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.

In the *zone of body cooling* circulation to the skin is greatly reduced; the feet and hands cool sharply; *gooseflesh* appears early; the rectal temperature falls progressively until shivering or work increases heat production. Adolph and Molnar[8] showed that shivering or work can increase heat production four- or five-fold and so constitute protection from exposure to cold. They showed that the cutaneous vaso-constriction during chilling produces a temperature gradient averaging 4.4 cm in thickness below the skin in chilled nude men. Their subjects complained of pain, especially in the feet, which progressed to numbness. Discomfort from cold was followed by mental confusion, dullness and stupor. Fatigue limited their shivering response and shivering stopped with sleep. Hypothermia (abnormally low body temperature) was then inevitable. These authors observed no acclimatization to cold. There is no good evidence that man can adapt himself to cold by increasing heat production except that due to exercise or shivering. In animals and even in certain mammals, such *chemical regulation* is known to exist.

In the zone of evaporative regulation the burden of heat dissipation is assumed by evaporation, radiation and convection losses already being maximal from the warm skin, flooded by maximal cutaneous blood flow[9]. 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

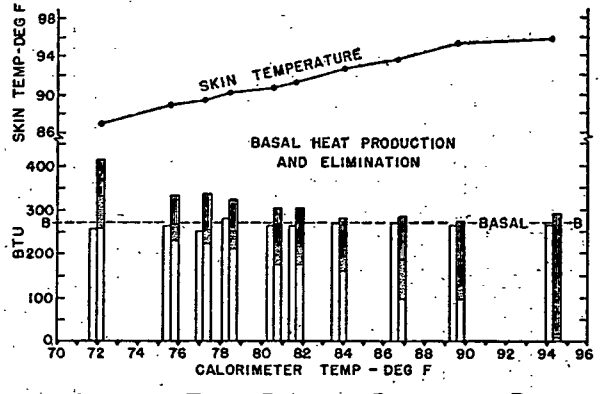

FIG. 1. HEAT LOSS FROM HUMAN BEINGS BY EVAPORATION, RADIATION, AND CONVECTION[a].

[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.

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.

Some of the phenomena of body temperature control are shown graphically in Fig. 2. The dotted curves, from a study at the John B. Pierce Laboratory of Hygiene[10], are for subjects lightly clothed in a semi-reclining position and give the relation between the dry-bulb temperature of the environment (with about 45 per cent relative humidity) and the metabolic rate (heat production), the rate of heat dissipation by radiation and convection combined, and the latent heat loss due to evaporation from the skin and the respiratory tract. The smooth line curves from the work of the A.S.H.V.E. Research Laboratory[11] give the same relationships for