Comment on the Word "Cooling" as it is Used in Beam Physics

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Abstract: Beam physicists use the word "cooling" differently than it is used by the general public or even by other physicists. It is recommended that we no longer use this term, but replace it with some other term such as: "Phase Density Cooling" (PDF) or "damping", or alternatively "Liouville Cooling", which would make our field more easily understood by outsiders.

Keywords: Beam cooling, phase space, Liouville, beam damping

PACs: 29.27.-a, 29.27.Eg. 41.75.-i, 41,75,Lx

Many millions of years ago, our ancestors understood that there were hot objects and cold objects. Surely they also understood when something was heating up (say over a fire or sitting in the sun) and when something was cooling down (say due to shade or wind). They must have developed signs, and later words, to describe the phenomena. In English, the word "cooling" has been in use for thousands of years.

This concept is very much with us, for it is deeply ingrained in our psyche as a result of common experience. Each of us, from early childhood on, knows about "hot" and "cold" (perhaps the very second, or third, word that a child learns). Throughout our lives we have a deep emotional understanding of hot, cold, and cooling.

The development of thermometers took this basic understanding and made it quantitative. Thermometers allowed a rather accurate measurement of temperature and, therefore, a rather accurate meaning to the concept of "cooling". It was now possible to ascribe units to the concept and to numerically evaluate it experimentally. With the advent of thermodynamics in the 19th century, physicists were for the first time able to make the concept of temperature very precise with the use of ideal Carnot cycles, (introduced in 1824) and so, therefore, made very precise the concept of “cooling”. [1, 2, 3]

The development of statistical mechanics, again in the 19^{th} century, provided a molecular basis for thermodynamics. If the distribution function in velocity space was Maxwellian (concept introduced in 1860) then the results of thermodynamics could be explained on a molecular level. [4] For example, if a container of gas was put in a refrigerator, the physical size (except for negligible contraction) remains the same, but the velocity of molecules is reduced (although the distribution is still Maxwellian). In this case, statistical mechanics would say that the Maxwellian describing velocity space is narrower, that the density in phase space is increased and the gas is cooler. [5]

Another example might be the adiabatic expansion of a gas leading to cooling of the gas according to the well known law that PV^{γ} remains a constant. Statistical mechanics describes this process as a narrowing of the Maxwellian and an increase or decrease of phase density to a degree that depends upon the value of γ, which depends on the gas in question. (Only for $\gamma=3$ is phase density preserved.)[6]

Even at the forefront of physics; namely while making Bose-Einstein condensates down to tiny fractions of a degree, a thermodynamic concept is employed; namely evaporative cooling. [7] In this case, just as in the evaporation of water, the more energetic molecules leave the condensate and so the temperature of the condensate is reduced. Statistical mechanics simply describes this process as a narrowing of the Maxwellian with a reduction in phase volume, but not as an increase in phase density.

In beam physics it is very different. We only consider a beam as being cooled if the density in six dimensional phase space is increased. Let me give some examples of what we consider *non-cooling*.

Consider the case where there are beam scrapers so particles of larger transverse oscillations are scraped off. The transverse average energy certainly goes down, just as in evaporative cooling. We beam physicists would certainly *not* call this “cooling”.

Consider a transport channel in which the beam is rather dilute (so space charge effects can be neglected) and the amplitudes are small (so a linear approximation is valid). Neither of these approximations is necessary, but they make the discussion simpler. When the beam goes through a region in which it expands, and because collisions are negligible, the transverse velocity, even energy, is reduced. Everyone else would call this “cooling” as the transverse temperature has certainly gone down. We beam physicists would certainly *not* call this “cooling”.

Consider a system that transfers phase volume from one degree of freedom to the other, for example, a coupling resonance. If the dynamics can be described by a Hamiltonian, and in most cases this is true, then, again, we would *not* consider this “cooling”, but simply a transfer of phase space.

We beam physicists carefully reserve the term ”cooling” for non-Hamiltonian processes where Liouville’s theorem (1838) is violated; i.e., where there is an increase in phase space density. [8,9] There are a good number of methods for “cooling” such as: Stochastic Cooling, Electron Cooling, Radiation Damping, Laser Doppler Cooling, Energy Loss Foils, etc. [10] I suggest that we call these processes for what they are; namely “Phase Density Cooling (PDC)”, or more simply, “damping”, or alternatively “Liouville Cooling”.

Then, reserving the word “damping”, or “Liouville Cooling” for violations of Liouville’s Theorem, we might use the term “cooling” in the same way as all the other physicists use it; namely for a simple reduction in transverse (or longitudinal) oscillation energy. This change would remove some confusing terms from our field and, consequently, make our work more accessible to other physicists and students.

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* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. DE-AC02-05CH11231.

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