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## Physics and physiology of heat therapy : with special consideration of conversive heat

W. A.G. Armbrust  
*University of Nebraska Medical Center*

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The  
PHYSICS AND PHYSIOLOGY  
of  
HEAT THERAPY  
with  
Special Consideration of Conversive Heat

Walter Alwin Georg Armbrust

Senior Thesis  
Presented  
to  
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## CHAPTER I

### INTRODUCTION

Heat was used in the latter half of the seventeenth century exactly as it was used in the time of King David.

In the first book of the Kings in Chapter I it says:

Now king David was old and stricken in years; and they covered him with clothes, but he gat no heat. Wherefore his servants said unto him, Let there be sought for my lord the king a young virgin; and let her stand before the king, and let her cherish him, and let her lie in thy bosom, that my lord the king may get heat.

Thomas Sydenham (1624-1689) was particularly partial to this method (*Accubitis junioris*) and speaks of its efficacy with great confidence:

Having had recourse to other remedies without success I was compelled to turn my thoughts towards new quarters, and to apply to the patients the lively and vigorous warmth of young people. Let no one wonder at the strangeness of this method, when he hears that so much has the sick man been restored by it, and so much has debilitated nature been renovated, that it has unloaded itself of the remnants of the matter that it secretes and eliminates; since it is very credible that a notable supply of fresh effluvia from a sound and athletic body may be transfused into a sick and exhausted one. I have never found that the repeated application of warm flannels even had the effect of the plan I have described. In this the warmth is of a kind congenial to the human frame, and it is, at the same time, bland, humid, equal and permanent.

Now this principle of transfusing into the body of the patient effluvia and exhalations which perhaps may be of a balsamic nature, although at first adopted it, by others as well as myself, and that with good results; and I am by no means ashamed of it, even although some few from amongst the arrogant, impertinent and supercilious despisers of everything common may sneer at me by reason of it. I put the well doing neighbour far above the vain opinions of the like of such men as these. (1)

Thermotherapy is the application of heat from any of its various sources to the body for therapeutic effects.

The application of heat to relieve pain and to modify pathological conditions is probably the oldest form of therapy known. Beginning with the application of hot stones, sand and natural hot water, it has been developed and refined continuously up to the present day.

The temperature of tissues may be raised by means of heat applied to them. This may be by conductive, convective or conversive heat.

Conductive heat includes the application of heated solid bodies directly or through other solid material to the surface of the body. Among the common materials used are hot stones, water bottles, electric pads, mud and metal.

When heat is conveyed to the surface of the body by means of heated particles of gases or liquids the term convective heat has been used to describe it. In this classification, therefore, would fall the use of hot water, steam, melted paraffin and air superheated by any means.

In conversive heat various kinds of energy are



converted into heat within the depth of the tissues, as typified by the action of diathermy from the d'Arsonval type of high-frequency current. To a certain extent other types of electricity may simulate this effect and radiant energy may also be liberated as heat within the tissues.

Most of the common methods of applying heat to the body have other effects than that of simple heat production. In radiant light we have the selective effect of radiant energy on the cell metabolism. With the use of the high-frequency currents for heat production there is a sedative action on the sensory nerve endings. With the use of various other electrical currents also the effect produced is complicated by their chemical and mechanical action on the tissues. In the application of one of the commonest forms of thermotherapy, the use of hot water, we have besides temperature effects, other varying results depending upon the technique by which the water is applied to the body.

Forms of convective heat tend more greatly to dilate the subcutaneous blood-vessels and so automatically impede depth of heat penetration. Types of convective heat on the other hand may be applied to any desired

degree or depth in human tissue. Radiant energy may be liberated as heat to the extent of light penetration, which has been shown to be about one and three-eighths inches at the maximum. The monopolar high-frequency currents of Tesla and Oudin as usually applied probably do not have marked heating effects greater in their penetration than that of radiant energy.

That the metabolic processes in the cells of the living body may be modified by the application of heat has never been doubted, but the laws governing such effect have not yet been well worked out. There is no question but that a wide variation of effect upon cellular activity is produced by the application of heat to the tissues. It differs according to the mode or type of heat applied, the amount of body surface to which the heat is directed, the length and intensity of application, and the distance of the particular tissue in question from the heated surface.

Whirling water and air, and water under pressure have a reflex nervous effect quite beyond that of the heat they produce, but this effect again is limited where the area treated is small. Radiant energy is partly convective and partly conversive in type, i. e., the surface is directly and intensely heated and in addition

TABLE 1.

Sources of Heat in Treatment.(2)

Source	Form of energy	Heat transmitted
Hot-water bottle	Long infrared rays (non-penetrating)	By conduction
Hot compress		By conduction
Hot-water bath		By conduction
Hot-air bath		By convection
Steam bath		By convection
Electric heating pad	Long infrared rays (non-penetrating)	By conduction and radiation
Infrared generator	Long and short infrared rays (penetrating)	By radiation
Incandescent light bulb (heat lamp)	Visible rays Short infrared rays (penetrating)	By radiation
Carbon arc lamp Sun	Short infrared rays Visible rays Ultraviolet rays	By radiation
Diathermy apparatus	High-frequency oscillations (300-meter wave)	By electric oscillations
Short-wave diathermy apparatus	Short radio waves (3 to 30 meters)	By electric oscillations

the penetrating light energies are changed into heat in the tissues. There is also an associated counterirritant effect upon the skin which is only transitory. The capillary hyperemia from this source of heat is greater than in most others, and the stimulation to the metabolism of the affected cells is also greater. There is distinct metabolic stimulation of the cell protoplasm acted upon by light energy. The very exact degree to which conversive heat as illustrated by diathermy may be regulated has been taken up in detail in the description of the diathermy.

Physical therapy rightfully forms part of the practice of medicine and surgery and will be of most value in the treatment of disease and injury when employed by or under the immediate supervision of the physician who has learned why there is a scientific basis for the use of some physical energy or its combination with others or who knows when and how to apply it (3).

General practitioners interested in the practical application of physical measures are handicapped by the fact that in the majority of medical colleges, until recently, there was no basic instruction in this important field available and there is as yet none offered in medical physics. The remnants of high school training in

physics are as a rule insufficient as a foundation for the comprehension of the physical nature of the energies employed in treatment.

There is a great need for scientific workers in University departments of physical therapeutics, who might apply to such therapeutic agents the intense analytical study which has proved so profitable in the realm of pharmacology; until this need is met progress is apt to be slow(4).

The object of physical therapy is the bringing about of certain physical responses.

It behooves every practicing physician to learn in what conditions he might utilize physical therapy methods to good purpose. He should also learn what simple physical measures can safely be applied or prescribed for home use. He should not rely too much on the aid of a technician, for it should be axiomatic in the practice of medicine that no physician should ever expect his technician to perform procedures diagnostic or therapeutic which he himself cannot carry out properly.

Heat has been used for centuries--much has been learned about its effect upon the body--much has been written concerning these effects. I do not claim to have exhausted this field in literature--but I have be-

come better acquainted as well as more interested in this phase of medicine and will only try to include in this paper such information as I should like to maintain and from which I hope to be able to more rationally study heat and its physiological effects on the human body.

There is bound to be much overlapping where so many types of applications of a single energy are concerned. An attempt has been made to avoid as much of this as possible. Electrosurgery is not included in this work.

## CHAPTER II

### CONDUCTIVE HEAT

(a) Local Effects.- The most marked result of the application of surface heat is that of analgesia, especially in local infections, and in tissue relaxation. All spastic muscle tends to be directly relaxed when heated. For that reason pain due to muscle spasm or cramp is promptly relieved. This applies to both skeletal and smooth-muscle tissue. Vasodilatation in varying amounts affecting primarily the capillaries also occurs. The capillary wall is thinned and the intercellular spaces are increased, which permit the extravasation of a greater amount of blood serum into the tissues. There is also a direct effect upon sensory nerve endings which brings about circulatory changes in the deeper organs through reflex action. This is necessarily limited in degree in the local application of thermotherapy, but is one of the marked effects of its general application.

The local effects are further modified by the degree of vascularity of the tissues treated, the amount of subcutaneous fat present and the form of heat used. The rapid diffusion of heat which occurs in a vascular region will not permit any considerable rise in

temperature (5). More dense tissues with a limited blood supply will conduct the heat more deeply and to a higher degree, limited only by the skin tolerance. The presence of gases within the tissues is an impediment to heat diffusion. Under many pathological conditions there is associated marked stasis of the body fluids which tends to the deeper conduction of such heat if the amount of fluid is not greatly increased. The fact remains that the sensitivity of the skin to high degrees of temperature limits distinctly the degree to which the deeper lying structures may be heated. This tolerance is much greater for melted paraffin than for water and is still greater to superheated dry air. Profuse perspiration is induced in the skin but there is a tendency under certain conditions for venous stasis to be increased.

(b) Penetrability.-Some work (cited by Stewart (6) of J.J. R. Macleod and N.B. Taylor of England has demonstrated the degree of penetration of conductive heat applied directly to the skin to be somewhat greater than had previously been assumed. The penetration is of course modified by the vascularity of the part, the rapidity of the circulation and the thickness of the subcutaneous adipose layer, which acts as an insulating



medium to heat conduction. These investigators used for their work rabbits whose subcutaneous fat was markedly less than in the average human being, but nevertheless their findings give us important information as to what depth of heat penetration may be secured in the human body.

Upon the direct application of heat to the surface of the thigh there was an immediate rise in temperature which diffused directly inward and laterally for a distance of about three-quarters of an inch. The heat was applied at about 116°F. Upon the application of 125°F. to the abdominal wall temperature increase was noted to a depth of three inches spreading laterally to nearly one inch of additional surface. This rise in temperature must be largely dependent upon the actual conduction of heat through the tissues. That it is not due simply to vasodilatation is shown by the fact that the temperature rose to beyond blood heat. It is interesting to note that the penetrative chilling of the animal's body following the application of cold was even more marked. It was comparatively easy to raise the temperature of the brain by the external application of heat, while the internal organs such as the kidney and liver could be but slightly affected. Temperature of

106°F. obtained a rise of one degree at a depth of three-quarters of an inch.

The therapeutic use of heat applied to the external abdominal wall is therefore accompanied by an increase in the subjacent intra peritoneal temperature (7).

Hepburn and coworkers (8) observed in their experiments when physical therapeutic agents (electric pad, hot-water bag, infrared lamp, diathermy and hot wet pack) were applied over either the stomach or the upper part of the intestine, usually for an hour or longer, none of the observed changes in visceral temperature exceeded the maximum variation in gastric temperature during similar periods of time in a control series.

## CHAPTER III

### CONVECTIVE HEAT

(a) Superheated Dry Air Bath.-For the general elimination of the waste products of metabolism and of toxins from the body, superheated dry air given by means of the so-called oven bath surpasses in its efficiency any other type of general application of heat for the following reasons:

1. The skin will tolerate far higher temperatures of dry air than of heat applied to the skin by means of water or radiant light.

2. It stimulates the sensory nerve endings and through them the sympathetic nervous system to a very much greater degree than the other types of heat mentioned (6).

3. The period of stimulation preceding that of relaxation is more lasting when high temperatures of dry air are applied than by other methods. For the proper application of the oven bath to indicated cases there are certain essential features of the apparatus.

a. It should be capable of generating a temperature of 400' to 450' F. in less than five minutes.

b. It must be so ventilated as to remove moisture rapidly and provide for its substitution by dry

fresh superheated air. Any accumulation of moisture within the oven may scald the patient.

c. There should be a sliding table upon which the patient may lie during treatment and be removed from the oven while remaining recumbent.

d. The gas supply must be sufficient in quantity and pressure to rise quickly and maintain the desired temperature.

e. A heavy canvas covering for the open end of the oven should be provided which will encircle the patient's neck.

There should be provided a bath tub near by not less than six feet in length and eighteen or twenty inches in depth, equipped with some lowering device so that the patient may be lowered while still in a horizontal position into the warm water. An additional table upon which the patient may be raised after the bath, dried, and covered with blankets, should be at hand.

The treatment technique is as follows:

The oven bath should not be given sooner than one hour after a meal. The room must be warm and well ventilated. No draft should be allowed to strike the patient during his transferences from the oven to the

tub, or from the latter to the bed. After the patient is placed in the oven he should be covered with several layers of Turkish toweling or light blankets. As in the case of local treatment to the legs it is necessary to protect the feet with extra layers of covering. The drawstring of the curtain is then tied around the patient's neck and shoulders and the oven lighted. The temperature should be raised to between 400' to 450'F.

Lower temperatures and less covering will not obtain the same results. The application of cold moist cloths to the head and sometimes to the neck should be continued through the oven bath, tub, and occasionally for a short time after the patient is placed in bed. Shortly after the beginning of the treatment the patient shows its stimulating effect, manifested as a feeling of buoyancy and well-being. The pulse becomes slower, stronger and steadier if it was slightly irregular before. From fifteen to thirty minutes later marked changes occur in the patient's pulse which becomes soft and full.

It seems probable that significant changes in blood volume may be attained by steady, moderate but maintained rise in environmental temperature, while it

is doubtful whether a fluctuating temperature can produce the same response (9).

These characteristic changes do not occur in oven baths of lower temperature than those just cited; in the latter case depression instead of stimulation often follows. The treatment should be continued always until the stimulation period has passed, the pulse has become soft and the patient shows a tendency toward drowsiness. This characteristic reaction and not the patient's temperature (which is difficult to obtain accurately at best) is the proper guide for determining the optimum effect.

There is believed to be, during the application of best, a reflex stimulation of all body glandular activity. During the period of relaxation which follows that of stimulation, the vasomotor and cardiac muscle tone is greatly diminished and the sudden chilling of the body or the assumption of the upright posture might entail a severe strain upon the heart. Therefore, the body is gradually cooled by the patient being transferred from the oven to the water bath in the horizontal position. The water in the tub should be about 108°F. and should never vary more than a degree or two from this standard.

The coverings of the body are not removed until after the patient is taken out of the bath. The duration of the tub bath is from five to fifteen minutes, during which time the water is allowed gradually to cool. The pulse becomes somewhat harder and faster during this period.

No air currents should strike the skin during the time the patient is being manipulated, dried and wrapped in warm blankets or sheets. Massage if used should be gentle and superficial in type. The patient may then be placed at rest during which he may be given warm water if thirsty. Quiet rest in the recumbent position for two to five hours if possible is desirable. During this time the tone of the vasomotor mechanism is restored, the heart muscle regains its tone, all tendency to excessive perspiration stops and the patient is ready to resume his regular activity. A twenty-four hour specimen of urine will show a marked increase in the total solids, proving that increased elimination does take place; in fact patients near or actually in come from uremic poisoning have shown remarkable results when treated by this technique (6).

In diabetics also there is a greatly accelerated elimination of sugar which persists for several days

after the treatment. Other forms of physiotherapy aimed at increasing metabolism may be used coincidentally with the oven bath (6).

There has developed of late the question of salt deficiency as a result of these high fever or temperature treatments. McCanee (10) in his experiments on a number of patients showed that there must be long continued and frequent high heatings to produce salt deficiency. He also found that there are marked variations in patients as to the time of their showing the symptoms and signs of their deficiency.

(b) Local Superheated Dry Air.-There are numerous kinds of apparatus for the local application of superheated dry air. The smaller, lighter and less expensive types are heated by means of an alcohol burner beneath the apparatus, the large types usually by gas. A local temperature of from 250' to 450'F. may be obtained in this way. This degree of temperature is indicated by a thermometer thrust in the top of the apparatus. It is improbable that the heat reaching the skin beneath the many coverings that must be employed comes anywhere near this temperature. The part must be covered with several layers of absolutely dry Turkish toweling or similar material, with extra heavy wrappings over such elevated



areas as the toes. Since the heat is more widely diffused than with radiant heat an examination for scars or anesthetic areas must be made.

Proper ventilation must be provided for in the apparatus and the vent must never be completely closed off with the idea of intensifying the heat because of the fact that the moisture induced by perspiration may lead to a burn. The apparatus, especially when of the gas-burning type, must be regularly inspected to see that no soot or other material which might catch fire is allowed to collect. In the treatment of a single limb a temperature of 350°F. for fifteen or twenty minutes is usually sufficient. As a rule the depth of heat penetration by this method is comparatively slight, the danger of skin burns considerable, the part under treatment is hidden from the operator's view, the apparatus is not under the patient's control and for local effect at least the high radiant heat method is generally to be preferred.

(c) General Water.- In certain conditions associated with a high degree of nervous tension and excitability, prolonged hot tub baths have proved beneficial. It should be remember that there is a lowering of cardiac tone here as well as in the radiant bath cabinet and the patient should be removed, dried and wrapped in blankets

and rested for an hour if possible without at any time assuming the upright position.

(d) Local Water.- The use of local immersion baths of hot water has been largely superseded by the employment of whirling hot water mixed with air by the Bardwell modification of the local whirlpool arm and leg bath. This type of apparatus demands an efficient water pressure and heating plant to be of any great use. In the army hospitals this apparatus was of great service in the treatment of amputation stumps and numerous peripheral neuritic conditions. A cold, cyanotic and tender stump becomes hyperemic and less sensitive. Painful scars and neuromata were rendered less painful by means of this bath (11).

The contrast baths of hot and cold water are a useful means of developing a better vasomotor tone in superficial vessels (11).

Norman E. Titus of New York devised a further modification of the Bardwell apparatus which is comparatively inexpensive, and far less of a drain upon local hot water supply. It consists of an ordinary boiler with a small faucet drain near the base, into which, on a frame is placed a washing-machine motor, together with an air vent pipe. One filling of water at heat tolerance is suffi-

cient for a treatment.

Arm-baths have been used to relieve hypertension. There is at the same time an increase in general body temperature (12).

Carlson and Orr (13) have reported some very interesting experiments on the penetrating ability of moist heat when applied to the abdomen. They also observed its effect on intestinal movements.

The use of heat in the treatment of abdominal conditions, particularly peritonitis or localized abscesses, has become a frequent procedure in hospitals. Patients as a rule state that they feel better when such treatment is instituted. The relief from pain which heat affords in intestinal or pelvic conditions is commonly known.

Carlson and Orr applied warm moist heat to the abdomens of small and large dogs, adults and a child, for a period of from one to three hours in a total of forty experiments. The temperature was recorded either in the colon or in the intestinal fistula. The effect of heat on intestinal contractions was noted in dogs with Thiry-Vella loops by the use of kymographic tracings. It was determined that local applications of heat to the abdomen produced a rise in temperature within the

abdomen, if the abdominal wall was not too thick. Definite penetration was noted in the child and in the dogs, but the penetration in the adults was negligible. Prolonged application of heat did not increase the degree of penetration.

The application of heat to the abdomen or of warm water to the intestine did not effect intestinal tone or intestinal movements.

(e) Paraffin Bath (14).--This apparatus won a distinct place for itself in the British as well as in our own Army work, and is extremely efficient in selected conditions. The apparatus costs only fifty dollars, and can be built easily of assembled parts which consist of an electric grill with three degrees of heat, or perhaps better still a gas burner, and a large double boiler, the outer partly filled with water, the inner with about sixty-five to seventy-five pounds of paraffin. These are placed on a rough steel frame which can be made up by any blacksmith. The electric grill or gas burner kept on 'low' is sufficient as a rule to keep the paraffin liquefied once it has been melted provided there is sufficient water maintained in the outer boiler. An exceptionally high stool with a back is convenient for leg treatments. When not in use it is well to keep the

bath covered with a blanket to conserve the heat. It is important to remember that both inner and outer containers of the double boiler must be either of copper or zinc, as a mixture of the two will induce electrolysis, and soon produce sufficient destruction of the inner boiler to allow interchange of paraffin and water.

The cost of maintaining the paraffin bath at proper temperature by means of gas is about one-third that by electricity. However, to run the type of arm and leg baths devised by U.V. Portmann of the Cleveland Clinic, the amount of electricity is extremely small. This apparatus consists of a double metal wall with a poor heat conducting material between and a tightly fitting lid of the same construction. Here very little loss of heat is permitted, and the paraffin cools only when being used by the patient (6).

The advantage of this type of local thermotherapy is that heat may be applied and easily borne by the patient at a temperature some 20°F. higher than that at which he can stand water on the skin. The paraffin melts at about 122°F. and treatments at 135°F. can usually be tolerated. From 128°F. to 130°F. is the best temperature to use as a general rule. When the hand or foot is thrust below the surface of the melted paraffin a thin coating of

solidified wax completely covers the part. There is no heat lost through perspiration and the treatment may be comfortably stood for fifteen minutes to one-half hour.

Great care should be used in the treatment of scars or anesthetic areas as severe blisters will occur in scar tissue which seems to be in pretty good condition and covered with a good layer of skin. If the material is so warm that the patient has to withdraw the hand or foot he should keep the hand or foot perfectly still until it is reinserted. Moving the fingers or toes will split the glove of paraffin and when reinserted the melted paraffin pouring through the rents in the solidified wax feels extremely hot and may burn the skin. The knee may be treated by ladling the melted wax over it by means of a small dipper. The disadvantages of this method are that only the arm to above the elbow and the leg including the knee can be conveniently treated.

## CHAPTER IV

### CONVERSIVE HEAT

#### (a) Electrophysics.-

The physician should be able to visualize at all times (1) what is going on inside of the apparatus when the current is turned on from the source of electric power and (2) what is going on in the patient when the current is applied through the electrodes.

Electricity forms an integral part in the structure of all matter. Anything which has weight and occupies space is called, matter, which is composed of some ninety primary substances. The atom is the most minute unit of matter (Dalton 1808). A molecule consists of two or more atoms. In 1897 J.J.Thomson, a physicist of Cambridge, England, discovered electrons and Millikan the American physicist measured and isolated them. Every atom of matter in the neutral state is made up of a certain number of elementary positive units and an equal number of negative units called electrons. Electrons are all the same in electric charge and weight. Electrons are the units of electricity.

Rutherford established the second universal constituent of the atom called the proton. It is 1800 times as heavy as the electron and of opposite charge.

A negatively charged body is one which contains more electrons than its normal number; a positively charge body is one which contains less electrons than its normal number.

Electrostatics refers to electricity at rest and electrodynamics refers to electricity in motion or electric currents. In electrophysics we are chiefly concerned with the latter.

Substances which lead off the electric charge quickly are called conductors; those which prevent the escape of an electric charge are called nonconductors or insulators.

The larger the number of free electrons in any substance the greater will be its conductivity. The substances which are good conductors of electricity are also good conductors of heat. The tissues of the human body are good conductors on account of their saline ingredients, but the horny substance in the superficial layers of the skin serves as a fairly good insulator. By moistening the surface of the skin, its insulating property is overcome. In applying medical electricity to the body, part of our technique is directed toward overcoming skin resistance, so as to secure a free passage of the current to the well conducting tissues be-



neath. For transferring electrical charges, conductors such as wires or metal plates are used; at the same time, these must be insulated from other conductors by nonconducting material. When a charge is impressed upon a metallic conductor it distributes itself always on its surface. An insulating substance which offers great resistance of the passage of electricity by conduction, but through which electrical force may act by induction, is called dielectric substance (15).

Two forms of current are employed in every day commercial life, the direct and the alternating. Central generating stations generate a difference in electrical potential through their line of distribution. In the case of the direct current, constant pressure (electromotive force) is applied in one direction and the flow of electrons continues unchanged in the same direction. In the case of alternating current the direction of the flow of electrons is changing periodically. Pressure begins at the zero mark (no difference in potential) steadily increasing until the maximum is reached: then it drops down to zero and the whole process is repeated in the opposite direction, returning again to the zero point--and so on. The voltage of the alternating current is represented by a double curve: one-half above

and one-half below the neutral level. Each curve is called an impulse, two successive impulses constituting a cycle. The time consumed in the completion of a cycle is called a period (16). The number of cycles occurring in a second are called the frequency of the current. The ordinary alternating current usually alternates at a rate of sixty per second and is therefore a current of sixty cycles and 120 alternations (15). In everyday usage we designate as low-frequency currents those of a frequency of less than 10,000 a second; while the term high-frequency current designates a current of 100,000 or more cycles per second.

There are three principal actions of electricity on conductors, viz., chemical, thermal, and electromagnetic. Chemical action is mainly produced by direct currents; the changes in direction of flow in alternating currents interferes with the regular movement of the ions upon which chemical action is based. Currents of very rapid alternation exert no chemical action at all. Thermal action is produced by both direct and alternating currents and also by those of very rapid alternations, i.e., high-frequency currents. Electromagnetic effects are produced by all forms of currents. (15)

Joule's Laws (1877)

1. The heat produced is directly proportional to the square of the current strength.

2. The heat produced in different conductors is directly proportional to the resistance of each conductor.

3. The resulting quantity of heat is in direct proportion to the duration of the passage of the current.

In electric radiators and heaters the resistance of the wire produces the desired heat. In the electric cautery a loop of platinum wire becomes heated (15).

The laws of electromagnetic induction were formulated by Faraday in 1831 as follows:

1. An electric current can be induced in a closed circuit by moving a magnet near to it or by fixing the magnet and causing the circuit to move in relation to the magnet.

2. A current, the strength of which is continually changing (an alternating current or a direct current which is constantly made and broken) will induce a current in a second closed circuit near it.

The unit of current is the ampere. For commercial purposes a current flow up to 200 and more amperes is used. For electro-medical work much less rate of flow is required and as a measuring unit only 1/1000 ampere,

the milliampere, is employed. One MA equals 0.001 ampere.

Of the various therapeutic currents, the static current employs the smallest rate of flow of electricity, 0.1 to 1 MA; the faradic current amounts to a little over 1 MA; the galvanic current varies from 1 to 20 MA; the largest rate of flow is used in high-frequency treatments--from 500 to 1500 or frequently, even more milliamperes.

The unit of electrical resistance is the ohm. The resistance of any conductor depends (1) on its material, (2) on its length and (3) on its cross-section.

The unit of electromotive force or pressure is known as the volt and it represents the electromotive force or "push" needed to drive a current of one ampere through a resistance of one ohm. For electrotherapeutic currents the voltage of the commercial circuit is considerably modified through the resistance in the circuit and the various means of transformation. To pass a certain amount of current through the skin a definite potential or voltage is necessary. The galvanic-faradic-sinusoidal currents employ up to about 75 volts; diathermy up to several hundred volts; the old type of high-frequency current is stepped up to several thousand

volts, while static electricity employs a voltage up to 100,000 and more.

amperes =  $\frac{\text{volts}}{\text{ohms}}$  or  $I = \frac{E}{R}$  (intensity =  $\frac{\text{electromotive force}}{\text{resistance}}$ )

Practically all electrical measurements require calculations with the aid of Ohm's Law, and likewise this law underlies every application of electrical current in medicine.

Increasing the size of electrodes, decreasing their distance from each other and decreasing the resistance of the skin by moistening, all tend to decrease the ohmic resistance and thus increase the flow of current through the body (16).

Most electro-medical meters are read in milliamperes, expressing 1/1000 part of an ampere.

The total amount of electrical energy is the product of volt times ampere, which is expressed in watts. The watt is the measurement of the rate at which power is consumed. One kilowatt is equal to one thousand watts; one kilowatt per hour is called a kilowatt hour.

One farad represents the capacity of a condenser which, charged with one coulomb gives a difference of potential of one volt. The capacity of condensers is usually expressed in microfarads.

Practical use is made of the varying resistance of

conductors in the form of resistance units, or rheostats, which are placed in the path of the incoming current in electro-medical apparatus and serve to regulate the amperage. The rheostat for direct current consists of a coil of resistance wire so arranged that a swinging or turning arm throws into the circuit little or much of the coil and thereby decreases or increases the resistance.

For the regulation of the strength of the alternating current entering an apparatus, a rheostat constructed on the principle of the choke coil is used. Each alternation of the current induces in the same circuit a momentary current in the opposite direction.

Like any other form of energy electricity can neither be created nor destroyed.

If two sets of dissimilar metals, such as German silver and an alloy of zinc and antimony, are soldered together and heated at one end and cooled at the other an electric current is produced. A number of such elements joined together are called a thermocouple or thermopile and furnish a delicate instrument for the determination of minute difference in temperature. The accuracy of this is not affected by the frequency of the current.

(b) Currents of High Frequency.-

Physical characteristics: high voltage and high rate of oscillations.

Primary physical effect: thermal changes.

Secondary physiological effects: stimulation of vasomotor system, profound hyperemia, sedation of neuromuscular system.

The high frequency current (diathermy). A current with alternations or oscillations of extreme rapidity (1,000,000 or more per second) and at rather high voltage and fairly high amperage (16)(17). These oscillations may occur at intervals (intermittent) or are sustained and may show a decrease in their height (damped), or continued at the same strength (undamped).

Source. Electromagnetic induction, step-up transformer and condenser **spark-gap** action.

The source and means of production of any current has but little relation to the response of the tissues of the body. The final form of the therapeutic current and the technique of application will determine the effect that it will exert.

Conduction through the body. In medical electricity a current of sufficient strength and duration is applied to the body in order to exert certain physical effects; these effects in turn produce certain physio-

logical changes or tissue destruction, according to the object of the treatment.

The human body consists of a composite mass of tissues with varying electrical conductivity. In human tissues, cells are surrounded by a solution of lymph and an electric current in order to reach the cells has to pass through this lymph fluid. According to Hemingway and Stenstrom (18), the problem of electrical conduction in the tissues is a problem of conduction in an electrolytic solution and a tissue may be regarded as a non-homogenous solution. In applying an electric current to the body, conduction and subsequent effects will depend (1) on the form, strength and duration of the current (2) on the structure and area of the application.(16)

The factor of skin resistance is of primary importance in electrotherapy (15). Generally speaking, the skin can be considered a partial conductor, the conductivity of which is increased by thermal or chemical stimuli. It is an important organ of protection, reception, absorption and excretion. It varies in thickness in the different regions of the body, from one-half to four millimeters. The topmost of its two principal divisions is the epidermis, consisting of a superficial horny layer, the protecting and insulating coat, and a



heavy subcutaneous layer; neither of these containing any blood-vessels, but they admit the flow of nutritional fluids from below through little channels. These nutritional channels and mainly the openings of the ducts of the sweat glands, serve as paths for the entrance of low tension currents. The lower division of the skin, the corium or true skin is formed of connective tissue united with elastic, smooth muscle fibers and it contains an abundance of capillary blood-vessels.

The relative resistance of the various parts of the skin is determined by their histological difference. The horny layer of the skin offers most of the resistance. Parts habitually exposed offer less resistance on account of the thinness of the skin. The relative porosity or the distribution of the sweat glands influence skin resistance considerably, hence the much better conductivity of the palms of the hands as compared to the backs of the hands in spite of the thicker horny layer. The soles of feet are the most resistant on account of their horny layer and the absence of sweat glands. Heat decreases skin resistance by bringing on perspiration due to an increased activity of the sweat glands. In experimental studies, subcutaneous injections of pilocarpin well away from the hand increased the conductivity of the

palms of the hands.(2)

It is evident that a current of greater strength will have greater power to overcome skin resistance.

The mode of current flow has also marked influence on the resistance of the skin. The high resistance toward the galvanic current is due to the phenomenon of polarization.(15)

Richter(19) demonstrated that the resistance offered to a direct current of a small strength is localized practically in the skin; a minute puncture made through the skin with a needle decreased the resistance from any level to zero.

Currents of low tension and low frequency exert a certain amount of electrochemical effect like the galvanic current and thus a certain amount of polarization occurs. Lacquer(20) showed that the length of the path adds to the resistance(according to Kovacs(2)).

Currents of high frequency, such as diathermy and the pulsatory discharge of the static wave current, cause no polarization on account of the very short duration of each impulse. This and their high voltage explains the minimal amount of skin resistance toward them (21).

In applying currents of high voltage, such as diathermy or the static wave current, plain metal electrodes

are used. The smooth passage of current is aided by directing the rays of a luminous heat or infrared generator for a few minutes to the area to be treated and by slight warming of the plates by the same source of heat (2).

The size of the electrodes and the distance between them plays an important role in skin conductivity (15). When electrical currents are applied in a full water bath very large amounts can be introduced. Resistance to the current varies in direct proportion to the distance between the electrodes. Pressure upon moist electrodes decreases skin resistance by better contact and by producing greater saturation with moisture. Too much or uneven pressure may lead to burns through relative eschemia of the skin or through excessive current density.(21)

Electrical conductivity of all tissues of the body depends (1) on their content of water and (2) on their relative density. A study by Bachem(22) on the resistance of the dead organs of the human body corroborates this and demonstrates as well that the resistance depends also on the variety of current. It is smallest for high-frequency, medium for low-frequency and greatest toward direct current.

TABLE 2.

Specific Resistance of Human Organs. (Bachem) (22)

	Current,		
	High frequency, Ohms.	Alternating, Ohms.	Direct, Ohms.
Liver. . . . .	.230.	.1,600.	8,000
Spleen . . . . .	.230.	.2,100.	7,700
Muscle . . . . .	.255.	.1,500.	9,000
Skin:			
Dry . . . . .	.435.	.300,000.	4,000,000
Wet . . . . .	.435.	.250,000.	380,000
Fat. . . . .	.2,700.	.3,250.	108,000
Lungs:			
Collapsed . . . . .	.485.	.1,820.	5,400
Bone (tibia) . . . . .	12,300.	15,400.	22,500
Kidney . . . . .	.200.	.1,400.	8,500
Brain. . . . .	.630.	.2,170.	10,700

The density and hence the physiological effect of a current is directly proportional to the square of its strength and inversely proportional to the cross-section of the area through which it flows. It is estimated that each square inch of normal skin can comfortably tolerate about 75 to 100 milliamperes of the high-frequency current. Much smaller amounts for direct and low frequency currents. Under physiological conditions the comfortable toleration of the patient is the principal guide of safe current density (23).

Employing two electrodes of equal size, the density beneath each of them is equal; while using one twice as large as the other, the density of the current under the

smaller will be twice as great as under the larger (16). As the current spreads across the body its density must gradually decrease so that midway between the electrodes the density is usually less. The nearer the electrodes are applied to each other, the greater will be the density of the current between them. If both electrodes are placed on the same side of the body or of an extremity, the density of the current will be the greatest in the skin and in the superficial parts. The closer they are placed the greater is the density on the surface, with a resulting "edge" effect; this is first manifested by an unpleasant and burning sensation, and when unheeded, may result in a superficial blister or deep burn. Edge effects are noted only between the near edges of electrodes and none on their far side (15). In the following is considered the influence of the position and relative size of electrodes upon the passage of a current of adequate strength through homogenous tissue. The technique of application in clinical practice is based upon these considerations.

1. When two electrodes of equal size are placed exactly opposite and with their surfaces in parallel (transverse application) there will be equal current density all the way through, provided that the electrodes

are not too far apart. Increasing the distance between the electrodes decreases the current density between them, so that one must use proportionately larger electrodes in order to obtain a fairly equal density all way through (16). Kowarschik (24)(cited by Kovács (2) demonstrated by a series of experiments with diathermy that as long as the distance between the electrodes is not more than one and a half times their greatest cross section, the density and thus the heat effect, will be equal all the way through. With increase of the distance there will be an inevitable current dispersion in the central area between the electrodes; to overcome this, then, electrodes of proportionately larger cross-section are necessary (25).

2. When electrodes of unequal size are placed exactly opposite to each other the density will be proportionately greater under the small area. The decrease of electrode size does not increase current toleration but simply limits its principal effect to the area under the active electrode. This may be desirable when the action of the current is to be restricted, mainly under the area of one electrode (16). In surgical applications the current density under the active electrode, a needle point, is increased far

beyond physiological toleration (15).

3. When electrodes are tilted toward each other the greater part of the current will take the shorter path and thus the density will be greater where the edges approximate each other.

4. When the cross section of the area between the electrodes is narrower than that of the electrodes there is greater density of current in that area.

5. If two electrodes are placed on the same plane the current will be almost entirely limited to the area between the approximate edges. When two electrodes are placed far enough from each other, however, some of the current will travel under the skin, along the muscles and other soft tissue (15).

It is estimated that the distance between these electrodes must be not less than ten inches; such technique of application is designated as longitudinal application. A modification of this technic is known in general as the "cuff" method, when electrodes are placed circularly around a limb in the form of cuffs(26).

#### (1) High Frequency--Physics

High-frequency current is attained by condenser discharges through an oscillating circuit. The oscillating current produced in a high-frequency

circuit depends on the capacity of the condensers, on the inductance of the solenoid and the resistance of the air gap (15). d'Arsonval's original apparatus produced a high-frequency current of relatively high voltage (50,000 to 100,000) and low amperage (500 to 1000 milliamperes), the oscillations of which were intermittent and damped. This was due to the fact that the induction coil charged the Leyden jars intermittantly and their capacity was relatively small. The single spark gap had the tendency to over heat and deteriorated rapidly. On account of these structural imperfections, the amount of local heat produced was relatively small. The patient was also in direct connection with a dangerous high-voltage circuit. The original d'Arsonval apparatus is practically obsolete now, at least so far as the use in America is concerned and has been replaced by the modern diathermy apparatus (2).

#### (2) Diathermy Apparatus of Spark-Gap Type

The modern type of high-frequency apparatus differs from the simply d'Arsonval apparatus by the production of sustained oscillations of relatively low voltage and relatively high amperage. Such a current when applied to the body produces marked local heating and hence the term of "diathermy" or through and through heating is



used to designate this type of apparatus and its product (15).

Diathermy currents can be produced by either a spark-gap type of apparatus or by a thermionic tube apparatus; generally speaking, the first furnishes damped oscillations while the second one furnishes oscillations of undamped character (2).

The two principal steps in the production of a diathermy current are: (1) the incoming alternating current supply is raised to a high voltage by electromagnetic induction by means of a transformer, (2) this higher voltage current charges a set of condensers--multiple plates or Leyden jars--and these discharge across a multiple spark gap. The spark discharge sets up oscillations of fairly well sustained damped character, at a rate from several hundred thousand to a million or more per second. The high-frequency current thus produced is conducted to the patient from the terminals of the apparatus (16).

Diathermy apparatus depends on a supply of alternating current either directly from the main lighting circuit or through changing the direct current supply of the main by a rotary converter.

In case of direct current supply this current enters a small rotary converter, usually housed in the lower

part of the apparatus. The converter consists of a direct current motor; the rapid revolutions of the coil induce the brushes, bearing collector rings, an alternating current of a potential of about 75 volts and a frequency of about 60 cycles. When the main switch is turned on in a direct current diathermy apparatus a gentle humming is heard, indicating the working of the rotary converter (2).

Whether the alternating current enters the apparatus from the main or from the rotary converter, it passes first through a controlling device (rheostat or impedance) also described as a choke coil. This is usually arranged so that at its lowest point the whole resistance is in circuit and as the control is advanced-- it may have three to ten buttons--more and more resistance is cut out, until finally the full amount of the current enters (15).

The alternating current having passed through the regulation choke coil enters the static transformer. This device replaces the induction coil of the d'Arsonval apparatus. It consists of thin plates of electromagnetic steel, shaped like a picture frame, surrounded on the side of the incoming current(primary) by relatively few turns of insulated coarse wire and on

the secondary side by a great many turns of insulated fine wire. The difference in the number of turns between the primary and the secondary side represents a step-up transformer (2).

It is estimated that in the average spark-gap type of apparatus the 110 volt alternating commercial current is stepped up to 2000 volts or more. No change in the number of alternations or frequency takes place in the transformer. As the amount of electrical energy or wattage in the circuit remains unchanged, it is evident that with an increase of voltage a decrease of amperage must take place for the energy in-put.

### (3) The High Frequency Circuit

The high voltage current from the secondary side of the transformer acts on the principal part of the apparatus, the high-frequency circuit, consisting of a spark gap, a condenser and a resonator. The main purpose of this part of the apparatus is to accumulate electrical energy at sufficient high voltage in the condensers and discharge it across a spark-gap.

(a) The condenser.-In most diathermy machines, instead of Leyden jars, plate condensers composed of alternate sheets of metal and mica are used, and the increased surface thus permits the accumulation of a large volume of current. When filled to capacity and

the sliding rods of the spark gap are brought within a suitable distance, the condenser empties itself by an oscillatory discharge. The discharge period of the condenser takes about 1/10,000 second, and as soon as the charge is dissipated the condenser is charged again from the static transformer, and the process of discharge is repeated.

(b) The spark gap.-The old type single gap of the original d'Arsonval apparatus had a tendency to over-heat and deteriorate, and as a result the oscillations were often irregular, causing a faradic sensation, even muscular twitches, in the patient. Their cooling was quite troublesome and they developed unpleasant combustion products. In modern diathermy apparatus the spark gap is of multiple type, consisting of two or more metallic, usually tungsten, discs insulated from each other. Cooling is provided by mounting the discs on metal blocks with radiating fans. This type of spark gap is much more sturdy, offering an ample surface for the oscillatory discharge and need not be opened wide. The opening and closing of the spark gap is effected by a control (2).

The function of the spark gap is to act as a variable resistance which allows the condenser to be

discharged through high voltage oscillations. The wider the spark gap, the higher the voltage needed to jump across, at the same time the frequency of the wave trains is lowered (16).

(c) The oscillatory transformer or resonator-In addition to the single solenoid of the d'Arsonval machine, the modern diathermy apparatus contains another coil, described as the Tesla coil and the two together are known as the resonator.

The Tesla coil is essentially another step up transformer with an air core which serves to increase the voltage of the high-frequency oscillations. The primary of the resonator (the original d'Arsonval coil) is the inductance of the oscillating circuit and consists of a few turns of heavy wire. It is wound over the secondary (the Tesla coil) consisting of many turns of small magnet wire. The primary and secondary are well insulated from each other so that the electromagnetic effects take place inductively and not by direct conduction. The inductance coil in the oscillating circuit may be provided with taps, whereby it may be used as an "auto-transformer" and current may be drawn directly from it for the patients circuit (2).

The frequency of a diathermy current is determined

by the capacity of the condensers and the inductance of the current, and the frequency is the natural frequency to which the combination of coil and condenser resonates.

Most high-frequency machines contain a third coil or solenoid, first constructed by Oudin. It consists of a coil of fine wire connected to a lead-off from the resonator. The Oudin coil constitutes an additional step-up transformer and produces high voltage modification of the high-frequency current known as the Oudin current. This is led off by the Oudin (monoterminal) outlet.

(4) Diathermy Apparatus of Vacuum (Thermionic) Tube Type.-

Of particular interest is the development of vacuum tubes capable of producing even shorter radiations than those used in therapy at present. The radiations from these oscillations are of the order of centimeters instead of meters, and such radiation has more pronounced optical properties than the radiation of the short wave field (27).

Undamped oscillations of stable and efficient character are produced through the employment of the three element or amplifier tube of de Forest. In the two element thermionic tube, an electric current will

flow in the anode to the cathode circuit when anode is positive. The amperage of the current will depend on the electrostatic field, caused by the positive voltage of the anode and the temperature of the filament. The grid or third electrode consists of a fine-wire mesh or screen and is placed like a sieve between the plate and filament. It serves the purpose of controlling the flow of electrons from the filament to the plate. The electrons passing from the filament to the plate must pass through the holes in the mesh, and their passage to the plate is controlled to any desired extent by varying the voltage applied to this grid. Tubes of similar construction can be used for the production of high-frequency current and are then called oscillator tubes.

In diathermy machines working on the tube principle the oscillations are transferred to a patient circuit by a resonator arrangement (inductive coupling) as in the spark-gap machines. Oscillator tubes have the ability to produce higher frequency and power than it is possible by a spark-gap apparatus. The oscillations produced by vacuum-tube apparatus have a uniform amplitude and are of lower voltage than those of the spark-gap apparatus.

#### (5) Effects of Medical Diathermy

A high-frequency current is an alternating current,

consisting of oscillations of a million or more in a second (17). When applied to the human tissues within limits of physiological toleration its action differs from that of all other forms of electricity, principally through the absence of sensory or motor effects. The extremely rapid alternations of the current preclude the development of electrochemical reactions on which the polarity action and the neuromuscular effects of the low-tension, low-frequency currents are based. The very short duration of the impulse of an oscillation can hardly cause any ionic movement, and if it should the same would immediately be counteracted by an impulse coming from the opposite direction (15).

The generally accepted conception of the physical effect of the high-frequency current when applied through two metal electrodes placed in close contact to the body is that the frictional energy of the rapidly oscillating current is transformed along its path into thermal energy. The production of heat is not a specific property of the high-frequency current, for any electric current, in accordance with Joule's laws, will heat up tissues in direct proportion to its strength and to the resistance encountered. The electrolytic or polarity effects of the low-frequency currents prevent their use in



sufficient strength to cause appreciable heat effect. Heat production by diathermy extends from electrode to electrode, and serves as a unique means of through and through warming of any part of the body (28). The high-frequency current is either applied for treatment within physiological toleration of tissues--medical high-frequency treatment; or for destruction of diseased parts or new growths--surgical high-frequency treatment.

#### Characteristics (15)

1. High-frequency currents have no electrolytic action.
2. The high-frequency current exerts heating effects without causing neuro-muscular response in the body.
3. The heat developed by a high-frequency current penetrates from one electrode to the other and does not effect the surface alone. Maximum heat develops at the site of greater current density.
4. The maximum heat effect of diathermy occurs along the line of the shortest path of the current where its density is greatest.
5. The high-frequency current prefers to pass along the shortest path between the electrodes if the resistance is not unduly high.
6. The skin offers comparatively little resistance to the high-frequency current. The current passes with

equal ease through dry and wet skin. Moistening of electrodes is, as a rule, unnecessary. The classical investigations of Binger and Christie (29) at the Rockefeller Institute for Medical Research, show that; (1) the heat gradient of the body is reversed during diathermy so that heating occurs from without inward--the maximum heating occurring at the point of greatest concentration of the lines of current flow (affirmed by Osborne and Coulter (30)); (2) deep heating during diathermy is greater than that which results from the application of local heat to the skin; (3) the lung can be heated by diathermy in spite of simultaneous cooling of the chest wall.

#### The Primary Heat Effect

##### 1. Factors on which heating depends.

The greater the milliamperage employed and the longer the current flows the greater will be its heating effect.

Depending on the histological structure of the tissues and their quantity of blood supply, a varying degree of heat develops under diathermy. There are definite measurements available of the resistance of human tissues to electrical currents, the degree ranging from the lowest resistance of muscle to increased

resistance in the skin, liver, lungs, brain, tendons, fat and the highest resistance of bone (30).

According to Joule's second law the heat developed in a conductor is in direct proportion to its resistance, and it has been claimed that diathermy causes proportionally more heat in bones and fatty tissues than in muscles and the circulating blood. This view overlooks the fact that the electrical current always prefers the shortest path and that of least resistance. As any cross section of the body consists of tissues of varying electrical resistance, there is no reason why a current should travel along the more resistant bony and ligamentous structures when a parallel path of equal length and of lower resistance through soft tissues is open.

It has been found that the resistance of the tissues to the diathermy varies with the frequency of the current, Dowse and Iredell (31), from Kovács (2).

## 2. Distribution of Heating.

It follows from the considerations of the resistance of the various parts of the body, that the heat distribution caused by diathermy current is not uniform in the body. Bowman (32) formulated his findings as to the distribution of heating as follows:

"1. If a high-frequency body (bone, fat, etc.) extends from one electrode to the other, surrounded by a low-

resistance portion--flesh, blood-vessels, nerves, etc.-- the currents will be concentrated in the low-resistance path.

"2. If a high resistance body extends parallel to the plates and between them with only a long path of low resistance to avoid it, heating will be concentrated in the high resistance and the low resistance on either side of it will be comparatively cool.

"3. Blood-vessels will, by circulation, carry away a great deal of heat, when they extend from one electrode toward the other for a considerable portion of the electrical path; there may be heat generated in the blood sufficient to overcome this effect.

"4. For uniform masses the heating will occur fairly uniformly between the center of the electrodes, with the superficial structures slightly warmer than the deeper structures."

A study by Pariseau (33) demonstrated anew that the greatest amount of heat will be produced where the current density is greatest, and this occurs always near the electrodes and proportionately less in the depth.

In considering heat distribution in the various parts of the body, the question of heat loss by conduction, radiation and convection must likewise be

taken into account. In highly vascular organs, such as the lung, the blood stream always carries away a considerable amount of heat (34). This occurs especially when the general direction of the bloodstream is across the path of the current, such as in transverse application of diathermy to the organs of the chest or abdomen. When the lines of the current flow are the same as the general direction of the blood stream, such as in the case when the current is directed along an extremity, the distribution of the heat effect is more even and a smaller proportion of the heat is carried away by the blood. For this reason, conditions for the control and uniformity of heat distribution along a limb are more satisfactory than in internal organs (35).

Temperature distribution with different types of diathermy electrodes was investigated by Hemingway and Collins (36) and Gale (35), who found that a metallic electrode caused greater cutaneous than muscular heating, while with a saline pad electrode a higher increase of temperature occurs in the muscles than in the superficial layers of the tissues.

There are numerous experimental data available as to the degree of heat production within the limits of physiological toleration.

Stenstrom and Nurnberger (37), in a series of observations of the rise in temperature of the skin after diathermy, showed that the increase in temperature varied with the pre-treatment temperature and with the length of treatment. The average increase of temperature over various joints ranged from 5.9' to 24.1' C.

The maximum temperature which the skin can tolerate without pain is about 117'F. Other tissues can stand up to 116' to 118'F. of heat without damage. Mucous membranes, on account of their more extensive circulation and lack of insulating covering, tolerate a greater amount of heat than the skin (38). Cumberbatch (39), according to Kovács(2), found that the female urethra will bear only about 113'F., while the cervix can stand up to 120'F.

The measurement of the increase in heat in internal organs is complicated, as it requires the insertion of thermocouples in living tissues. However, fairly accurate records have been obtained by placing a thermometer in contact with the urethra, cervix, etc. subjected to diathermy. Royston, Ewerhardt and Co-workers (40) reported measurements undertaken with a special four-blade cervico-vaginal electrode; a standard technique resulted in temperatures in the cervical canal of 111'F.,

urethra 108°F., rectum 108°F., with extreme high temperatures of 115', 112' and 110°F., respectively. They found that it is impossible to maintain this degree of heat for a period of over four to eight minutes due to the dissipation of heat by the blood stream. There was found universally a rise of temperature by mouth and an increase in pulse and respiration.

The raising of the internal temperature of joints was studied by Edstrom (41), according to Kovács(2), on the carpal joint of the horse, which resembles in its dimensions the knee-joint in man. He concludes that diathermy enables the raising of joint temperatures by 4' to 5' C. Binger and Christie (29), in their experimental work in anesthetized dogs found that the temperatures of the lungs was raised not more than 0.4'C. above the rectal temperature by the dosage commonly employed in treatment practice. If they interfered with the circulation in the branch of the pulmonary artery they could elevate the temperature in the lung which it supplies about 1.5'C. (2.7'F.) above the rectal temperature. In experiments in which the temperature of the arterial and venous blood coming from the lungs was measured, it was found that the blood coming from the lungs was about 0.3'C. cooler than blood going to

the lungs. With diathermy applied to the lungs the arterial blood coming from the lungs became slightly warmer than the venous.

According to Kovács (2), it was shown by Stewart and Baldgreff (42) that diathermy could increase the secretion of gastric juice and raise the temperature of the stomach from 1' to 1.5'F. and that of the pancreas by 1' to 6'F.

Schmidt, Beazell and Ivy (38) in their experimental study of the effects of short waves on the blood and lymph flow of the intestine and colon were able to show that temperatures of about 52 degrees C. applied locally to mucous membranes stimulated secretory activity considerably, while body temperatures of 41.5'C. induced by diathermy had no measureable effect. Lymph formation was not altered by either procedure until temperatures high enough to produce injury were employed.

These same men, contrary to current belief, demonstrated in artificial fever, that circulation through the viscera as well as the peripheral tissues is definitely augmented.

Some effects of the Elliot treatment and short wave diathermy heating were investigated by quantitative methods in the dog. Total venous blood flow from various



levels of the gastro-intestinal tract was measured over a two and one-half hour period. Heat applied during the second and third thirty-minute intervals increased the blood flow from two to four times, under optimum conditions. In instances where injury was afflicted by the local application of heat the increase in blood flow was less.

In experimental studies of diathermy applied to the eye in narcotized dogs, Moncrieff, Coulter, and Holmquest (43), found that it was possible to produce temperatures which appeared to be within the limits of safe clinical application. For heating of deep lying tissues, diathermy was found to be superior to both hot applications and radiant heat. Whereas Putteney and Osborne (44) have shown that it is difficult to localize the heating energy to the eye. They have presented new photographic evidence to show that the caliber of the retinal vessels in the anesthetized dog is not altered by short-wave diathermy.

Rosenwasser and Bierman (45) were able to produce an elevation of the temperature in the nose, in the antrums and in the sphenoidal sinuses by means of the short-wave diathermy. The preceding application of a solution of cocaine and epinephrine interfered with this

rise of temperature.

According to Hemingway (46), to measure diathermy heat increase, a thermocouple voltmeter together with a thermocouple ammeter is necessary. The heat imparted to tissues can be computed from the effective high-frequency voltage drop across the tissue and the diathermy current (milliamperere reading).

As any cross-section of the body consists of tissues of varying electrical resistance, the increase of voltage will simply send proportionally more current through the path of less resistance and consequently there will be more heat produced in the parts already under the influence of diathermy (16).

It is not always possible to draw a well-defined dividing line between local and general heating by diathermy (47). With every local treatment, including a fairly large area, there is a certain amount of general heating, as proved by the rise of body temperature and often a feeling of warmth all over the body. In applying the current with multiple electrodes over an extended area (general diathermy), and in sufficient intensity, a heating of the entire body is produced. In the newly introduced methods of artificial fever treatment by general diathermy, temperature rises over 106°F. have

been attained and maintained with currents of 4,000 or more milliamperes. The factors in producing such temperatures are the amount of current, the efficiency of insulation and the mass of the patient.

#### Secondary Physiological Effects

Turrell (48) states: "There are good reasons for believing that the vibrations set up by the high-frequency oscillations may have an important therapeutic effect apart from the heating action." In our present state of knowledge, however, the most satisfactory explanation of the physiological and clinical effects of diathermy is that of raising the temperature of the parts. All of the physiological effects of thermal measures are brought about by the endeavor of the heat-regulating mechanism to maintain a constant temperature. When heat is applied to a part from any external source, the vasomotor mechanism responds with an effort to dissipate the excess heat. There follows an active vasodilatation of the capillaries and subsequent increase of arterial and venous circulation. There appears to be an inherent tone in the capillaries which causes vasoconstriction. Lewis (49) has shown that irritation of the tissues by the application of heat produces a release of vasodilator substance--histamine--

which in turn results in the dilatation of the capillaries. Upon the absorption of the vasodilator substance a greater portion of the capillaries dilates instead of the few which carry blood under normal conditions; as a result a greater blood supply to the part occurs. This local hyperemia in turn brings about an increase of the rate of removal of local tissue products and stimulation of the local resistive forces.

Weisz, Pick and Tomberg (50) were unable to obtain data in animal experiments for a specific effect of short waves on the blood-vessels. Osborne and Coulter (30) could obtain no true evidence indicating that living tissues manifest a specific thermal response to short waves of various lengths.

When heating is applied in sufficient intensity to a sufficiently large part of the body surface, general physiological effects arise. A comprehensive study of the combined local and general effects of heating produced by hot baths and radiant energy was recently presented by Bazett as follows:

TABLE 3.

Effects of Heating. Modified by Kovács (2) from Bazett (51).

On Circulation:

Superficial arterioles....	Dilated.....	Dilated
Superficial capillaries...	Dilated.....	Dilated
Superficial veins.....	Dilated.....	Dilated
Circulation rate.....	Increased.....	Increased
Pulse-rate.....	Unchanged.....	Increased
Blood-pressure arterial..	Unchanged.....	Decreased
Blood-pressure capillary.	Increased.....	Decreased or increased
Blood-pressure venous....	Increased.....	Decreased or unchanged

On the Blood:

Alkalinity.....	Decreased.....	Increased
Alkaline reserve.....	Unchanged.....	Decreased
CO <sub>2</sub> tension.....	Increased.....	Decreased
O <sub>2</sub> tension.....	Increased.....	Decreased
O <sub>2</sub> content (arterial)....	Unchanged.....	Unchanged or decreased
O <sub>2</sub> content (venous).....	Decreased..	Usually increased
Phagocytosis.....	Increased.....	Increased or unchanged

On the Lymph:

Formation.....	Increased.....	Decreased
Alkalinity.....	Decreased.....	Increased

On Tissues:

Metabolism.....	Increased.....	Unchanged or increased
CO <sub>2</sub> and O <sub>2</sub> tension.....	Increased.....	?

On Respiration:

Rate.....	Unchanged.....	Increased
Depth.....	Unchanged.....	Increased
Volume per minute.....	Unchanged.....	Increased

On Urine and Sweat:

Volume.....	Unchanged.....	Increased
Alkalinity.....	Unchanged.....	Increased
NaHCO <sub>3</sub> in urine.....	Unchanged.....	Increased
Alkalinity of sweat.....	Unchanged.....	Increased

Infections:

Local immunity.....	Increased.....	Increased (if heat is continued)
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The generally recognized local and general physiological effects of heating by diathermy are alike in character to those following external heating.

These effects can be grouped as follows:

1. Effects on Circulation (a) Local Effects.-The local application of diathermy results in an active arterial hyperemia which appears to be more penetrating and longer lasting than the hyperemia following external forms of heat application. There is also an increased flow of lymph and as a result of both hyperemia and hyperlymphia there is an increase in the volume of the part thus affected. In glandular organs there is a marked increase of secretion.

(b) General Effects.-Diathermy applied by a method of general administration result in a dilatation of peripheral blood-vessels, which appears very rapidly: this is accompanied by a rise in body temperature, which in turn results in an increase of the pulse-rate and respirations and an increase of the general body metabolism. Regarding blood pressure, there are contradictory reports in the literature, some authors reporting very marked decrease, which lasts for some time (52) others found an increase. Experimental observations in normal subjects usually show a primary

fall, a secondary rise and finally a fall below normal.

Neymann and Osborne (53) reported the following physiological changes following general diathermy: The blood-pressure first showed a systolic rise and later a diastolic drop; thus a pronounced increase in the pulse-pressure often occurred. This is not due to aortic dilatation but rather to an increase in the heart-rate and dilatation of peripheral vessels. After a series of treatments the blood-pressure, both systolic and diastolic, in uniformly decreased and remains permanently at a lower level. The electrocardiogram shows an increase in the rate after treatment. The blood picture shows a concentration phenomenon (the high temperature was kept up for several hours): Red blood corpuscles, white blood corpuscles and hemoglobin increase (54). There is slight relative increase in the polymorphonuclears and eosinophiles. There is an increase in the non-protein nitrogen and uric acid content of the blood; the carbon dioxide capacity of the plasma decreased (55). These changes are not permanent and the individual returns to his normal level after an interval of a few days.

Basal metabolic studies conducted at the Massachusetts Homeopathic Hospital showed that under autocondensation, low basal metabolic rates became

progressively higher and that in the great majority of cases they tended to remain at an appreciably higher rate after cessation of treatment. Urinary solids hitherto deficient, doubled and even trebled in quantity (Granger,56).

This newer research work amply corroborates d'Arsonval's early findings on the effects of general high-frequency treatment on general body metabolism, as well as those of Steel (57), cited by Kovács (2), who reported an increased quantity of urine, increase of urea and increase of elimination of nitrogen products after high-frequency treatment.

Wilhelm and Schwartz through their experiments on the effect of short-wave therapy on guinea-pig testis could show no evidence of pathological change on gross and microscopical examination. Seventeen guinea-pigs were exposed to a single short-wave radiation of twenty to sixty minutes (58).

2. Effects on the Nervous System. There is marked sedative effect on irritative conditions of sensory nerves (pain) and motor nerves (spasms and cramps), (59), (60), (61). There is no generally accepted explanation for the pain-relieving effect. It may be that heat in some way lessens nerve sensibility, perhaps, as a result



of inhibition through the temperature nerves of the skin. Tactile sensibility of the skin increases at 98°F., decreases at 113°F., and disappears entirely at 130°F. The current from the original d'Arsonval apparatus caused marked sedative effects without producing any appreciable heating, and this would leave the possibility of a specific sedative high-frequency effect still open.

The sedative effect on hypertonic conditions of motor nerves is generally explained by the effect of heating. The relief of muscle cramps by heat is well known and the effect of diathermic heat on hypertonic conditions of the unstriated muscles of the stomach and intestines is the more efficient sequel to the old-fashioned use of a hot brick to relieve colic. In seeming contrast to this action, heat also causes an increase of peristalsis in normal or hypertonic muscles; consequently, there appears to be a sedative effect in hypertonus and a stimulating effect in hypotonus (62).

Dixon has shown through experimentation that the carbohydrate catabolism of the cerebral cortex rises very quickly when the temperature is raised very abruptly above 42°C. (63).

General Diathermy and Hyperpyrexia by

Diathermy

General Diathermy

**Physiological Effects**--The object of general diathermy is to pass through large electrode surfaces, a diathermy current of sufficient intensity to influence general circulation and body metabolism.

#### Autocondensation

One or two electrodes (metal cylinders or plates) are applied by direct contact to the body (palms, fore-arms, soles of feet or chest), and connected to one terminal of a diathermy apparatus; a very large electrode separated from the body by an interposing pad of insulating material (dielectric) is connected to the other terminal. When the current is turned on the body becomes one part of a condenser, the metal plate under the dielectric being the other. Every set of oscillations of the high-frequency current traverses the body of the patient. If a glass vacuum electrode, grounded through the operator's hand, is held at some distance from the patient and still further from the machine, it will light up and thus prove the presence of an electric charge all over the body of the patient.

The physical effect of an autocondensation treatment is two-fold: (1) Local heating of the parts to which electrodes are applied directly (2) general heating of the body. The patient at first feels a slight

heat extending from the contact electrodes; later a feeling of warm glow may occur all over the body and the patient gets into slight perspiration. There will be a rise in temperature of one or more degrees if the treatment is continued long enough and the apparatus is sufficiently powerful.

The physiological effects of autocondensation correspond with those of general diathermy.

#### Hyperpyrexia by Diathermy

Neymann and Osborne (64) were the first to report on artificial fever produced by diathermy and additional experiences of many clinicians have been recorded.

To bring about hyperpyrexia by diathermy, it is necessary to employ a current which is sufficient to produce more heat than is lost; in addition one must prevent heat loss by suitable insulation. Especially constructed apparatus, capable of producing about double the output of an ordinary standard apparatus has been found desirable by Neymann (65). Some of the efficiently built large machines appear capable of delivery 4,000 to 5,000 milliamperes through the patient's trunk. Combined with suitable insulation, this current strength applied for a sufficient period is able to bring about a fever rise as well as special high-power machines. The

physical characteristics of high-frequency oscillations produced in the more powerful machines are the same as in regular diathermy and their frequency is about 1,000,000 cycles per second (corresponding to a wave length of 300 meters). The electrodes employed must be large and flexible and should allow the best possible contact with the body.

A rise of temperature of any desired height can be equally well produced and maintained by diathermy or radiotherapy.

Painstaking studies by many physiologists and clinicians have furnished an abundance of data of manifold physiological changes accompanying artificial hyperpyrexia. To a certain extent these changes are an intensification of those following any general heating of the body as shown comprehensively by Bazett: Table 3. The phenomena observed fall in three groups: (1) Changes in pulse and respiration, as well as in blood-pressure, in proportion to the rise in temperature; (2) concentration phenomena in the blood due to loss of fluids; (3) changes in blood chemistry possibly of specific character including the sedimentation rate, not explainable by concentration phenomena; (4) changes in the sensorium.

The pulse-rate increases in proportion to from 5 to

9 beats per minute, to each degree Fahrenheit. The skin capillaries become dilated, capillary pulsation appears at the height of fever and the entire surface of the skin becomes congested and moist. The respiration also increases at a rate of about 2 to 12 per minute to an increase of 10°F. At a temperature of about 105°F., it is about 25 to 30 per minute.

The blood-pressure usually at first undergoes a slight elevation of systolic pressure, then declines. The diastolic pressure falls, as a rule, as soon as the temperature begins to rise and its usual range is from 60 to 50 mm. in contrast to 120 to 80 mm. for the systolic.

Every patient who has undergone five hours or more of fever treatment will lose from four to five pounds of weight, due to the fluid excreted by perspiration. The kidney secretion is increased at first--later there is evidence of concentration of urine. Mortimer (66), Neymann and Osborne (64) found that there is an increase in the blood calcium, non-protein-nitrogen and uric acid. The chlorides usually drop. All these change to normal after a few hours. They may be due to concentration of blood as well as to an increase in the metabolic-rate. Ingestion of a copious amount of fluid does not change

the average loss of weight and often makes the patient nauseated.

There is an increase in the number of red and white cells and leukocytosis occurs at the height of the fever with usually a high polymorphonuclear count and a relative decrease in the lymphocytes and monocytes. Although the number of white cells decreases with the fall in temperature, an increase above the original count persists sometimes for several days. Some of the observers interpret these blood-cell changes as due to concentration phenomenon, owing to excessive perspiration, others, as due to a stimulus of the hematopoietic function of all blood-forming tissues (54).

Besides the changes briefly enumerated, data based upon the careful study of the effect of hyperpyrexia on hydrogen ion concentration, metabolism, permeability of cells, sweat glands etc. are available. These changes suggest that hyperpyrexia acts as a stimulus to the function of all hematopoietic tissues and that there is a mobilization of reserve leukocytes which is greatest at the height of the fever.

#### Short-Wave and Ultra Short-Wave Diathermy

Electromagnetic waves are propagated at the speed of light. They travel 186,000 miles or 300,000 kilometers per second. The wave length is obtained through

a simple equation by dividing the distance covered in one second by the number of oscillations occurring in one second. The generally accepted standard of measurement is now the metric system and hence all wave lengths are calculated in meters. They can be measured by especially constructed wave meters (67).

The number of oscillations of frequency of short waves is from ten to a hundred times higher than that of ordinary diathermy; it ranges from 10,000,000 to 100,000,000 oscillations per second. The wave length is correspondingly ranging from 30 meters to 3 meters in contrast to the 300 meter waves produced in the ordinary diathermy apparatus (17).

This new form of high-frequency treatments is generally referred to as short-wave treatment because the frequency of the electromagnetic energy is determined by measuring its wave length. As the term of short waves also occurs in the infrared, ultraviolet and roentgen-ray part of the electromagnetic spectrum, short-wave diathermy appears to be a definite term, especially as the essential physical effect of these high frequency currents seem to be the same in diathermy: heating the tissues (68).

The distinction between short-wave and ultra short-wave diathermy as it is made now is based on the follow-

ing considerations: (1) Short-wave diathermy comprises wave lengths from 12 to 30 meters; oscillations of such wave length differ little in their clinical effects from ordinary diathermy. They are used for both general and local heating; (2) Ultra short-wave diathermy comprises wave lengths below 12 meters; their mode of heating and their field of clinical application differs definitely from regular diathermy. There is a difference in the reports of various clinicians and physicists as to the borderline between short and ultra short waves.

Schliephake (69), as cited by Kovacs (2), did most of his short-wave work with 14 meter waves; others state that only the wave lengths at 12 meters or shorter give characteristic ultra-short-wave effects (15).

Oscillations for short-wave diathermy can be produced either by vacuum-tube oscillators or by spark-gap apparatus. For practical production an alternating current source is required. The steps of production are similar to those in ordinary diathermy machines; (1) there is a power transformer to step up the alternating current to the required voltage; (2) there is an oscillatory circuit, consisting of oscillator (radio) tubes or a spark gap combined with suitable inductance and capacities. In vacuum-tube apparatus for the production of ultra



short waves the circuits make use of the capacity of the tube instead of an extra condenser (15).

The oscillations produced in the oscillatory circuit are transferred to the treatment circuit, which can be visualized as an outdoor radio aerial with the ends bent together. The treatment plates are attached to the ends and form a condenser. The part to be treated is introduced into the electric field between the plates; this field conveys regular impulses to the particles of the substance (70).

Tube apparatus as well as spark-gap apparatus produce oscillations of either one or more wave lengths. There are machines available in which the wave length can be varied continuously. In both types of machines the patient circuit contains a variable condenser in resonance with the main oscillator circuit. In case of resonance the energy drawn from the apparatus is an optimum. The resonance point is easily determined by varying the means of "tuning" and determining the highest reading of a suitable ammeter in the patient circuit (70).

Apparatus with vacuum tubes generates undamped waves while the spark-gap type of apparatus generates damped oscillations. There is no evidence available that the extent of heating and the therapeutic effect are materially influenced by the wave form; in other words, both

vaccum tube and spark-gap apparatus will produce short waves suitable for treatment, as long as the apparatus itself delivers enough energy (71).

The mode of heating of the body in the condenser field is quite different from heating through contact plates by regular diathermy. In the latter, heating of the tissues varies with the electrical conductivity of tissues and is developed in conformity with Joule's law (70). The diathermy current flows along the path of least resistance--bone, fasciae, inner organs with capsules are as a rule only indirectly warmed by the current.

In a body placed in a condenser field and traversed by short-wave oscillations of sufficient intensity, marked heating occurs in ordinarily electrically non-conductive tissues. This is due to the electrical phenomenon of dielectric hysteresis (70). The non-conducting substances of the body known as dielectrics, may be considered in their smallest particles as of electric dipoles, that is, small particles possessing a positive charge at one end and a negative charge on the other. In a sufficiently powerful electric field, changing its direction a few million times a second, these dipoles tend to line up in the same manner as the unit

magnets in a magnetic field; at each change in the electric field they twist back and forth and the friction of neighboring particles creates considerable heat (15).

It has been shown by a number of investigators, first in solutions and in small animals and then in the human body, that the higher the frequency of the oscillations the more dielectric heat is generated in the condenser field. At very high frequencies above 20,000,000 oscillations, a considerable amount of energy can pass through a block of glass or any other non-conductive substance and create a great amount of heat in such a non-conductor. The only substance which does not heat up even under the highest frequencies in the condenser field is air. In liquid dielectric substances, the heating which occurs is still far more pronounced than in solid dielectrics. In the case of a semi-conductor, some of the energy passes due to the dielectric properties of such substances and some passes due to pure conductive (ohmic) heating occurring because such substances are partially conductive. This is the condition which prevails in the human body (72).

Each dielectric substance differs from other dielectrics by its ability to transmit high-frequency charges. The higher the "dielectric constant" of the

substance filling a given condenser the higher is its capacity.

The physical factors which define the ratio of energy to be transformed into heat in a body are its conductivity and its dielectric constant. There exists for each tissue a wave length for the maximum heat efficiency and on the other hand there are wave length regions in which they react nearly uniformly. Measurements on different tissues on different wave lengths showed that between twelve and thirty meters heat is produced in almost every tissue by equal energies to the same extent, Reiter (73), according to Kovács (2). Halphen and Auclair (74) state that this occurs in 25 meters. Reiter concludes that from the standpoint of heating in therapy the use of short waves is indicated whenever a moderate uniform heating is required, while ultra-short waves should be used where stronger effects, localized to certain parts or objects and confined to various depths, might be desirable.

Investigators of the physiological effects of short-wave diathermy of wave lengths from thirty to twelve meters report that they do not differ in principle from that of long-wave diathermy (17), (25), (75), (76). Their mode of heating the tissues however seems to permit a

more efficient heating of certain tissues, (77), (78), (79).

In applying local short-wave and ultra short-wave diathermy it is necessary to provide an insulating layer between the condenser plates and the body. The relative depth effect varies to a certain extent conversely with the distance of the condenser plates from the skin (16).

The condenser electrodes for short-wave treatments consist of flexible metal completely covered with pliable rubber. For ultra-short-wave treatments, in which the maintenance of a fixed distance is especially important, special glass electrode covers have been introduced by Schliephake. Glass has the advantage over all other material that it does not become heated by conduction from the skin as rubber electrodes do, and does not deteriorate through use (16).

Condenser electrodes must be placed like diathermy plates in such a way the oscillations passing between them travel in a straight line through the part to be treated.

The closer the electrodes are applied to the body, the more heat will be generated in the skin and the less will remain for the heating of deeper parts. If one electrode is nearer to the skin than the other, more superficial heating will occur at the nearer site (80).

The relative size of electrodes will influence the distribution of heating just as in ordinary diathermy.

General body heating by short waves requires bulky apparatus of large capacity. The first efficient apparatus for artificial fever production by short waves was developed in the Schenectady laboratories of the General Electric Company, following the accidental discovery that persons working near a powerful short wave radio transmitter becomes hot and complained of headaches. According to Kovács (2) the apparatus was reported on by Whitney (81) and DeWalt (82) as the radiotherm and the method of hyperpyrexia by the short waves subsequently became designated as radiothermy.

In the radiotherm a high potential alternating voltage (about 6,000 volts) is applied to two hot cathode rectifier tubes, each of which generates a unidirectional high voltage pulsating current. In a rectifier circuit the two unidirectional currents are united into a smooth unidirectional full wave circuit of high voltage and this voltage is applied to two "oscillator" tubes of 500-watts capacity. The output of these powerful tubes are undamped oscillations of a frequency of 10,000,000 per second which corresponds to a thirty-meter wave length. These oscillations are

transmitted through two large aluminum condenser plates.

It is interesting to note here that the more high frequency energy a short wave machine is capable of producing, the greater will be the likelihood of long distance radio interference through radiation from the patient circuit (83).

Most of the basic experimental and clinical work on artificial fever treatment in this country was done with the radiotherm and according to Kovacs (2) the first report on its employment was made by Hinsie and Carpenter (84).

A spark-gap short-wave diathermy apparatus for fever treatment was first developed by von Lepel and its clinical use was first reported on by Kovacs (85). In this apparatus the incoming current of 220-volts at 15 amperes is regulated by a special "stabilizer".

A transformer of the usual type steps up the voltage. The heart of the apparatus is a twenty-unit spark-gap of a "super-quenching" type. The oscillatory circuit contains only a very small condenser, which acts like a valve producing a powerful impact excitation of the resonator. There are only a few turns of coil in the primary of the resonator which is linked by a variable coupling to the secondary. This apparatus also produces high-frequency oscillations of a frequency of 10,000,000

cycles (thirty-meter wave lengths) and these oscillations are transmitted to the condenser plates.

Through experimentation in Kovacs clinic it was discovered that the condenser plates could be placed underneath the treatment table, as long as they are separated and their relative size is changed in accordance with the capacity of the parts over them.

There is no difference in producing artificial fever with the radiotherm or with the short-wave spark-gap apparatus (15).

The heating of the body tissues in the high-frequency condenser field varies with their consistency and their content of fluid (16, 86). Measurements, taken with thermocouples inserted in the tissues and veins of patients receiving short-wave fever treatment at Polyclinic Hospital, demonstrate that while apparently equal heating occurs in the skin and in muscular tissue, the temperature of the blood stream was 2°F. less. This is explained by the fact that the circulating blood is able to cool off better than the solid tissues.

~~Short-Wave~~ Therapy in an Electro-Magnetic Field.

(Inductothermy)

A vacuum tub oscillator generating approximately 26 meter waves which are administered by placing a cable electrode around or adjacent a part to be treated has



been recently developed. (Merriam, Holmquest, and Osborne (87). This application will generate heat in the part but the essential difference claimed in regards this heating from that in a condenser field is (1) that it is caused by electromagnetic induction and not by dielectric heating, (2) that heat is produced at a greater rate in the more conductive, than in the less conductive tissues (85), (89). The apparatus has been named Inductotherm and the mode of heating may be designated as inductothermy.

When an electric current flows through a coil, there is set up within that coil a magnetic field. The strength of this magnetic field depends on the intensity of the current and the number of turns of the coil, increasing with increase in current and with increase in number of turns. If the current alternates in direction of flow, the magnetic field will also alternate and its frequency of alternation will be that of the exciting current. If the current from the Inductotherm, having a frequency of 12,000,000 cycles per second, is applied to the coil, the magnetic field set up will have a frequency of 12,000,000 cycles or 24,000,000 alternations per second.

In a conductive material placed within an alternat-

ing magnetic field of sufficient strength voltage will be induced and as a result currents will flow. These induced currents will flow in a random fashion much like the eddy currents in a stream of water. Because of their eddying manner of flow they are called eddy current heating.

If, instead of a simple homogenous conductive material, living tissues are placed within the high-frequency magnetic field of the inductotherm coil, eddy currents will also be induced and heat generated as in the case of the simple conductor. The eddy currents induced in the more conductive materials will be greater in these than in the less conductive materials.

It is claimed that with inductothermy, maximal heating (89), (90), is produced in the more vascular tissues of the body, blood-vessels, muscles and possibly the inner organs because they are more conductive and less heating is produced in the adipose and other less conductive tissues in accordance with the table of Bachem (22) Table 2. Laboratory experimentations with electrolytes and animals have been performed to substantiate that claim (91).

Blatt and Fouts (92) applied an inductotherm over the region of the kidneys and showed by clearance tests ( a rough measure of kidney flow of blood) that heat

reduces rather than induces the flow of blood to the kidney. This is probably produced by vasodilatation to other parts of the body.

In the same experiments they found that the diastolic blood pressure was moderately reduced while the heat was being applied, but quickly rose to its original level on discontinuing the heat.

#### Ultra Short-Wave Therapy

Ultra short-wave diathermy according to the present generally accepted classification deals with the electromagnetic oscillations of a wave length of from about 12 meters to 2.5 meters. Treatment in a condenser field has its lower limits as 2.5 meters, because below this limit the small size of the treatment circuit makes the placing of parts of the body in it impossible.

Both spark-gap and tube apparatus can be utilized to produce ultra short waves. In comparison with ordinary diathermy the relation between input and output (the efficiency) of apparatus for short-wave diathermy becomes progressively smaller with the lowering of the wave length.

The power output or wattage plays an important role in the heating efficiency of ultra short waves. It has been conclusively shown by Schliephake that production

of deep heating without over exposure of the skin and subcutaneous tissue by waves between five and twelve meters requires considerable distance--from one-half to two inches--between the condenser plates and the skin: sufficient short-wave energy at such a distance in turn requires apparatus of considerable power output or wattage.

The most important factor in the efficient administration of ultra short waves is the proper type of electrodes and their proper adjustment. Flexible condenser electrodes are satisfactory only for short-wave treatment; for ultra short waves, the glass electrodes constructed by Schliephake seem to be essential (93). They consist of a hollow cylindrical glass or vulcanite body containing a metal plate; this plate can be moved backward and forward parallel to the bottom of the cylinder and secured at any desired point. Thus the distance of the metal plate from the skin (the air gap) can be adjusted to fully two inches.

The adjustment between the electrode and the patient's body and the size of the electrode depends on the effect which is desired. If uniform heating of the body is wanted, the electrodes should be at the same distance on each side; the larger the part to be treated

the larger must be the electrodes and the greater their air gap between the plate and body. Placing the electrode nearer or further increases or decreases the heating on that side, and thus a variation of heating under the electrodes and in the depth can be accomplished (2).

The primary physical effect of ultra short-wave diathermy consists of heating of the tissues.

A specific inflammatory effect has been described by Reiter (73). After exposure to waves below ten meters the treated parts show all the signs of inflammation: the veins are dilated and remain so for a period of many hours and even days, blood is found outside the veins and the treated part eventually becomes swollen. This reaction cannot be produced by the same dose of short wave or long wave diathermy. It cannot be influenced in any way by previous applications of adrenalin. Reiter is of the opinion that the rise of local resistance of the body produced by this effect is responsible for the fundamentally different action of ultra short waves on purulent process and on local infections caused by different bacteria.

Interesting as these findings are from the standpoint of possibility of selective heating of certain

tissues, they do not allow, at present, definite conclusion of the optimum heating effect on living tissues (94).

Jellinek feels that there are not only heating but other specific effects of electric energy and that in addition to the electrochemical effect, the electro-mechanical factor plays a part (95). To this agrees Kobak (96) and Schliephake (97). Bauwens states that in short-wave therapy we have acquired a therapeutic agent capable primarily of making tissues react against antigens and secondarily of causing local pyrexia, thus accelerating biochemical activity (98). Although the possibility of the existence of specific physiological effects cannot yet be absolutely denied, nevertheless, it must be concluded that in the light of present observations, physiological effects other than those of heating have not been proved to exist (99).

Benson and Bowman (100) made an attempt to devise some method by which the relative deep tissue heating efficiency of various agents could be determined without inserting a thermocouple into the tissues. The method used was based on the theory that if heat be applied at the elbow region, a certain portion of the deep heat would be taken up by the arterial flow and be detectable

at the hand; the temperature of the latter in turn would rise in proportion to the amount of deep heat delivered.

Considering single results, the electromagnetic coil produced the greatest rise in temperature; short wave and hot water next in order; and the electric heating pad was the lowest in the production of heat. In regard to the time that elapsed to reach maximum temperature, coil technique required the longest; then the electric pad, and water, next in order, with the short wave involving the shortest time.

Temperature tests were also made on the opposite arm with the aim of determining the relative reflex effect of the agents used. In this, water proved most; short wave second; inductotherm third; and the electric pad least effective.

### (c) Radiant Energy

#### (1) Physics.

It was stated that a current of electricity denotes a flow of electrons which is set up by a disturbance of the atomic structure and takes its path through a set of conductors, called an electric circuit. The therapeutic effects of the different electrical currents are produced by making the human body part of the path of the electrical circuit.

We are now to present the therapeutic aspects of another broad division of physical science, that of radiant energy. Radiation is the process by which energy is propagated through space. Infrared, luminous and ultra-violet energy all are forms of radiant energy, produced in various ways by different sources. Every substance with a temperature above absolute zero emits radiant energy in the form of heat radiation. When electrical or chemical forces of suitable intensity are applied to various forms of matter, luminous and other forms of energy radiations are produced. The common characteristics of all forms of radiant energy are as follows; they are produced by applying electrical and other forces to various forms of matter; they all may be transmitted without the support of a sensible medium; their velocity of travel is equal in vacuum but varies with different media. They are designated collectively as electromagnetic radiations.

Light is a form of radiant energy which makes objects visible by stimulating the retina of the eye. Ultra-violet and infrared radiation does not render objects visible. The general term of light therapy or phototherapy by custom includes also the employment of the invisible infrared of heat and ultraviolet or



actinic rays, because they are all, as a rule, produced at the same time but in different relative and absolute amounts.

The application of radiant energy for the treatment of disease or the stimulation of lagging biological processes forms one of the most interesting and most complex chapters of present-day physical therapy. A maze of clinical and experimental material has been accumulated in recent years on every phase of the subject.

It is now believed that a light ray consists of an enormously large number of exceedingly small entities known as photons. These photons are produced by profound atomic changes when a swiftly moving electron collides with an atom. The impact transforms the kinetic energy of the electron into a photon.

The graphic representation of the various energy waves in an ascending order of length is known as the electromagnetic spectrum.

The classification of the therapeutic parts of the electro-magnetic spectrum is made by stating their wave lengths. The term spectrum denotes a charted band of wave lengths of electro-magnetic radiation obtained by refraction or defraction by means of a prism or grating. Continuous spectra are those emitted by

incandescent lamps; they are pure temperature radiations and contain a whole scale of wave lengths, the extent and energy distribution of which depends on the temperature of the hot body.

The physical phenomena which occur when electromagnetic radiations encounter other substances may be the following:

1. The rays are reflected or thrown back by all substances. The reflectors mounted around the various lamps reflect both visible and invisible radiation and add to its amount.

2. The rays penetrate all substances to some extent. The various layers of the skin are variously transparent to certain wave lengths.

3. The rays are absorbed by all substances to a certain extent.

In administering radiant energy from any source one must be cognizant of the fact that the intensity of radiation varies inversely with the square of the distance from the source.

Patients receive optimum radiation if the source of radiation is at right angles to the center of the area to be radiated.

Photothermal radiations, comprising infrared and

visible radiation, comparatively speaking, penetrate subcutaneous tissues, heat the blood, accelerate vital reactions and act instantaneously; they produce a burning sensation or immediate burn when their intensity is too great (101).

## (2) Infrared and Luminous Radiation

Any object heated to a higher temperature than its surroundings will send out its excess of heat by radiations to the surrounding objects. An iron rod when heated first "feels" hot without showing any change in color (so-called black body radiation), then starts glowing and becomes "red-hot", and later "white-hot". At each stage of heating a variety of radiation is emitted; in the stage of low heat there occurs long-waves or far infrared radiation, invisible to the eye; at a further stage of heat the red, green and blue rays of the visible spectrum are added and the stage of white-heat long-wave ultraviolet radiation can be demonstrated. The quality as well as the quantity of radiations emitted from any source depend not only on the energy input, but also on the intensity of heat produced in the radiating object (101).

The generally accepted classification of infrared radiation differentiates between two regions:

(a) Long-wave or Far Infrared Rays.-These are emitted from bodies at low temperatures, such as hot-water bottles, electric heating pads. Their wave length extends from 15,000 to 120,000 Angstroms; one Angstrom (abbreviated A' or A.U.) represents 1/10,000,000 mm. or 1/10 millimicron (mr). They do not penetrate deeper than 0.1 or 3 mn. and are strongly absorbed in the upper layers of the skin (corium). The human body emits long wave infrared radiation of about 9,400,000 Angstroms (102).

(b) Short-wave or Near Infrared Rays. These are emitted from bodies at high temperature such as the sun, carbon arc lamps, incandescent lamps and from especially built infrared generators: their wave length extends from 7000 to 15,000 Angstroms; they penetrate to a depth of ten to thirty millimeters through the skin into the underlying subcutaneous tissue: they are able, therefore, to influence the blood-vessels and lymph vessels and other tissues including nerves and nerve endings markedly (103), (102).

It is evident that for purposes of effective therapeutic heating the sources of short-waves or penetrating infrared radiation are preferable, hence the replacement of old fashioned heating devices which emit

only a feeble amount of longwave radiation and transfer most of their heat by conduction by modern short-wave infrared generators (102).

Sources of infrared radiation-The source of therapeutic heat radiation can be placed under two headings:

1. Luminous Sources of Infrared Radiation.-

Among these belong the sun, the carbon arc, lamps and incandescent lamps with carbon tungsten filaments.

The proportion of infrared radiation in the average sunlight is over sixty per cent, the remainder ultraviolet and visible light. Hence the importance of the sun as the most important source of heat radiation and hence the necessity of recognizing that in the therapeutic effects of heliotherapy infrared radiation plays a considerable role.

Carbon arc lamps produce about eighty per cent infrared, fifteen per cent visible and five per cent ultraviolet radiation. The spectrum of the mercury vapor arc is weak in rays at the red end of the visible spectrum.

The principal sources of infrared radiation from luminous sources are incandescent filament radiators (electric light bulbs); they consist of tungsten or carbon arc filaments, each one enclosed in a glass bulb

mounted on the center of a concave reflector. Tungsten filament lamps burning at a wattage from 150 to 1500 are the most generally used forms of these luminous heat generators, popularly known as heat lamps. They emit a radiation of about ninety-five per cent infrared, four and eight-tenths per cent visible and one-tenth per cent ultra-violet radiation. The wave length of the infrared extends from 4000 to 40,000 Angstroms with a maximum emission at from 7,000 to 16,000 Angstroms. Carbon filament lamps which were more frequently used in previous years emit more of the long infrared and less of the short (101).

The penetration of the radiation from these luminous heat generators through the skin is the same whether they are of small (150 to 250 watts) or large (1500) wattage.

Two or more incandescent bulbs of small candle power (25 to 50 watts) mounted in semi-circular containers are designated as electric light "bakers". The temperature rise in the skin produced by these bakers never exceeds more than about 110°F. under safe limits.

## 2. Non-luminous Sources of Infrared Radiation.-

These sources are generally known as "Infrared generators". A heating element mounted in the center of a parabolic reflector is warmed up by an electrical current to a

dull red heat and a concave reflector concentrates the heat rays on the surface of the body, evenly and without hot spots. In the popularly known bathroom heater, which is also an infrared generator, the wide hood reflects the rays over a wide area and the heater itself is not adjustable. The heating element may consist of either a resistance wire wound or embedded on a non-conducting material (porcelain or steatite) or a rod or circular plate of resistant metal (carborundum). Similar to luminous heat generators, infrared generators are marketed in small units, drawing 50 to 300 watts of current, and large units drawing up to 1500 watts.

Infrared generators from a non-luminous source emit radiation throughout the entire length of the infrared spectrum to 150,000 Angstroms; the quality of radiation varies according to the surface heat of the heating element. At low red heat (from 570° to 750° F) the maximum emission occurs at the wave lengths from 40,000 to 50,000 Angstroms; this is in the long-wave infrared region; at intense red heat the emission changes toward the shorter wave lengths, from 20,000 to 30,000 Angstroms, at the same time the intensity of radiation becomes about ten times more powerful (Coblentz (104), cited by Kovacs (2)).

TABLE 4.

Summary of the Physical and Biological Characteristics of the Principal Areas of the Electromagnetic Spectrum. Coblentz (104).

Spectral region.	Penetration of rays.	Physiological action.	
Far ultra-violet; 180 to 200 mr.	Superficial, 0.1 to 0.3 mm.	Photochemical	Metals in carbon arc and spark of metals (mercury arc).
Near ultra-violet; 290 to 365 mr.	Superficial, 0.3 to 0.5 mm.	Photochemical	Sun; metals in carbon arc and arc of metals.
Visible spectrum; 390 to 790 mr.	Superficial, 0.5 to 5 mm.	Thermal; nerve stimulation	Sun; carbon arc.
Near infra-red; 760 to 1500 mr.	Deep, 10 to 30 mm.	Thermal; nerve stimulation	Sun; carbon arc; gas-filled tungsten lamp.
Far infra-red; 1500 to 15,000mr.	Superficial, 3 to 0.1 mm.	Thermal; nerve stimulation	Carbon arc; infrared (radiant, heaters).

Wave lengths are expressed in millimicrons; 1 mr. is equal to 10 Angstrom units.



Any form of radiation, be it infrared or luminous, will exert certain physiological actions, only, when it becomes absorbed by the skin and subcutaneous tissues.

Coblentz shows that near infrared radiation penetrates to the greatest extent ten to thirty millimeters (over one inch); the table of Bachern and Reed (105) shows that most of the visible and near(short) infrared radiation is absorbed in the corium, the deepest layer of the skin and pronounced radiation reaches the subcutaneous layers; while the far or long infrared radiation has practically no penetration and is all absorbed in the most superficial layers of the skin. Recent surface temperature measurements corroborate these investigations.

An interesting work has been done by Anderson (106) who compared the penetrating qualities of radiations from tungsten and iron filaments. His work shows that thirty-four per cent of the incident radiation is reflected. The reflection is the same for both the radiation from the tungsten and that from the iron. The remaining sixty-six per cent radiation enters the skin and is absorbed and converted into heat in the dermal layers. Within the first five-tenths millimeters comprising the stratum corneum and stratum lucidum,

twenty per cent of the radiation from the tungsten and fifty-nine per cent from the iron are absorbed and converted into heat. Forty-six per cent of the radiation from the tungsten and seven per cent of the radiant energy from iron enter the stratum granulosum. About sixteen per cent radiation from the tungsten and six per cent from the iron remain in the stratum granulosum, stratum mucosum and stratum germinativum and are converted into heat. Thirty per cent of the radiant energy from the tungsten and six-tenths per cent of the energy from the iron resistor penetrate more than one millimeter of skin and enter the corium. The skin shows selective absorption. Radiations penetrating a depth greater than one millimeter are in wavelength approximately one micron. Nineteen per cent of the radiant energy from the tungsten and the six-tenths per cent of the energy from the iron are absorbed and converted into heat in the corium. These radiations can produce heat effects upon the blood-vessels, nerves and papillae located in the corium. Eleven per cent of the radiation from the tungsten and zero per cent from the iron passes into the layer of muscle and fat. These are the radiations which penetrate more than two millimeters.

It has been reported (Cartwright) that some radiation from the tungsten is detectable even at a depth of ten millimeters.

It is, therefore, evident that infrared generators emitting a preponderance of visible and near infrared radiation usually warm the depth of the skin, while those emitting a preponderance of long infrared exert their maximum heating effects on the surface (107), (108).

The total intensity and the emission at various wave lengths of infrared generators depends on the type of generator, the wattage employed and also on the reflector.

The formation of heat in the superficial tissues of the body by infrared radiation has effects in two directions, locally and generally; these effects depend on the extent of the area exposed to heating and on the intensity of radiation. There is often an interplay between the two sets of effects.

The immediate local effects of exposure to heat radiation consist of (a) stimulation of the vasomotor mechanism and (b) stimulation of the sensory nervous system of the skin.

1. The stimulation of the vasomotor mechanism manifests itself by active vasodilatation of the capillaries and subsequent increase of arterial and venous circulation.

There exists an inherent tone in the capillaries which causes vasoconstriction and the application of heat produces a release of vasodilator substance. Upon the absorption of the vasodilator substance more capillaries become active and as a result a greater blood supply to the part occurs. The local hyperemia in turn brings about an increase of local nutrition, increase of the rate of removal of local tissue products and stimulation of the local resistive forces to infection.

Within a few minutes after exposure to radiant heating the skin becomes red and feels hot. The resulting erythema appears in the form of red spots or a network of red lines; it persists depending on the length of exposure from ten minutes up to one hour. Repeated exposure to infrared radiation may lead to permanent pigmentation which is always mottled like the surface of marble.

The erythema caused by dilatation of the capillaries in the corium of the skin occurs after exposure to any form of infrared radiation; in addition, luminous sources containing a large amount of the more penetrating infrared cause a marked stimulation of the sweat glands located in the subcutaneous tissue, as a result, drops of perspiration soon appear in the area under exposure.

This effect becomes especially evident when large areas of skin are exposed to general heat radiation from incandescent sources, as in an electric bath cabinet.(109).

Excess amount of infrared radiation or special sensitivity thereto results in wheal formation, unexplained, (110), local edema and eventually in blistering. Careless exposure may cause deep sloughing not only in the skin but also in adjacent subcutaneous and fibrous structures.

2. Stimulation of the sensory nervous system of the skin is the second important local effect of heat radiation. It results in sedation or relief of pain when mild heating is employed and marked counterirritation when strong superficial heat stimuli are applied (101). The mechanism of counter irritation may be explained by the desensitization of superficial sensory nerves or by a considerable increase of the stimuli which pass over them; the effect is that of relief of local painful stimuli as well as of those originating from deeper parts and possessing the same nerve center as the area of the skin under the influence of heat. Beside these two groups of effects explainable by the local thermal effects on tissues, there is no evidence of any specific action of infrared rays (102), (111).

Every local application of heat brings about a certain amount of general heating. The local excess heat is taken up by the blood stream and carried into the general circulation. The temperature control mechanism of the body will immediately throw off the additional heat by mild perspiration (109), (112). Intense general heat application from large wattage heating units (body bakers) or high-wattage lamps stimulates the heat regulating mechanism to full activity in its endeavor to make the output of heat equal to the increased input (112).

The generally recognized effects of general body heating are:

- (1) Increased heat eliminated and profuse perspiration;
- (2) increased circulation, a rise of the pulse rate in the ratio of about ten beats for each degree Fahrenheit, much as it does in fever,
- (3) a lowering of blood pressure ( in contrast to the effects of cold),
- (4) increased respiration,
- (5) increased elimination through the kidneys.

There is a loss of water, salt, urea and other nitrogenous substances, with a relative excess of

alkali remaining in the blood and in the tissues, while there is also temporary loss of body weight, general nervous sensibility is usually markedly lessened. Prolonged and excessive heat application may cause profound depression.

In this connection Schmidt was able to show a depression in the thyroid activity of guinea-pigs kept at thirty-two degrees for two to four weeks (113).

Through experiments on rabbits, Giles, Harvey and Dampere (114) were able to show that following four to five hours of radiant heat some of the animals died, while others that survived after a lapse of a year still possessed libido and sexual power, but did not have the power to procreate. Their experiments may prove of value to the extent that prolonged sessions of radiant heat may produce alterations in the testicular secretions in man.

Visible radiation is present in all radiation from incandescent sources, carbon arc and mercury vapor lamps, but its total quantity is relatively small (five to fifteen per cent) the thermal effects of radiation are attributable principally to the near (short) infrared rays (108). The generally accepted conception of the physics of luminous radiation in relation to the tissues

is as follows: eleven per cent of the visible radiation from the tungsten filament lamp is absorbed by the glass bulb and thirty-three per cent of the short infrared is reflected by the skin, all of the remainder is absorbed by the superficial layers of the skin but does not penetrate as deeply as the short infrared.

### (3) Radiant Light Cabinet Bath

Pemberton of Philadelphia and his collaborators have reported their findings on the changes in the chemistry of the perspiration, saliva, urine and blood of arthritics and normal individuals treated by the routing technique in the radiant light cabinet. They found a fall in alveolar carbon-dioxide in both types of persons which later rose to normal. Arthritic patients have a slightly greater acidity of urine, sweat and saliva than normal individuals. Radiant light baths increase the alkalinity of these fluids in all patients. The increase of carbon dioxide is noticeable when the temperature rises about 33°C.(6).

When one arm of a patient was heated while the other was chilled there was an increase in the percentage of oxygen saturation in the heated arm and a falling-off in the one chilled. This saturation is increased in the venous blood by both local and general heat with no



marked change in the amount of blood sugar.

Bazett and Haldane found a fall in alveolar carbon dioxide with profuse alkaline sweat and alkaline diuresis after a body bath at a temperature of 38°C.(6).

The type of systemic treatment should be selected only after the indication for its employment is determined definitely because the mode of application will greatly vary the results obtained by the treatment. Not only do the systemic application of hot water, radiant light and superheated dry air differ sharply in the physiological reaction they induce in the body, but under certain conditions one of them might be indicated while the other two might be harmful. These qualitative differences do not obtain to any appreciable degree in the local application of heat. These types of heat differ greatly in degree as limited by the skin tolerance, in their collateral effects upon the body, in time required to develop their full efficiency, and lastly, and perhaps most important of all, in their reflex nervous effects.

Both radiant energy and water have mechanical effects upon the skin and sensory nerve endings differing both in quality and quantity from that produced by superheated dry air. They intensely stimulate skin

cell activity but do not bring about increased general body elimination to any great extent. The eliminative function of the perspiration has probably been over emphasized. The body does not get rid of any appreciably greater amount of toxin by a temporarily induced perspiration. Superficial vasomotor dilatation and tissue relaxation, particularly of the muscles, probably follows the general application of heat to the body by any method to about the same degree. There is a consequent lowering of systolic blood-pressure and of general muscle tone including that of the cardiac muscle. The degree of lessening of cardiac tone varies with the type of treatment, length of its application and the position of the body during the treatment. The degree of relaxation or lessening tone obtained in the heart muscle has been emphasized and under certain conditions grave injury to cardiac muscle may ensue. This is particularly true of the Turkish bath establishments and indiscriminate use of the light cabinet without sufficient rest following the treatment, within which time the heart may regain its normal tone. The quick cooling of the skin leads to superficial vasoconstriction, to increased work upon the heart and if done before cardiac muscle has recovered its tone is

distinctly dangerous. Under certain conditions even the retention of the sitting position in a bath cabinet may result in temporary cardiac failure.

Emotional excitement of all kinds should be strictly avoided during and immediately after systemic thermotherapy of all types.

During general treatment from sunlight there is not sufficient heat produced to cause any appreciable lowering of cardiac tone. A light cabinet bath of low intensity and short duration should not, in an otherwise normal patient, produce much lowering of heart-muscle tone.

For the reasons just cited when the average intensity of radiant heat and treatment time is employed, it is far safer to use a horizontal cabinet than one in which the patient must sit erect. It is wise to insist upon at least an hour rest period in the recumbent position following the treatment. When a cabinet designed to treat the patient in the sitting posture must be used the treatment should be brief in duration, not over twelve minutes as a rule. The patient's head should be wrapped in a cold wet towel and the tonic after-treatment by shower, sponge bath, tub or Scotch douche should be gently and gradually applied. Again the point should be emphasized that not enough general

elimination can possibly be secured through even the profuse perspiration developed to justify long-continued and intensive radiant bath treatments. Temperatures of 100' to 104'F. will induce profuse perspiration. The properties of sweat depend on acclimatization, the rate of sweating, inherent characteristics of the individual, and probably other factors. It becomes dilute with adaptation to hot atmospheres. Its inorganic constituents increase in concentration as sweating becomes more profuse; at the same time, nitrogen excretion diminishes.(115).

Pemberton has pointed out that mild cabinet bath treatments reduce acidity. If too long continued, or too severe in amount, they may actually produce alkalosis. The decrease in cardiac muscle tone incident to light cabinet baths must constantly be kept in mind. This factor with a patient with unsuspected cardiac weakness makes the common employment of this method in beauty parlors, Turkish baths and other institutions managed by laymen, a distinct danger.

A type of radiant energy chamber has been devised in which a moving column of air is maintained around the body. Some what greater degrees of heat may be endured by this means with a slightly increased amount of internal temperature rise than is obtainable in an

unventilated cabinet.

The smaller types of apparatus containing from two to eight carbon or tungsten filament bulbs may be applied quite closely to the patient's skin. An intervening covering is not only unnecessary but undesirable since this type of heat is preferred only when the associated stimulating effects of the light are desired. The use of a tent of sheeting or toweling to enclose both apparatus and part treated may be employed to augment the thermal effect upon the skin. It is interesting to note that this procedure of walling in the heat is not as essential in the use of radiant heat as in other types. Even a cool breeze or electric fan draft between the patient and part under treatment will not prevent the development of heat on and in the supervicial tissues as it will in the case of superheated dry air (116) The smaller types of low wattage radiant light apparatus are most useful for very prolonged applications, but are not very efficient where intense heating is required.

The higher wattage radiant heat apparatus ranging from 100 to 1,500 or 2,000 watts is especially useful for the more intensive types of local application. The treatment is under the constant control of the conscious

patient who can adjust the distance or change the position of the part under treatment. A further advantage lies in the fact that the amount of skin reaction is constantly within the vision of the operator. The localization of heat effect is possible to a far greater extent than in most types of hot air apparatus. Skin tolerance to heat in nonanesthetic areas forms a sufficient guide to the intensity of the treatment. If the patient thoroughly understands the amount of heat he is expected to bear, a burn or blister practically never occurs except on scars.

## CHAPTER V

### SUMMARY

1. Energy is never made from anything that is not energy, or turned into anything that is not energy.

Heat is the energy of motion of the molecules, atoms and electrons of which a body is composed.

Every substance with a temperature above absolute zero emits radiant energy in the form of heat radiation.

A light ray consists of photons, which are produced when a swiftly moving electron collides with an atom. The kind of light, whether roentgen-ray, ultraviolet, visible or infrared, is associated with the size of the photon.

Radiations are absorbed by the tissues and converted into heat.

In passing electricity through the body, the electrical energy is converted into heat energy. The body acts as a conductor.

2. The various modalities for the application of heat are listed in order of their efficiency and penetration, starting with the least so:

- a. Hot-water bottle
- b. Hot compress
- c. Steam bath

- d. Hot-water bath
- e. Hot-air bath
- f. Paraffin bath
- g. Electric heating pad
- h. Sun
- i. Carbon arc lamp
- j. Incandescent light bulb (heat lamp)
- k. Infrared generator
- l. Diathermy apparatus
- m. Short-wave diathermy
- n. Ultra short wave diathermy

3. The above may be divided into three groups according to their penetration: (1) a-i, superficial, 0.1 to 3 mm.; (2) h-k, deep, 10 to 30 mm.; (3) l-n, throughout.

Heat production by diathermy extends from electrode to electrode, and serves as a unique means for through-and-through warming of any part of the body.

Short-wave diathermy comprises wave lengths from 12-30 meters; oscillations of such wave lengths differ little in their clinical effects from ordinary diathermy. They are used for both general and local uniform heating. Short-wave diathermy's special advantages are contained in the relatively greater heating of deeper tissues



without excessive surface heating and the possibility of using electrodes not in contact with the skin. These advantages are due to the high frequency of the alternating current. The disadvantages consist in the uncertainty of estimating the true heating current and the possibility of deep burns in tissues with a poor blood supply.

Ultra short wave diathermy comprises wave lengths below 12 meters; their mode of heating and their field of clinical application differs definitely from regular diathermy; they are at present employed for local treatment purposes only.

4. The hot-water bottle, hot compress, hot-water bath and the heat lamp may be easily applied at home. The heat lamp has the only deep penetration.

The advantages of infrared radiation over the time-honoured methods of conductive heating are: (1) That its action extends to a much greater depth; (2) that there is no pressure over the parts treated; and (3) that the parts may be kept under constant observation without difficulty.

Heat is, perhaps, the most valuable physical force in healing, and has been employed since ages, in the form of poultices, hot baths, heating pads and lamps.

These "external" forms of heating do not penetrate deeply, for the heat-regulating mechanism of the body will immediately tend to distribute local heat through increased circulation and perspiration. The heat of diathermy is generated in the tissues by the direct action of electrical energy, and the gradual introduction of the latter does not appear to bring about a marked reflex action of the heat-regulating mechanism.

The electromagnetic method (coil technique) is by far the most effective method of producing heat in the depths of human tissues.

5. The primary physical effect of all the modalities named is thermal

The secondary physiological effects include; hyperemia, relief of pain, relaxation of tissues, attenuation of germs and reflex stimulation.

No specific physiologic effects, are obtained from diathermy, other than those attributable to heating, have been proved to exist.

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