria and yeast by ultrashort waves are not yet conclusive.*

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