IRREVERSIBLE PROCESSES IN QUASI-EQUILIBRIUM

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Abstract

We develop the ideas of R.S. Silver, who in 1971 published a textbook *An Introduction to Thermodynamics*, subtitled *with new derivations based on real irreversible processes*. Silver's point was that many irreversible thermodynamic processes are in a state of quasi-equilibrium. In a paper presented at the 1994 MaxEnt conference Silver emphasised that the Seebeck, Peltier and Thomson thermoelectric effects are all easily understood in terms of a passive flow of electrons *around* the circuit whilst heat flows *through* the circuit. Silver highlighted the analogy between these thermoelectric effects and the gravity-driven domestic hot water systems that were common in British houses until the 1960s, with a boiler on the bottom floor. This paper begins with a description of the 1954 system installed in the first author's childhood home, and provides estimates of the convective rate of fluid flow and the thermal efficiency. In this system there is a passive flow of water *around* the circuit whilst the heat flows *through* the circuit. We then provide an analogous account of the thermoelectric Seebeck effect. Many textbooks give a simple derivation of the thermoelectric relations, due to W. Thomson (later Lord Kelvin), but promptly disparage it as giving right answers by a wrong method. The present viewpoint justifies his simple derivation; more complicated derivations depend on superfluous extra assumptions and are unnecessary.

A different example of an irreversible quasi-equilibrium process is the hydrodynamical shock front. Supersonic fluid having velocity v_1 upstream of the shock passes through a dissipative region until the post-shock flow settles down to the new equilibrium state of velocity, v_2, as required by the Rankine-Hugoniot conditions. This dissipation is caused by additional stresses τ and, since the fluid has to pass through every intermediate velocity $v_1 \geq v \geq v_2$, the stress $\tau(v)$ can be determined as a function of the velocity. If we know the physical nature of the stress, moreover, we can compute the structure of the shock as a function of position through the dissipative region. Two cases are solved. First, for ordinary gas viscosity we find that the shock becomes narrower as the upstream Mach number increases. Second, in the case of an anomalous bulk viscosity quadratic in $\mathrm{div}(\boldsymbol{v})$, as proposed by Richtmyer & Morton (1967) in the context of numerical hydrodynamics, the dissipation region turns out to be of finite thickness; remarkably, this thickness does not depend on the Mach number.

As a final example of a quasi-equilibrium flow process, we study the energy dissipation in a hydraulic jump as a function of the upstream Froude number.