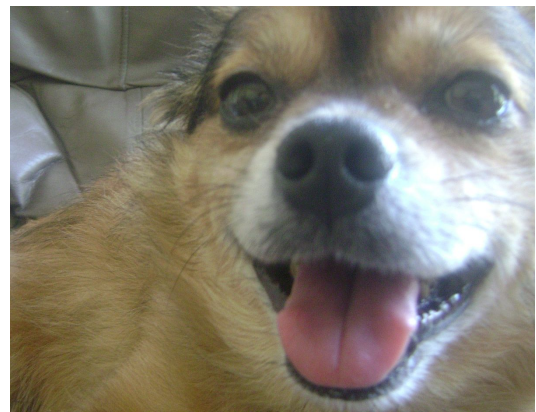


Thermoregulation

Thermoregulation is the ability of an organism to keep its body temperature within certain boundaries, even when the surrounding temperature is very different. This process is one aspect of homeostasis: a dynamic state of stability between an animal's internal environment and its *external* environment (the study of such processes in zoology has been called ecophysiology or physiological ecology). If the body is unable to maintain a normal temperature and it increases significantly above normal, a condition known as hyperthermia occurs. For humans, this occurs when the body is exposed to constant temperatures of approximately 55° C, any prolonged exposure (longer than a few hours) at this temperature and up to around 70° C death is almost inevitable. Humans may also experience



A dog panting is an example of thermoregulation.

lethal hyperthermia when the wet bulb temperature is sustained above 35 °C (95 °F) for six hours. ^[1] ^[2] The opposite condition, when body temperature decreases below normal levels, is known as hypothermia.

Whereas an organism that *thermoregulates* is one that keeps its core body temperature within certain limits, a **thermoconformer** is subject to changes in body temperature according to changes in the temperature outside of its body. It was not until the introduction of thermometers that any exact data on the temperature of animals could be obtained. It was then found that local differences were present, since heat production and heat loss vary considerably in different parts of the body, although the circulation of the blood tends to bring about a mean temperature of the internal parts. Hence it is important to identify the parts of the body that most closely reflect the temperature of the internal organs. Also, for such results to be comparable, the measurements must be conducted under comparable conditions. The rectum has traditionally been considered to reflect most accurately the temperature of internal parts, or in some cases of sex or species, the vagina, uterus or bladder.

Occasionally the temperature of the urine as it leaves the urethra may be of use. More often the temperature is taken in the mouth, axilla, ear or groin.

Classification of animals by thermal characteristics

Endothermy versus Ectothermy

Organisms can generally be divided into two types of thermoregulators, endotherms and ectotherms. Endotherms create most of their heat via metabolic processes, and are colloquially referred to as warm-blooded. Ectotherms temperature comes mostly from the environment.

Ectotherms

Ectothermic cooling

- Vaporization:
 - Getting wet in a river, lake or sea.
- Convection:
 - Climbing to lower ground from trees, into valleys, burrows, etc.
 - Entering a cold water or air current.
 - Building a nest that allows natural or generated air/water flow for cooling.
- Conduction:
 - Lying on cool ground.
 - Staying wet in a river, lake or sea.
 - Covering in cool mud.
- Radiation:
 - Finding shade.
 - Entering a burrow shaped for radiating heat (Black-box effect).
 - Expanding folds of skin.
 - Exposing wing surfaces.



Seeking shade is one method of cooling. Here Sooty Tern chicks are using a Black-footed Albatross chick for shade.

Ectothermic heating (or minimizing heat loss)

- Convection:
 - Climbing to higher ground up trees, ridges, rocks.
 - Entering a warm water or air current.
 - Building an insulated nest or burrow.
- Conduction:
 - Lie on hot rock.
- Radiation:
 - Lie in sun.
 - Fold skin to reduce exposure.
 - Conceal wing surfaces.
- Insulation
 - Change shape to alter surface/volume ratio
 - Inflate the body

To cope with low temperatures, some cows have developed the ability to remain functional even when the water temperature is below freezing; some use natural antifreeze or antifreeze proteins to resist ice crystal formation in their tissues. Amphibians and reptiles cope with heat loss by evaporative cooling and behavioral adaptations.

Endothermy

An endotherm is an animal that regulates its own body temperature, typically by keeping it at a constant level. To regulate body temperature, an organism may need to prevent heat gains in arid environments. Evaporation of water, either across respiratory surfaces or across the skin in those animals possessing sweat glands, helps in cooling body temperature to within the organism's tolerance range. Animals with a body covered by fur have limited ability to sweat, relying heavily on **panting** to increase evaporation of water across the moist surfaces of the lungs and the tongue and mouth. Birds also avoid overheating by **angular fluttering**, flapping the wings near the singular (throat) skin, similar to panting in mammals, since their thin skin has no sweat glands. Down feathers trap warm air acting as excellent insulators just as hair in mammals acts as a good insulator. Mammalian skin is much thicker than that of birds and often has a continuous layer of insulating fat beneath the dermis — in marine mammals such as whales this is called blubber. Dense coats found in desert endotherms also aid in preventing heat gain.

A cold weather strategy is to temporarily decrease metabolic rate, decreasing the temperature difference between the animal and the air and thereby minimizing heat loss. Furthermore, having a lower metabolic rate is less energetically expensive. Many animals survive cold frosty nights through torpor, a short-term temporary drop in body temperature. Organisms when presented with the problem of regulating body temperature have not only behavioural, physiological and structural adaptations, but also a feedback system to trigger these adaptations to regulate temperature accordingly. The main features of this system are *stimulus*, *receptor*, *modulator*, *effector* and then the feedback of the newly adjusted temperature to the *stimulus*. This cyclical process aids in homeostasis.

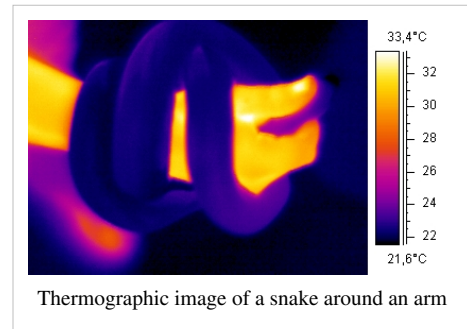
Homeothermy versus Poikilothermy

Homeothermy and poikilothermy refer to how stable an organism's temperature is. Most endothermic organisms are homeothermic, like mammals. However, animals with facultative endothermy are often poikilothermic, meaning their temperature can vary considerably. Similarly, most fish are ectotherms, as all of their heat comes from the surrounding water. However, most are homeotherms because their temperature is very stable.

Thermoregulation in vertebrates

By numerous observations upon humans and other animals, John Hunter showed that the essential difference between the so-called warm-blooded and cold-blooded animals lies in observed constancy of the temperature of the former, and the observed variability of the temperature of the latter. Almost all birds and mammals have a high temperature almost constant and independent of that of the surrounding air (homeothermy). Almost all other animals display a variation of body temperature, dependent on their surroundings (poikilothermy).

Certain mammals are exceptions to this rule, being warm-blooded during the summer or daytime, but cold-blooded during the winter when they hibernate or at night during sleep. J. O. Wakelin Barratt has demonstrated that under certain pathological conditions, a warm-blooded (homeothermic) animal may become temporarily cold-blooded (poikilothermic). He has shown conclusively that this condition exists in rabbits suffering from rabies during the last period of their life, the rectal temperature being then within a few degrees of the room temperature and varying with it. He explains this condition by the assumption that the nervous mechanism of heat regulation has become paralysed. The respiration and heart-rate being also retarded during this period, the resemblance to the condition of



Thermographic image of a snake around an arm

hibernation is considerable. Again, Sutherland Simpson has shown that during deep anaesthesia a warm-blooded animal tends to take the same temperature as that of its environment. He demonstrated that when a monkey is kept deeply anaesthetized with ether and is placed in a cold chamber, its temperature gradually falls, and that when it has reached a sufficiently low point (about 25 °C in the monkey), the employment of an anaesthetic is no longer necessary, the animal then being insensible to pain and incapable of being roused by any form of stimulus; it is, in fact, narcotised by cold, and is in a state of what may be called "artificial hibernation." Once again this is explained by the fact that the heat-regulating mechanism has been interfered with. Similar results have been obtained from experiments on cats.

Brain control

Thermoregulation in both ectotherms and endotherms is controlled mainly by the preoptic area of the anterior hypothalamus.^[3] Such homeostatic control is separate from the sensation of temperature.^[3]

Thermoregulation in birds and mammals

In cold environments, birds and mammals employ the following adaptations and strategies to minimize heat loss:

1. using small smooth muscles (erector pili in mammals) which are attached to feather or hair shafts; this non-shivering thermogenesis distorts the surface of the skin as the feather/hair shaft is made more erect (called goose bumps or pimples)
2. increasing body size to more easily maintain core body temperature (warm-blooded animals in cold climates tend to be larger than similar species in warmer climates (see Bergmann's Rule))
3. having the ability to store energy as fat for metabolism
4. have shortened extremities
5. have countercurrent blood flow in extremities - this is where the warm arterial blood travelling to the limb passes the cooler venous blood from the limb and heat is exchanged warming the venous blood and cooling the arterial (e.g. Arctic Wolf^[4] or penguins^[5] ^[6])

In warm environments, birds and mammals employ the following adaptations and strategies to maximize heat loss:

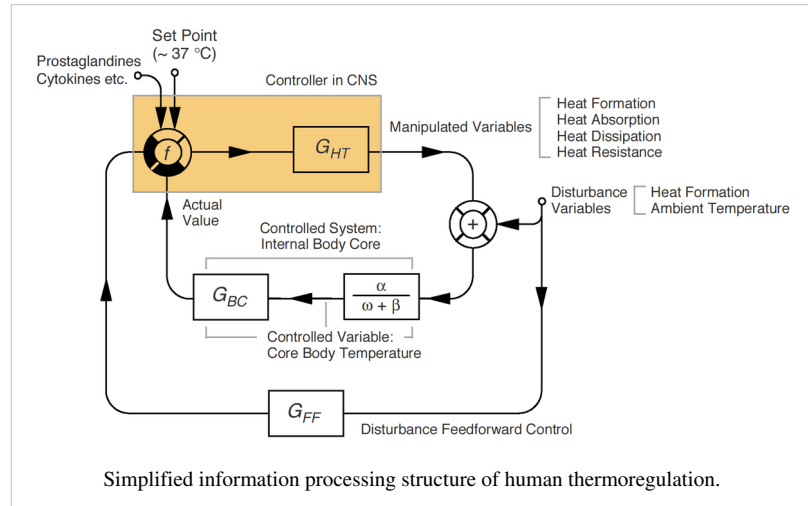
1. behavioural adaptations like living in burrows during the day and being nocturnal
2. evaporative cooling by perspiration and panting
3. storing fat reserves in one place (e.g. camel's hump) to avoid its insulating effect
4. elongated, often vascularized extremities to conduct body heat to the air



Kangaroo licking its arms to cool down on a very hot day

Thermoregulation in humans

As in other mammals, thermoregulation is an important aspect of human homeostasis. Most body heat is generated in the deep organs, especially the liver, brain, and heart, and in contraction of skeletal muscles.^[7] Humans have been able to adapt to a great diversity of climates, including hot humid and hot arid. High temperatures pose serious stresses for the human body, placing it in great danger of injury or even death. For humans, adaptation to varying climatic conditions includes both physiological



mechanisms as a byproduct of evolution, and the conscious development of cultural adaptations.^{[8] [9]}

There are four avenues of heat loss: convection, conduction, radiation, and evaporation. If skin temperature is greater than that of the surroundings, the body can lose heat by radiation and conduction. But if the temperature of the surroundings is greater than that of the skin, the body actually *gains* heat by radiation and conduction. In such conditions, the only means by which the body can rid itself of heat is by evaporation. So when the surrounding temperature is higher than the skin temperature, anything that prevents adequate evaporation will cause the internal body temperature to rise.^[1] During sports activities, evaporation becomes the main avenue of heat loss.^[10] Humidity affects thermoregulation by limiting sweat evaporation and thus heat loss.^[11]

The skin assists in homeostasis (keeping different aspects of the body constant e.g. temperature). It does this by reacting differently to hot and cold conditions so that the inner body temperature remains more or less constant. Vasodilation and sweating are the primary modes by which humans attempt to lose excess body heat. The brain creates much heat through the countless reactions which occur. Even the process of thought creates heat. The head has a complex system of blood vessels, which keeps the brain from overheating by bringing blood to the thin skin on the head, allowing heat to escape. The effectiveness of these methods is influenced by the character of the climate and the degree to which the individual is acclimatized.

In hot conditions

1. Eccrine sweat glands under the skin secrete sweat (a fluid containing mostly water with some dissolved ions) which travels up the sweat duct, through the sweat pore and onto the surface of the skin. This causes heat loss via evaporative cooling; however, a lot of essential water is lost.
2. The hairs on the skin lie flat, preventing heat from being trapped by the layer of still air between the hairs. This is caused by tiny muscles under the surface of the skin called Arrector pili muscles relaxing so that their attached hair follicles are not erect. These flat hairs increase the flow of air next to the skin increasing heat loss by convection. When environmental temperature is above core body temperature, sweating is the only physiological way for humans to lose heat.
3. Arterioles Vasodilation occurs, this is the process of relaxation of smooth muscle in arteriole walls allowing increased blood flow through the artery. This redirects blood into the superficial capillaries in the skin increasing heat loss by convection and conduction.

Note: Most animals can't sweat efficiently. Cats and dogs have sweat glands only on the pads of their feet. Horses and humans are two of the few animals capable of sweating. Many animals pant rather than sweat because the lungs have a large surface area and are highly vascularised. Air is inhaled, cooling the surface of the lungs and is then

exhaled losing heat and some water vapour.

Thermoregulation in hot and humid conditions

In general, humans appear physiologically well adapted to hot dry conditions.^[12] However, effective thermoregulation is reduced in hot, humid environments such as the Red Sea and Persian Gulf (where moderately hot summer temperatures are accompanied by unusually high vapor pressures), tropical environments, and deep mines where the atmosphere can be water-saturated.^[12] In hot-humid conditions, clothing can impede efficient evaporation.^[1] In such environments, it helps to wear light clothing such as cotton, that is pervious to sweat but impervious to radiant heat from the sun. This minimizes the gaining of radiant heat, while allowing as much evaporation to occur as the environment will allow. Clothing such as plastic fabrics that are impermeable to sweat and thus do not facilitate heat loss through evaporation, can actually contribute to heat stress.^[1]

In cold conditions

1. Sweat stops being produced.
2. The minute muscles under the surface of the skin called erector pili muscles (attached to an individual hair follicle) contract (piloerection), lifting the hair follicle upright. This makes the hairs stand on end which acts as an insulating layer, trapping heat. This is what also causes goose bumps since humans don't have very much hair and the contracted muscles can easily be seen.
3. Arterioles carrying blood to superficial capillaries under the surface of the skin can shrink (constrict), thereby rerouting blood away from the skin and towards the warmer core of the body. This prevents blood from losing heat to the surroundings and also prevents the core temperature dropping further. This process is called vasoconstriction. It is impossible to prevent all heat loss from the blood, only to reduce it. In extremely cold conditions excessive vasoconstriction leads to numbness and pale skin. Frostbite only occurs when water within the cells begins to freeze, this destroys the cell causing damage.
4. Muscles can also receive messages from the thermo-regulatory center of the brain (the hypothalamus) to cause shivering. This increases heat production as respiration is an exothermic reaction in muscle cells. Shivering is more effective than exercise at producing heat because the animal remains still. This means that less heat is lost to the environment via convection. There are two types of shivering: low intensity and high intensity. During low intensity shivering animals shiver constantly at a low level for months during cold conditions. During high intensity shivering animals shiver violently for a relatively short time. Both processes consume energy although high intensity shivering uses glucose as a fuel source and low intensity tends to use fats. This is a primary reason why animals store up food in the winter.
5. Mitochondria can convert fat directly into heat energy, increasing the temperature of all cells in the body. Brown fat is specialized for this purpose, and is abundant in newborns and animals that hibernate.

The process explained above, in which the skin regulates body temperature is a part of thermoregulation. This is one aspect of homeostasis-the process by which the body regulates itself to keep internal conditions constant.

Diseases and syndromes relating to thermoregulation

- Hypothermia
 - Hyperthermia
 - Heat stroke
 - Raynaud's phenomenon (Raynaud's disease)
 - Induced hypothermia
 - Erythromelalgia (hyperthermia)
-

Human heat output power

A human will output from around 70 Watts to 870 Watts, depending on the amount of physical activity undertaken.^[13]

Thermoregulation in plants

Thermogenesis occurs in the flowers of many plants in the Araceae family as well as in cycad cones.^[14] In addition, the Sacred lotus (*Nelumbo nucifera*) is able to thermoregulate itself,^[15] remaining on average 20 °C (36 °F) above air temperature while flowering. Heat is produced by breaking down the starch that was stored in their roots,^[16] which requires the consumption of oxygen at a rate approaching that of a flying hummingbird.^[17]

One possible explanation for plant thermoregulation is to provide protection against cold temperature. For example, the skunk cabbage is not frost-resistant, yet it begins to grow and flower when there is still snow on the ground.^[14] Another theory is that thermogenicity helps attract pollinators, which is borne out by observations that heat production is accompanied by the arrival of beetles or flies.^[18]

Behavioral temperature regulation

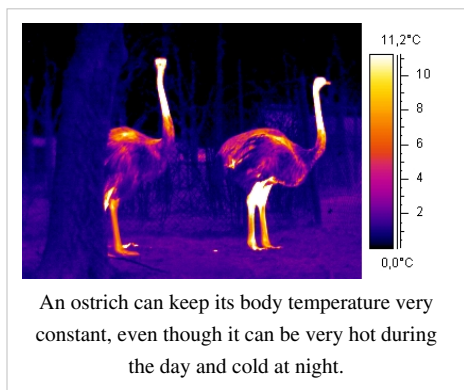
Animals other than humans regulate and maintain their body temperature with physiological adjustments and behavior. Desert lizards are ectotherms and so unable to metabolically control their temperature but can do this by altering their location. They may do this by in the morning only raising their head from its burrow and then exposing their entire body. By basking in the sun, the lizard absorbs solar heat. It may also absorb heat by conduction from heated rocks that have stored radiant solar energy. To lower their temperature, lizards may seek cooler objects with which to contact, find shade or return to their burrow. They also go to their burrows to avoid cooling when the sun goes down or the temperature falls.

Animals also engage in kleptothermy in which they share or even steal each other's body warmth. In endotherms such as bats^[19] and birds (such as the mousebird^[20] and emperor penguin^[21]) it allows the sharing of body heat (particularly amongst juveniles). This allows the individuals to increase their thermal inertia (as with gigantothermy) and so reduce heat loss.^[22] Some ectotherms share burrows of ectotherms. Other animals exploit termite mounds.^[23]^[24]

Some animals living in cold environments maintain their body temperature by preventing heat loss. Their fur grows more densely to increase the amount of insulation. Some animals are regionally heterothermic and are able to allow their less insulated extremities to cool to temperatures much lower than their core temperature—nearly to 0 °C. This minimizes heat loss through less insulated body parts, like the legs, feet (or hooves), and nose.

Hibernation, estivation, and daily torpor

To cope with limited food resources and low temperatures, some mammals hibernate in underground burrows. In order to remain in "stasis" for long periods, these animals must build up brown fat reserves and be capable of slowing all body functions. True hibernators (e.g. groundhogs) keep their body temperature down throughout their hibernation while the core temperature of false hibernators (e.g. bears) varies with them sometimes emerging from their dens for brief periods. Some bats are true hibernators which rely upon a rapid, non-shivering thermogenesis of their brown fat deposit to bring them out of hibernation.



Estivation occurs in summer (like siestas) and allows some mammals to survive periods of high temperature and little water (e.g. turtles burrow in pond mud).

Daily torpor occurs in small endotherms like bats and humming birds which temporarily reduce their high metabolic rates to conserve energy.^[25]

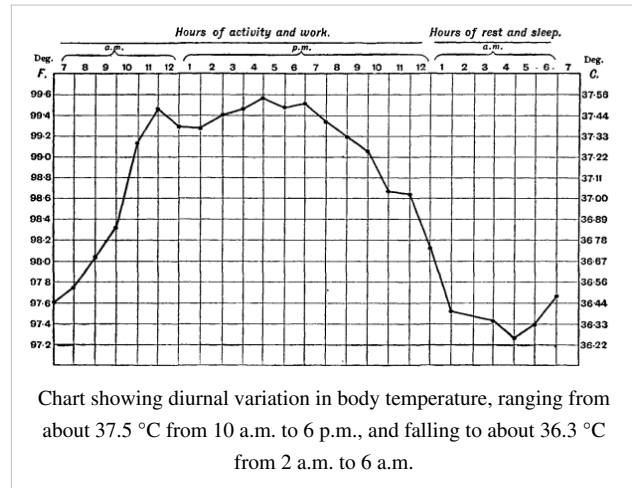
Variations in the temperature of human beings and some animals

Normal human temperature

Previously, average oral temperature for healthy adults had been considered 37.0 °C (98.6 °F), while normal ranges are 36.1 °C (97.0 °F) to 37.8 °C (100.0 °F). In Poland and Russia, the temperature had been measured axillary. 36.6 °C was considered "ideal" temperature in these countries, while normal ranges are 36 °C to 36.9 °C.

Recent studies suggest that the average temperature for healthy adults is 98.2 °F or 36.8 °C (same result in three different studies). Variations (one standard deviation) from three other studies are:

- 36.4 - 37.1 °C (97.5 - 98.8 °F)
- 36.3 - 37.1 °C (97.3 - 98.8 °F) for males, 36.5 - 37.3 °C (97.7 - 99.1 °F) for females
- 36.6 - 37.3 °C (97.9 - 99.1 °F)^[26]



Variations from thermometer placement

Temperature varies according to thermometer placement, with rectal temperature being 0.3-0.6 °C (0.5-1 °F) higher than oral temperature, while axillary temperature is 0.3-0.6 °C (0.5-1 °F) lower than oral temperature.^[27] The average difference between oral and axillary temperatures of Indian children aged 6–12 was found to be only 0.1 °C (standard deviation 0.2 °C),^[28] and the mean difference in Maltese children aged 4–14 between oral and axillary temperature was 0.56 °C, while the mean difference between rectal and axillary temperature for children under 4 years old was 0.38 °C.^[29]

Variations associated with development

Of the lower warm-blooded animals, there are some that appear to be cold-blooded at birth. Kittens, rabbits and puppies, if removed from their surroundings shortly after birth, lose their body heat until their temperature has fallen to within a few degrees of that of the surrounding air. But such animals are at birth blind, helpless and in some cases furless. Animals who are born when in a condition of greater development can maintain a fairly constant body temperature. In strong, healthy human infants a day or two old the temperature rises slightly when removed, but in that of weakly, ill-developed children it either remains stationary or falls. The cause of the variable temperature in infants and young immature animals is the imperfect development of the nervous regulating mechanism.

The average temperature falls slightly from infancy to puberty and again from puberty to middle age, but after that stage is passed the temperature begins to rise again, and by about the eightieth year is as high as in infancy.

Variations due to circadian rhythms

In humans, a diurnal variation has been observed dependent on the periods of rest and activity, lowest at 11 p.m. to 3 a.m. and peaking at 10 a.m. to 6 p.m. Monkeys also have a well-marked and regular diurnal variation of body temperature which follows periods of rest and activity, and is not dependent on the incidence of day and night; nocturnal monkeys reach their highest body temperature at night and lowest during the day. Sutherland Simpson and J.J. Galbraith observed that all nocturnal animals and birds - whose periods of rest and activity are naturally reversed through habit and not from outside interference - experience their highest temperature during the natural period of activity (night) and lowest during the period of rest (day). Those diurnal temperatures can be reversed by reversing their daily routine.^[30]

The temperature curve of diurnal birds is essentially similar to that of man and other homoeothermal animals, except that the maximum occurs earlier in the afternoon and the minimum earlier in the morning. Also that the curves obtained from rabbits, guinea pigs and dogs were quite similar to those from man. These observations indicate that body temperature is partially regulated by circadian rhythms.

Variations due to women's menstrual cycles

During the follicular phase (which lasts from the first day of menstruation until the day of ovulation), the average basal body temperature in women ranges from 36.45 to 36.7 °C (97.6 to 98.1 °F). Within 24 hours of ovulation, women experience an elevation of 0.15 - 0.45 °C (0.2 - 0.9 °F) due to the increased metabolic rate caused by sharply elevated levels of progesterone. The basal body temperature ranges between 36.7 - 37.3°C (98.1 - 99.2°F) throughout the luteal phase, and drops down to pre-ovulatory levels within a few days of menstruation.^[31] Women can chart this phenomenon to determine whether and when they are ovulating, so as to aid conception or contraception.

Variations due to fever

Fever is a regulated elevation of the set point of core temperature in the hypothalamus, caused by circulating pyrogens produced by the immune system. To the subject, a rise in core temperature due to fever may result in feeling cold in an environment where people without fever do not.

Variations due to biofeedback

A group of monks known as the Tummo are known to practice biofeedback meditation techniques that allow them to raise their body temperatures substantially.^[32]

Variations due to other factors

In Simpson's & Galbraith's work, the mean temperature of the female was higher than that of the male in all the species examined whose sex had been determined.

Meals sometimes cause a slight elevation, sometimes a slight depression—alcohol seems always to produce a fall. Exercise and variations of external temperature within ordinary limits cause very slight change, as there are many compensating influences at work, which are discussed later. The core temperature of those living in the tropics is within a similar range to those dwelling in the Arctic regions.

Low body temperature increases lifespan

It was long theorised that low body temperature may prolong life. On November 2006, a team of scientists from the Scripps Research Institute reported that transgenic mice which had body temperature 0.3-0.5 C lower than normal mice (due to overexpressing the uncoupling protein 2 in hypocretin neurons (Hcrt-UCP2), which elevated hypothalamic temperature, thus forcing the hypothalamus to lower body temperature) indeed lived longer than normal mice. The lifespan was 12% longer for males and 20% longer for females. Mice were allowed to eat as much

as they wanted.^{[33] [34] [35]} The effects of such a genetic change in body temperature on longevity is harder to study in humans. The UCP2 genetic alleles seen in humans so far are associated with obesity^[36]

Limits compatible with life

There are limits both of heat and cold that a warm-blooded animal can bear, and other far wider limits that a cold-blooded animal may endure and yet live. The effect of too extreme a cold is to decrease metabolism, and hence to lessen the production of heat. Both catabolic and anabolic pathways share in this metabolic depression, and, though less energy is used up, still less energy is generated. The effects of this diminished metabolism become telling on the central nervous system first, especially the brain and those parts concerning consciousness;^[37] both heart rate and respiration rate decrease; judgment becomes impaired as drowsiness supervenes, becoming steadily deeper until the individual loses consciousness; without medical intervention, death by hypothermia quickly follows. Occasionally, however, convulsions may set in towards the end, and death is caused by asphyxia.^[37]

In experiments on cats performed by Sutherland Simpson and Percy T. Herring, the animals were unable to survive when rectal temperature fell below 16°C.^[37] At this low temperature respiration became increasingly feeble; heart-impulse usually continued after respiration had ceased, the beats becoming very irregular, apparently ceasing, then beginning again. Death appeared to be mainly due to asphyxia, and the only certain sign that it had taken place was the loss of knee jerks.

Conversely, too high a temperature speeds up the metabolism of different tissues to such a rate that their metabolic capital is soon exhausted. Blood that is too warm produces dyspnea by exhausting the metabolic capital of the respiratory centre; heart rate is increased; the beats then become arrhythmic and eventually cease. The central nervous system is also profoundly affected by hyperthermia and delirium and convulsions may set in. Consciousness may also be lost, propelling the person into a comatose condition. These changes can sometimes also be observed in patients suffering from an acute fever. The lower limit of temperature that humans can endure depends on many factors, but no one can survive a temperature of 45 °C (113 °F) or above for very long. Mammalian muscle becomes rigid with heat rigor at about 50°C, with the sudden rigidity of the whole body rendering life impossible.

H.M. Vernon has done work on the death temperature and paralysis temperature (temperature of heat rigor) of various animals. He found that species of the same class showed very similar temperature values, those from the Amphibia examined being 38.5°C, Fish 39°C, Reptilia 45°C, and various Molluscs 46°C. Also, in the case of Pelagic animals, he showed a relation between death temperature and the quantity of solid constituents of the body. In higher animals, however, his experiments tend to show that there is greater variation in both the chemical and physical characteristics of the protoplasm, and hence greater variation in the extreme temperature compatible with life.

Human temperature variation effects

Hot

- **37 °C (99 °F)** - Normal body temperature (which varies between about 36.12–37.5 °C (97–100 °F))
- **38 °C (100 °F)** - Sweating, feeling very uncomfortable, slightly hungry.
- **39 °C (102 °F)** - Severe sweating, flushed and very red. Fast heart rate and breathlessness. There may be exhaustion accompanying this. Children and people with epilepsy may be very likely to get convulsions at this point.
- **40 °C (104 °F)** - Fainting, dehydration, weakness, vomiting, headache and dizziness may occur as well as profuse sweating. Starts to be life- threatening.
- **41 °C (106 °F)** - (Medical emergency) - Fainting, vomiting, severe headache, dizziness, confusion, hallucinations, delirium and drowsiness can occur. There may also be palpitations and breathlessness.
- **42 °C (108 °F)** - Subject may turn pale or remain flushed and red. They may become comatose, be in severe delirium, vomiting, and convulsions can occur. Blood pressure may be high or low and heart rate will be very

fast.

- **43 °C (109 °F)** - Normally death, or there may be serious brain damage, continuous convulsions and shock. Cardio-respiratory collapse will likely occur.
- **44 °C (111 °F) or more** - Almost certainly death will occur; however, patients have been known to survive up to 46.5 °C (115.7 °F).^[38]

Cold

- **37 °C (99 °F)** - Normal body temperature (which varies between about 36–37.5 °C (97–100 °F))
- **36 °C (97 °F)** - Mild to moderate shivering (body temperature may drop this low during sleep). May be a normal body temperature.
- **35 °C (95 °F)** - (Hypothermia) is less than 35 °C (95 °F) - Intense shivering, numbness and bluish/grayness of the skin. There is the possibility of heart irritability.
- **34 °C (93 °F)** - Severe shivering, loss of movement of fingers, blueness and confusion. Some behavioural changes may take place.
- **33 °C (91 °F)** - Moderate to severe confusion, sleepiness, depressed reflexes, progressive loss of shivering, slow heart beat, shallow breathing. Shivering may stop. Subject may be unresponsive to certain stimuli.
- **32 °C (90 °F)** - (Medical emergency) Hallucinations, delirium, complete confusion, extreme sleepiness that is progressively becoming comatose. Shivering is absent (subject may even think they are hot). Reflex may be absent or very slight.
- **31 °C (88 °F)** - Comatose, very rarely conscious. No or slight reflexes. Very shallow breathing and slow heart rate. Possibility of serious heart rhythm problems.
- **28 °C (82 °F)** - Severe heart rhythm disturbances are likely and breathing may stop at any time. Patient may appear to be dead.
- **24–26 °C (75–79 °F) or less** - Death usually occurs due to irregular heart beat or respiratory arrest; however, a woman named Anna Bågenholm was recorded to have survived with body temperatures as low as 13.7 °C (56.7 °F).

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