ON THE CORRELATION BETWEEN SPECIFIC HEAT ANOMALY OF WATER AND THERMOREGULATION IN MAMMALS AND BIRDS

P. Mallikarjuna Reddy[1*]
[1]Associate Professor
[1]Department of Physics
[1]V.R. College, Nellore, AP, 524 001, India.

Abstract: Keen analysis of normal body temperatures (t_b) of different classes of mammals and birds reveals that temperature of many of them is close to 37 ˚C and that of all endotherms may, generally, be expressed as 37 ˚C ± 0 to 5 ˚C. All the enzymes in them have maximum activity near their t_b and also when water in them is at an optimum level. Their bodies are filled mostly with water and specific heat capacity of water varies anomalously with temperature to take a minimum value near 37 ˚C (t_c). Conditions necessary for optimum functionality of enzymes and the apparent nearness of t_b and t_c prompted us to demonstrate, indisputably, how water in their bodies and its minimum specific heat capacity at a temperature close to 37 ˚C serve respectively as the temperature-sensing substance and its temperature-sensitive property of the thermostat in them.

Keywords: specific heat, thermoregulation, temperature, mammals, birds.

Study of normal body temperatures of mammals and birds is highly fascinating for a variety of reasons **(Morrison and Ryser (1952), McNab (1966), McNab (1970), Schimdt-Nielson (1974)).** They are endothermic animals whereas almost all other organisms are ectothermic by nature. Most of the heat in them is generated inside their bodies due to metabolic processes. They have a built-in homeostatic mechanism which automatically maintains their body at a fairly stable temperature in spite of large changes in their mass, size, shape, reproducibility and activity levels during their life time, occasional variations on a massive scale in pulse rate, blood pressure etc., and also wide variations in environmental conditions. As such, these warm blooded animals may be likened to internal combustion engines coupled with a bio-thermostat.

Most of the mammals, including humans, are eutherians. Their normal body temperatures cluster around 37 ˚C, the temperature of healthy human being **(Morrison and Ryser (1952), McNab (1966), McNab (1970), Schimdt-Nielson (1974)).** Normal temperatures of some of them are between 35 ˚C and 37 ˚C, many close to 37 ˚C and almost all others between 37 ˚C and 39 ˚C. Shrew and bumblebee-bat, the smallest and blue whale, the largest of all mammals and elephant, the largest terrestrial placental, have almost equal normal temperatures. Only a few hundred species of animals belong to the class of mammals known as marsupials. Bandicoots, kangaroos and koalas are quite familiar pouched mammals. The t_b of these mammals **(Schimdt-Nielson (1974))**, in general, is less than that of eutherians and is about 35 ˚C. Very few species form the group of mammals called monotremes. Duckbilled platypus and ant eating echidna are two well known monotremes. The t_b of these egg laying mammals **(Schimdt-Nielson (1974))** is about 32 ˚C. Most of the birds are highly mobile aerodynamic animals. They are almost always warmer than eutherians and their normal body temperatures flock between 38 ˚C and 42 ˚C **(McNab (1966), McNab (1970), Schimdt-Nielson (1974))**. Temperature of birds, unlike that of mammals, apparently depends on their mass and lighter birds are hotter than heavier ones. The t_b of hummingbirds, the mass of which is a few grams, is about 42 ˚C and that of ostrich, with a mass of about one hundred thousand grams, is close to 39 ˚C. Thus, normal body temperature of mammals and birds of any given class is apparently independent of their mass, size, habitat and the nature of their food.

Monotremes, marsupials, eutherians and avians, in general, have different narrow bands for their normal body temperatures. But, careful analysis of normal body temperatures of all mammals and birds prompts one to express temperature of all marsupials, almost all eutherians and many species of birds as 37±2 ˚C and the same of all homeotherms as 37±5 ˚C. It is interesting to note that the normal body temperatures of all warm blooded animals crowd around that of the man who is able to keep all these animals under his control.

Temperature may be considered as a universal perturbing agent as all physical properties of matter, all physical phenomena (except those as radioactivity), chemical reactions, biochemical processes and physiological activities are influenced by changes in temperature. A modest change in the temperature of mammals and birds can lead to a profound effect on all their activities and sometimes it even poses a threat to their life. This observation is supported by the facts that the temperature of their body, even during the time of intense fever and severe heat stroke, changes by only a few degrees and the difference between the fatal and their normal body temperatures is uniformly about 6 ˚C **(Schimdt-Nielson (1974))**. Hence, every endotherm strives to maintain its temperature in an optimum range. This inference is substantiated by the studies on the effect of temperature on the activity of enzymes in them **(Wright (1955), Ganong (1999), Murray (2000), Rama Rao and Suryalakshmi (2000)).** Rate of all chemical reactions, in general, increases with increase in temperature. But, enzymatic activity increases with rise in temperature, becomes maximum in some narrow temperature region and decreases with further increase in temperature as enzymes become denatured and hence inactive at high temperatures. Enzyme catalytic activity-temperature graph is a bell shaped curve with its maximum corresponding to the normal body temperature of the organism. Hence, mammals and birds, to survive, make every effort to maintain their temperature at a level where enzymatic activity is at its greatest in them.

Another amazing feature of mammals and birds is that the normal body temperature of any individual member of any of their species is the one and only physical property that remains stable, almost at the same value, throughout its life time and also over generations in spite of large scale variations in many of its parameters. Life time constancy of the range of normal body temperature of mammals and birds indicates that there is a very efficient and highly durable thermoregulation mechanism in their bodies. It balances heat production in the body with heat loss and keeps the temperature of the whole core of the body in a narrow range that is just right for optimal progress of enzymatic reactions and physiological activities all through their life time in spite of wide variations in ambient conditions. This balancing act is carried out automatically and relentlessly in a consistent and coherent manner by a small part of the brain called hypothalamus. Hypothalamus analyzes the information it receives from various sensory receptors in the body and sends commands to glands, blood vessels, limbs, muscles etc., to do everything that is appropriate to maintain the temperature of the body at its normal value. Thus, hypothalamus plays the role of a thermostat for the bodies of mammals and birds **(Schimdt-Nielson (1974), Wright (1955), Ganong (1999))**. But, review of literature discloses nothing about the two essential characteristics, the temperature-sensing substance and its temperature-sensitive property, of this bio-thermostat. Hence, we made an attempt to show how water in the bodies of mammals and birds and its minimum specific heat capacity near 37 °C serve respectively as these two characteristics of the thermostat in them.

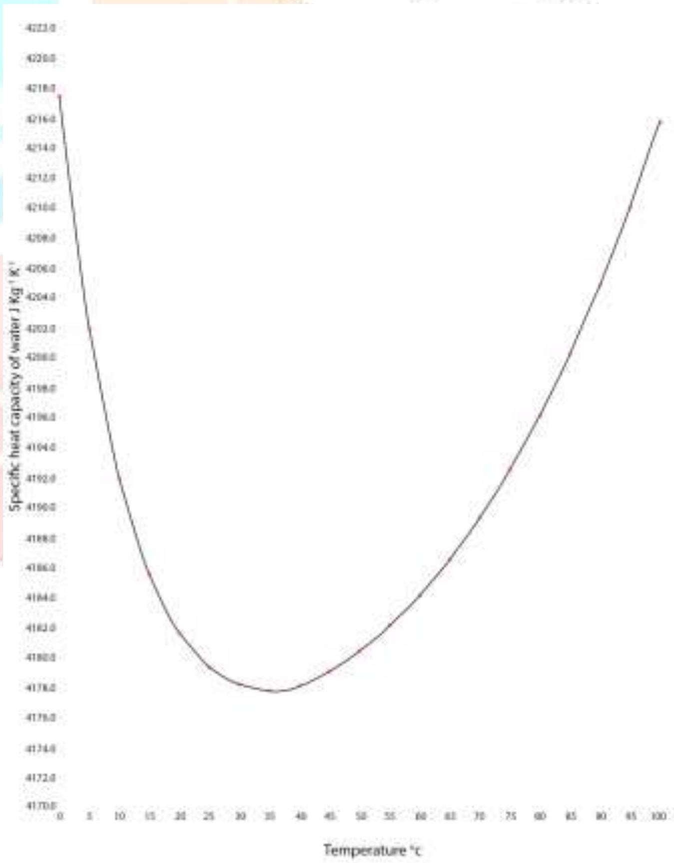

Figure 1. Isobaric specific heat capacity of water as a function of temperature

The ease with which a thermostat does its job effectively in the desired temperature range depends not only on the nature of the temperature-sensing element in it but also on the temperature-sensitive property of the element. Body of each and every mammal and bird is a bag of leather filled mostly with water **(Wright (1955), Murray (2000), Rama Rao and Suryalakshmi (2000))**. Water is the solvent of their bodies and regulates activity of everything it dissolves and serves as the medium for enzymatic and other biochemical reactions in the body. Thus, water has every reason to play the role of temperature-sensing substance in these bio-thermostats. Further, water has all the characteristics of a good temperature-sensing element of these thermostats. It is an integral part of the bodies of mammals and birds unlike a bimetallic strip or a thermistor inserted essentially for the purpose of sensing temperature in manmade thermostats. Water works in a harmonious and congenial combination with all parts of their bodies and serves many purposes in the body in addition to the job of sensing of temperature and its regulation.

Of all the physical properties of matter, including that of water, specific heat capacity is the only property that determines the extent to which the kinetic energy of the molecules of the substance changes and hence its temperature when it gains or loses heat. As such, specific heat capacity can play the role of absolute temperature-sensitive property of the thermostatic element. Isobaric specific heat capacity (c_p) of all substances increases with increase in their temperature (t) but that of water decreases as it is heated from 0 ˚C, becomes minimum, between 35 ˚C and 40 ˚C, at a temperature close to 37 ˚C and thereafter increases with further rise in temperature **(Osborne et al., (1939), Rajam (1960), Tkaczyk et al., (2015)).** The c_p-t graph of water (Figure 1) is a concave shaped curve with an open top and with its pole corresponding to a temperature close to 37 ˚C. Interestingly enough, this is the temperature around which the t_b of all mammals and birds cluster and also the activity of enzymes in them becomes the greatest. The nearness of these temperatures, huge c_p of water and the way in which c_p varies with temperature indicate that water and its c_p serve respectively as the temperature-sensing substance and its temperature-sensitive property of the thermostat in mammals and birds.

Minimum c_p of water satisfies all the requirements of an ideal temperature-sensitive property of the thermostatic element in the bio-thermostats. As c_p of water is minimum near 37 ˚C, temperature of water and hence that of a mammal or bird changes by maximum extent for a given quantity of heat exchanged at this temperature. Temperature of the body and also its c_p increase when heat is added to the body at the temperature of minimum c_p so that elevated c_p opposes increase in temperature preventing overshooting of temperature. Temperature of their body decreases as usual when it loses heat but loss of heat by the body at the temperature of minimum c_p leads to increase in its c_p so that steep fall in body temperature is prevented. Thus, temperature of their body, due to minimum value of c_p of water in it, swings with small and almost equal amplitudes on either side of the set point resulting in a narrow range for temperature variations. The period of these temperature oscillations will be large as water heats up slowly and cools down slowly because of its huge specific heat. Thus, water while serving as thermostatic substance at the temperature of its minimum c_p provides short range and large period for oscillations of temperature and hence improves the quality of temperature regulation, reduces burden on hypothalamus and saves energy of the body. Change in the entropy of any system during isobaric processes is proportional to its specific heat capacity and is more when the extent of change in its temperature is large **(Zemansky (1957))**. Hence, entropy of mammals and birds changes by a small extent during every cycle of temperature oscillations as these oscillations occur about the minimum value of c_p and within a short temperature range. Thus, minimum change in entropy and large period for temperature swings collectively enhance the longevity of the thermostat.

The preceding discussion related to c_p of pure water holds equally good for fluids in homeotherms. Fluids in their bodies are not simple binary or ternary aqueous solutions but contain many different organic and inorganic substances, either dissolved or not, in water. The exact nature and concentration of solutes and other substances in water in their bodies vary from species to species so that c_p of aqueous mixtures in them and the temperature at which c_p becomes minimum are lower or larger than or equal to that of pure water due to multiple solute-solvent interactions. For this reason, the optimal temperature for enzymatic activity in various mammals and birds and hence their normal body temperature is slightly below or above or equal to 37 ˚C. Thus, these aqueous fluids and their minimum c_p enable hypothalamus to regulate their body temperature effectively. These inferences are substantiated by the studies on the effect of temperature on c_p and on some other anomalous properties such as density and compressibility of aqueous mixtures **(Tkaczyk et al., (2015) Urban (1932), Zittle and Schmidt (1935), Kauzmann (1987), Kishore et al., (1993), Gallagher and Sharp (2003), Darros-Barbosa et al., (2003), Stanley et al., (2007), Wada and Saburo Umeda (1962), Subbarangaiah et al., (1982)).**

Though discussion here is focussed on thermoregulation in mammals and birds, it may not be out of context if it is extended to thermoregulation in some other organisms. Plants and all animals other than mammals and birds, in general, are poikilotherms. But, it is exciting to note that some insects and a small number of plants have the ability to regulate their temperature and keep it in a moderate range **(Morgan et al., (1985), Rutowski et al., (1984), Heinrich (1993), Seymour and Schultz-Motel (1998), Nagy et al., (1972), Knutson (1974)).** Male butterflies maintain their thoracic temperature in a narrow range of 38 ˚C – 42 ˚C and light-seeking robber flies between 35 ˚C and 41 ˚C during foraging in spite of large changes in atmospheric temperature. Bumblebees maintain their thorax temperature between 36 ˚C and 45 ˚C during their flight. Thorax surface temperature of honeybees is regulated to be between 34 ˚C and 36 ˚C regardless of ambient temperature. Similarly Japan beetles strive to keep their temperature between 30 ˚C and 34 ˚C while flying and the preferred body temperature of tiger beetles is 35 ˚C and they use thermoregulatory patterns to maintain it. Hawkmoth regulates its temperature and maintains it between 34 ˚C and 38 ˚C during its flight even when environmental temperature varies from 10 ˚C to 30 ˚C. Nelumbo nucifera (sacred lotus) regulates its floral temperature during anthesis to be between 30 ˚C and 36 ˚C. Philodendron selloum, whether grown outdoors or indoors, keeps its blooms in the same temperature range as sacred lotus even when temperature of its surroundings is 4 ˚C. Eastern skunk cabbage maintains its spadix temperature around 30 ˚C for many days even when ambient temperature falls to subzero values. Dead horse arum also exhibits thermogenesis and maintains its temperature at about 32 ˚C.

Review of thermoregulation exhibited by these insects and plants shows that the range over which they maintain their temperature is broader than that of any individual mammal or bird. This observation indicates that the mechanism of thermoregulation in them is not as developed as that in mammals and birds. However, the median of the range of temperatures over which regulation occurs in them is a few degrees below or above or close to 37 ˚C. Surprisingly, this is the temperature around which normal body temperatures of all mammals and birds are clustered. It demonstrates that thermoregulation in any organism, whether it is a monotreme, marsupial, placental, avian, insect or a plant, occurs about the temperature at which c_p of water is minimum. As such, the temperature of c_p minimum of water finds every reason for it to be called thermoregulation point and 37 °C may be considered as its numerical value.

Another interesting observation that deserves special attention in this connection is elaborated here. Water, under normal conditions, is available in liquid state between 0 °C and 100 °C and 1/e of the difference between its normal boiling and freezing points is equal to 36.8 °C (here e is the base of the natural logarithm). 36.8 °C may be called relaxation temperature or temperature constant of water molecules in the bulk sample of water in analogy with damped harmonic motion, time variation of radioactivity and working of LR and CR circuits. 36.8 °C is close to the temperature at which a) viscous forces in water and hence its viscosity become one e^{th} of their maximum **(Cho et al., (1999))**, b) viscosity of water is independent of pressure variations **(Cho et al., (1999))**, c) isothermal compressibility of aqueous solutions is minimum **(Stanley et al., (2007)),** d) flow of blood is nearer to that of ideal fluids because of low viscosity and small isothermal compressibility of water in it so as to maintain arterial blood pressure at optimum level **(Wright (1955))**, e) mammalian and avian enzymes have tightly folded, highly ordered three dimensional structure and enzymatic activity in them is the greatest **(Murray et al., (2000), Rama Rao and Suryalakshmi (2000))** f) normal body temperature of many homeotherms including humans, g) thermoregulation point of living organisms, h) cold stored red blood cells regain their metabolism when incubated in vitro with glucose **(Wright (1955))**, i) coagulation time of normal whole blood of humans is optimum **(Wright (1955))**, j) oxygen carrying ability of blood is maximum **(Ganong (1999))**, k) molecules of carbohydrates and many other biological compounds have proper dimensions and structural similarities with water for definite interactions to occur between them **(Warner (1962))** and l) animals like lizards choose to stay **(Schimdt-Nielson (1994)).** Further, it is observed that mammals and birds feel highly comfortable, both indoors and outdoors, when the temperature of their surroundings is between 23 °C and 24 °C. Interestingly enough, (1-1/e) of 36.8 °C is 23.3 °C and it represents their comfort point temperature. These facts exemplify the physiological and biochemical significance of 36.8 °C and suggest that it bears a strong relationship with the structural characteristics of water in bulk.

This report on the role of heat capacity of water in thermoregulation and a review of characteristics of water around 37 °C and all other properties of water prompt us to conclude that water, as if all living organisms and the earth as a whole collectively and singly requested it, modifies its bulk structure appropriately and assumes various properties as required for the survival and well-being of life on the earth. This observation gives additional strength to the age-old axiom that water is life. However, thorough investigation on water and fluids in the bodies of animals and plants must be conducted to know the exact structure of water in bulk and its response to changes in temperature to account for the unique behaviour of water, particularly near 37 °C.

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