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WILDERNESS ESSAY

Melting Ice and Boiling Water in the Mountains: A History and Physics Essay

This wilderness essay will review historical and physics aspects of melting snow or ice to provide liquid water, a long-time problem in the freezing high-altitude environment. The simplest method of heating snow or ice is by burning firewood carried high, but when far above the tree line, mountaineers have used petroleum products, alcohols, or solid fuels in stoves with varying success and difficulties.

Many people know that at high altitude it takes more time to cook some foods because of the lower boiling point of water. Camp life and camp stove observers often recognize the *results* but not the *why* of the thermodynamics of warming snow or ice, the phase change of melting, the resultant liquid water brought to boiling at that altitude, and how this is manifests in the heating timeline. The chronicles of British explorer Eric Shipton (1907–1977) and others will be used to illustrate this facet of wilderness living at high altitude. Shipton, often with H.W. "Bill" Tilman (1898–1977), was well known for his decades of pioneering exploration and mountaineering throughout Asia. In his book *Mountains of Tartary*, Shipton noted that at higher camps on the mountain "producing water from snow takes at least as long as boiling the water when produced."[1](p 557) It is this basic observation, here called the "Shipton Rule," and the physical science behind it, that is the subject of this essay.

Although most mountaineering medical topics are about hypoxia or hypothermia, and the theme of this wilderness essay might seem to be of limited practical value, it must be remembered that there are many types of challenges to living at higher altitudes. A cup of tea can rise to the occasion as paramount for hydration, warmth, and relief. During the first all-women's Himalayan expedition in 1955, Monica Jackson affirmed, "There are times when a mug of tea assumes an importance in a climber's life which is not to be underestimated."[2](p 178)

A simple thermodynamic model will be used to illustrate the science underlying the anecdotal observations of high-altitude explorers. A discussion of heat physics with calculations and charts will evaluate Shipton's observation. Measuring time to melt snow or ice on the mountain, and the shorter time from there to the boiling point of water, has already been given a qualitative answer in the Shipton rule. Doing a quantitative study of his observation might be simple if it were only a single experiment in a comfortable setting at sea level. Instead, a comparison of the results at several selected high altitudes is needed.

Unfortunately, comparative measurements of gross application of heat and time to warm, melt, and boil are problematic when actually performed in the field and at different altitudes. Multiple factors and/or or assumptions for a precise answer must be controlled. The daunting list of issues includes wind; insulation; using the same type stove and pot designs and surfaces under and around them that affect conductive and convective heat losses; thermometer placement; homogenous distribution of temperature within the vessel; ambient temperature and atmospheric pressure variations from altitude, latitude, and weather systems; consistent size and character of chipped ice or scooped-up snow particles; and how many times the pot lid must be lifted to add more of either, among other variables.

Then there is the fuel itself. Shipton once complained in China, on behalf of the stove, about the "indigestible quality of the Urumchi kerosene." [1](p 557) There are far more fuel and stove factors than this essay will evaluate—topics such as stove design and capacity, various fuel and blended fuel qualities and vaporization points, and stoichiometric consideration and efficiency that changes with altitude and temperature. Shipton points to much of the problem here: "Our primus stove ceased to function as the jets were too large for that altitude"[3](p 780) Said another way, the root cause is available oxygen, or rather, available air pressure and its effect on those stove jets. As one of today's premier winter high-altitude climbers, Simone Moro, anthropomorphized from 7700 m (25,262 ft) on Makalu, "the lack of oxygen affected not only our lungs but also the stove's feeble flame, which seemed as tired as we were."[4](p 140)

An experimental study of gross heat application and time could be controlled with difficulty on expedition in the field, but only if done in a very meticulous, scientific way. Instead, this essay will lend credence to Shipton's observation by calculating on paper the net energy needed to perform the tasks. At a given altitude, for constant heat output of the stove, the respective times to achieve warmed and melted snow or ice versus bringing the resultant water to boil will be proportional to net energy transferred. A clue about the results is Shipton's choice of the word "boiling" rather than a fixed temperature.

The main factors for the calculations are temperature and high altitude, with its lower atmospheric pressure and pronounced lowering of the boiling point of water. The Table shows 5 selected heights in both metric and English measure (for historical reasons), beginning with Shipton. In July 1948, while exploring the Bogdo Ola group in Central Asia, he made one of his melting/boiling proclamations near a glacier at a campsite plagued by snow, sleet, and rain at around 3353 m (11,000 ft). As he stipulated, the Shipton rule applied to even greater heights. The next greater height in the Table is 5490 m (18,000 ft), approximating Everest base camp heights and the definition of extreme altitude.[5(pp 4-5)] Higher still is the Death Zone, or *Todeszone*, named in 1952 by Swiss physician and alpinist Edouard Wyss-Dunant.[6(pp110-117)] Today, it tends to get rounded off to 8000 m (26,246 ft) for the 14 highest peaks. Next is Shipton and Smythe's Camp VI at about 8351 m (27,400 ft) on their 1933 attempt on the north slope of Everest.[7(p 388)] Finally, there is the Everest summit itself at 8850 m (29,035 ft), although it is uncertain that cooking has ever been performed there. Even if it has been, an attempted hard-boiled egg would only be partially so.[8]

Standard temperatures are used for calculation. These are helpful in engineering and aviation, but a mountain, as the saying goes, makes its own weather. Temperatures on the mountain may vary widely depending on local, diurnal, seasonal, latitudinal, barometric and humidity-related changes, wind, and more. Snow and ice obtained from the surface of higher glacier areas would have nighttime temperatures close to cold ambient air temperatures as opposed to daytime sun-exposed temperatures or deep subsurface ice melting from pressure.[9] The Table lists temperatures from a standard atmospheric lapse rate for use in the formulas for the model.[10] The initial temperature of the ice is assumed to be that of the standard atmospheric lapse rate temperature at the given altitude. These assigned temperatures will not fit all seasons or mountains, but a guideline must be chosen.

Altitudes and associated boiling points used for the calculations are listed in the Table.[10] Atmospheric pressure affects the boiling point of water; although there are many methods of arriving at a relationship for standard pressures versus altitude, their minor differences are ignored for the physics aspect of this essay. Deviation of the physical parameter of the boiling point of water would be so small that a change in energy or time for heating would be insignificant. For biological systems, on the other hand, low atmospheric pressure at extreme altitude accentuates what would otherwise be a small differential between a high-pressure day and a low one. Weather can sometimes produce more of a pressure fall than does a diurnal difference, seasonal swing, or deviation from a standard atmospheric model. This can raise the effective height of Everest and have a devastating physiological impact on a climber without supplemental oxygen who is at the very limit of survivability for the small fraction of people who might still be alive there in the first place.[11,12]

Definitions, formulas, and calculations

The formulas for the calculations are for pure snow or ice, having neither solutes nor suspended particulates nor being partially warmed by sunlight. The terms "WARM," "MELT," and "BOIL" will be defined as stages of heating snow or ice into boiling water that require different constants for energy inputs.[10] Energy transfers are presented as kJ/kg of ice or water.

Stage WARM is the amount of net energy required to raise snow or ice from an initial cold reading to the melting point. Snow is a form of ice with variable density, depending on compaction and history. Ice is a polycrystalline structure of water. To eliminate variable ice density in the model, a fixed mass is assumed throughout the ice and its subsequent meltwater. The

Table. Five selected heights and physical parameters

Location	*Altitude*	*Temperature*	*Boiling point of water*
Shipton on Bogdo	3353 m (11,000 ft)	–7°C (19°F)	89°C (192°F)
Extreme altitude	5490 m (18,000 ft)	–21°C (–6°F)	82°C (180°F)
Death zone	8000 m (26,247 ft)	–37°C (–35°F)	74°C (165°F)
Shipton camp VI	8351 m (27,400 ft)	–39°C (–38°F)	73°C (163°F)
Everest summit	8850 m (29,035 ft)	–43°C (–45°F)	72°C (162°F)

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