I. INTRODUCTION

Bruno Maddox’s article in the June 2006 Discover Magazine on the Nightmare of Divided Loyalties between Fahrenheit and Centigrade is timely for this age of information. That’s because thermodynamics texts (following pre-1960 papers) by Shannon and Jaynes have increasingly exploited reciprocal temperature (Garrod’s coldness) to capture the essence of temperature as equilibrant more generally (e.g., for spin systems), and as energy’s uncertainty slope i.e., a rate of increase in state uncertainty (information units) per unit increase in thermal energy.

One reason is that thermal physics insights of the last century have shown that reciprocal temperature (1/kT) has applications that temperature addresses less well. In addition to taking on negative absolute values under population inversion (e.g., of magnetic spins), bits and bytes turn 1/kT into an informatic measure of the thermal ambient for developing correlations within any complex system. We show here that, in the human-friendly units of bytes and food Calories, water freezes when 1/kT ≃ 200 ZB/Cal or kT ≃ 5 Cal/YB. Casting familiar benchmarks into these terms shows that habitable human space requires coldness values (part of the time, at least) between 0 and 40 ZB/Cal with respect body temperature ∼ 100°F, a range in kT of ∼ 1 Cal/YB. Insight into these physical quantities underlying thermal equilibration may prove useful for budding scientists, as well as the general public, in years ahead.

II. SAY WHAT?

How does coldness (1/kT, or energy’s Lagrange multiplier) work? Basically heat flows spontaneously (by chance maximizing uncertainty) from low to high uncertainty slopes that range between minus and plus infinity, at which end points reciprocal coldness (kT) asymptotically goes to absolute zero. Thus one thing traditional treatments miss is that negative absolute temperatures are routinely employed (say in the LASER on your DVD reader, or in a domino toppling contest) by moving up the temperature scale, rather than down through zero. Unlikely inversions (negative uncertainty slopes) even add something to the spectator value of gambling.

Taken in reverse, it also means that new correlations between subsystems extract a price in the thermalization of available work. The price decreases if the heat created can be dumped into a colder reservoir, making this observation relevant to molecular engines as well as to humans faced with a warming environment.

III. CALORIES AND BYTES

If (inspired by Bruno’s request for something everyone can relate to) you put coldness (1/kT) into everyday units (Calories and bytes) then you’ll find that water freezes at almost precisely 200 zettabytes per Calorie where zetta is the SI prefix for $10^{21}$. In other words, setting a 200 gigabyte DNA string or computer memory to specified values will convert at least a picoCalorie of available work into ice-melting heat. The same operation may generate less heat, if the heat can be dumped at lower temperature. Hence the bit depth of a digital camera can be made larger if its CCD is cooled, and when it’s cold outside you in principle really can get more work done.

As a result one can say (cf. Figure) that “chilly Europe” at 0°F is about 14 ZB/Cal colder than ice water, which at 0°C is about 15 ZB/Coldr rather than keeping us warm, generates waste heat that we must actively export to survive. Food is less useful then. Thus our “long term survival zone” extends from about 0 to 40 zettabytes per Calorie colder than 98.6°F. Weather persistently outside this range is a fundamental problem for each of us, even though it might not seem so if you mainly see persistent heat or cold from within a temperature-controlled shell.
FIG. 1: In ZB/Cal, 0°C is 200.208 with 0°F up by ∼14, room temperature down by ∼15 and 100°F down by ∼25, giving us a ∼40 ZB/Cal habitable range upward from 1/kT internal.

IV. OTHER BENCHMARKS

Boiling water’s coldness is around 50 ZB/Cal below ice water’s 200 ZB/Cal absolute. Even lower uncertainty slopes occur in the 9 ZB/Cal of our sun’s surface, the 0 ZB/Cal of a spin system with equal up/down populations, and the -7 ZB/Cal of a He-Ne LASER’s 99% excited-Ne inversion. Familiar things with really high coldness include dry ice at 35 ZB/Cal above freezing, liquid nitrogen at nearly 800 ZB/Cal absolute, liquid helium at over 13000 ZB/Cal, and our universe’s blackbody ambient at around 20000 ZB/Cal. Thus local issues notwithstanding, the larger world around us is pretty cold! The strange behaviors of liquid nitrogen and helium also reflect high uncertainty slopes, and thus the extreme increases in state uncertainty that result from adding small amounts of heat.

FIG. 2: In Cal/YB, 0°C is 5 with 0°F up by $\frac{1}{3}$, room temperature up by $\frac{1}{5}$, and 100°F up by $\frac{2}{3}$, giving humans a ∼1 Cal/YB habitable range downward from our internal kT.

V. SO WHAT?

In context of the Discovery article’s request for some resolution to the nightmare, energy’s uncertainty slope could therefore be the “hero” that Bruno was looking for in the face of summer days with respect to which our blood must run cold. More to the point, telling students about physical in addition to historical units for the parameter that equilibrates on thermal contact could further prepare them to recognize other cross-disciplinary connections. Such connections (in cross-cutting fields like nanoscience, informatics, and astrobiology) will likely prove useful for tackling the multiscale challenges that our species faces in the days and millennia ahead.

Of course given our cultures’ tenacity for repetition, plus the fact that kT is a useful measure of energy fluctuation in quadratic systems (e.g. kT is also 1/40 eV/nat at STP), it is unlikely that bytes per Calorie will become a routine part of the morning weather report anytime soon. In that context, perhaps the reader can instead find a mnemonic measure of kT (cf. Fig. 2) to assist in the clarifying move from historical, to natural, perspectives on that continuum from cool to warm and beyond.

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