maintains the body temperature well above that of the surrounding air in a cool or cold environment. At the same time, heat is constantly lost from the body by radiation, convection and evaporation. Since, under ordinary conditions, the body temperature is maintained at its normal level of about 98.6 F, the heat production must be balanced by the heat loss. During work, the body temperature may rise; in fact, afternoon temperatures of normal persons average 1 deg above the resting value of the morning whether working or not.

The fundamental thermodynamic processes concerned in heat interchanges between the body and its environment may be described by the equation:

$$M = \pm S + E \pm R \pm C \qquad (1)$$

where

M = rate of metabolism, heat produced within the body.
S = rate of storage, change in intrinsic body heat.
E = rate of evaporative heat loss.
R = rate of radiative heat loss or gain.
C = rate of convective heat loss or gain.

The rate of metabolism, M, is always positive. The storage, S, may be either positive or negative, depending upon whether heat is being stored or depleted owing to a rise or fall in body temperature. Under ordinary circumstances (when the dew-point of the air is below the body surface temperature) the evaporation loss, E, is always positive; that is, heat from metabolism supplies this loss. R and C are positive when body surface temperature is above that of walls and air, and negative when it is below.

DuBois,[7] after careful calorimeter studies on a fasting, nude man, plotted the partition of body heat loss and heat production as a function of temperature. Fig. 1 shows some disparity between heat production and heat loss. This disparity is S in Equation 1. In the central range of the experiments S was quite low and no increase in heat loss by vaporization was apparent.

Within the range of 81–86 F air temperature, with still air, there is, for a resting nude man, a point at which his body has to take no particular action to maintain its heat balance. If he is clothed, or if he is active, this point will naturally lie at a lower level. At this point, which may be termed the *neutral point* for that individual, conditions are neither too hot nor too cold. If, through a fall in air temperature, or a rise in air movement, the rate of heat loss from the skin to the environment is increased, then the body must do something to counteract this heat loss. Over a certain range, the body can achieve this by decreasing the flow of blood through the skin. This will result in some cooling of the skin and subjacent tissues, but the temperature of the deep tissues will be preserved. The range of external conditions over which this may be achieved, may be termed the *zone of vaso-motor regulation against cold.* Beyond this range, the temperature of the superficial tissues will fall still further, and that of the deep tissues will fall as well, unless some other steps are taken. The body normally does react; it increases heat production by increasing muscular tension, by shivering, or by spontaneous increase in activity.[8] As long as these are adequate to meet the increased rate of heat loss to the environment, a fall in deep body temperature may be prevented. Such conditions may be said to lie in the *zone of metabolic regulation against cold.* Beyond

this point, the body enters the *zone of inevitable body cooling.* Once body temperature starts to fall, man is headed for disaster.

It will be seen that, in man, deep body temperature is preserved over an important range of cold external conditions, at the expense of (1) a fall in the temperature of the peripheral tissues, and (2) an increased expenditure of energy. As regards the first of these, the farther away superficial tissue lies from the central body mass, the more readily will its temperature fall.

On the hot side of the neutral point, there exists a *zone of vaso-motor regulation against heat,* corresponding to that against cold. The blood flow through the skin is increased when the opportunities for heat loss to the environment are restricted.[9] This increase in blood flow may double the conductance of the superficial tissues over that characteristic of the neutral point, and the temperature of the skin surface may rise until it is only three degrees below that of the deep tissues. If this increase in blood flow is

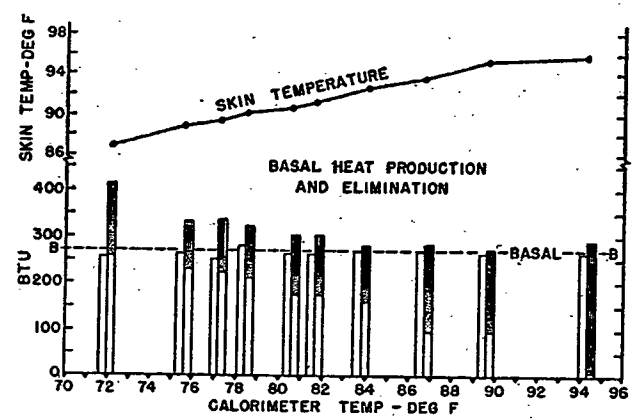


FIG. 1. HEAT LOSS FROM HUMAN BEING BY EVAPORATION, RADIATION, AND CONVECTION[a]

[a] Normal control, naked, in calorimeter at temperatures from 72.8 to 94.1 F. First column in each experiment represents heat production as determined by indirect calorimetry, the second column, heat elimination The portion marked with vertical lines represents vaporization; the dotted area, convection; the unmarked area, radiation. The skin temperature represents the average reading of 18 spots on the surface.

unable to balance the restriction in heat loss, the body has entered the next zone. Once again, the normal body takes steps to prevent a change in its deep temperature; but they are not the counterpart of the steps taken under similar circumstances on the cold side. There is, in fact, very little change in heat production, beyond that resulting from a disinclination for exertion. The second line of defense, on the hot side, is a new and powerful method of promoting heat loss—the provision of water, by the operation of the sweat glands, for evaporative cooling. As long as evaporation is adequate to restore the desired heat loss, the body is in the *zone of evaporative regulation against heat.* When this ceases to be adequate, the body is in the *zone of inevitable body heating.* The body enjoys a little more latitude in this zone than it did in the corresponding zone on the cold side, but when the deep temperature rises more than 4 deg F, it loses its efficiency. All factors which affect the evaporation of water from the skin affect heat regulation in the zone of evaporative regulation. Atmospheric vapor pressure