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 fasting, nude men, 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 81 to 86 F a zone of easy regulation of body heat exists for nude persons which may be called a *zone of thermal neutrality* in contrast with the chilling effect noted in the cooler part of the curve, the *zone of body cooling*, and in contrast with the *zone of evaporative regulation* at higher temperatures. In the narrow range of the neutral zone most men feel comfortable under similar conditions (nude and at rest). In this neutral zone the regulation of body temperature is accomplished by automatic variation in the blood flow to the skin, especially of the hands, feet, and head, to vary the radiation and convection losses as required to balance heat loss and heat production.

At lower temperatures throughout the *zone of body cooling* there is a progressive fall in the skin temperature, especially in feet and hands, which implies a diversion of blood from the skin into deeper organs, and a progressively greater loss of intrinsic body heat ($-S$), until the body temperature falls enough to induce shivering. The muscular activity of shivering increases heat production and so makes good the excessive heat loss, maintaining body temperature nearly normal. In cool environments heat loss by evaporation from skin and respiratory tract remains almost constant at about 25 per cent of the heat produced in resting or slightly active subjects.

In the zone of evaporative regulation the burden of heat regulation is assumed by evaporation, radiation and convection losses already being

maximal from the warm skin, flooded by maximal cutaneous blood flow. In such hot conditions the pulse rate rises. When sweat first appears it covers only part of the body, especially the head and neck, and gradually extends to drench the entire body surface. All factors which affect the evaporation of water from the skin affect heat regulation in the zone of evaporative regulation. Relative humidity and air motion are most important. With dry-bulb temperature above body temperature, air motion facilitates evaporative heat loss by removing hot humid air from contact with the skin and replacing it with relatively drier air.

Heat regulation in man requires an intact set of sensory nerves, a normal sympathetic nerve supply to sweat glands and blood vessels, a great many sweat glands, and a circulatory system capable of carrying heat from muscles and viscera to the skin by circulation of the blood.

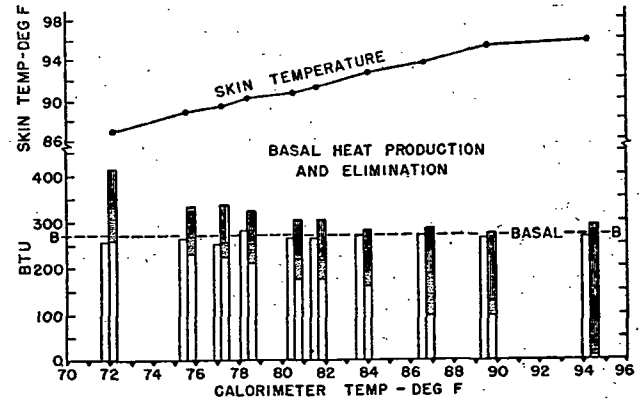

FIG. 1. HEAT LOSS FROM HUMAN BEINGS BY EVAPORATION, RADIATION, AND CONVECTION[a]

[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.

The human body possesses remarkable powers of adaptation to a narrow range of atmospheric conditions around an ideal optimum where storage is zero, and metabolism and skin and tissue temperature are at optimum values. Under these conditions, the body experiences a sensation of comfort. As skin and body-tissue temperatures rise or fall above or below an optimum, complex adaptive mechanisms come into play, chiefly associated with redistribution of blood supply between the skin and deeper tissues (in a cold environment) and with sweat secretion (in a hot environment). These reactions are governed by nervous or chemical stimuli from both skin and internal tissues. Nerves from the skin carry the sense impressions to the brain and the response comes back over another set of nerves, the motor nerves, to the musculature and to all the active tissues in the body, including the endocrine glands. In this way, a two-sided mechanism controls the body temperature by (1) regulation of internal heat production (chemical regulation), and (2) regulation of heat loss by means of automatic variation in the rate of cutaneous circu-