The second possible arrangement is similar to a gravity torsion balance (Fig. 2). The angular momentum generated by the force (3) produces in the case of free rotary motion an angular acceleration $\ddot{\phi}$ of $\approx 10^{-18}$ rad s $^{-2}$ for ω , Ω , ρ and R as above and a distance of 40 cm between the two disks. This would yield a change $\Delta\phi$ of about 10^{-8} rad after two days. Free rotary motion (vanishing directing moment) can be attained by a suitable magnetic suspension. For non-vanishing directing moment, the Coriolis force (3) could be brought into resonance with the eigenfrequency of the torsional oscillation by an appropriate change in the rotation of the cylinder.

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Cosmological Foundations of Entropy-Free Thermodynamics

THE origin of irreversibility in nature, as implied by several authors¹⁻⁴, is cosmological rather than local. Although these studies infer that the expansion of the universe generates time asymmetry no attempt has been made to apply this general conclusion for establishing new foundations to thermodynamics. I wish to show how the expansion of the universe can serve as a point of departure in laying a new basis for the second law of thermodynamics. A new, entropy-free thermodynamics can thus be constructed in which the second law is derived from the first law.

First, I consider Tolman's⁵ homogeneous non-static cosmological models filled throughout their entire extent with perfect fluid or black-body radiation. For an adiabatic expansion of space Tolman's result can be expressed as

$$\dot{w}_{ad}^{cosm} = p_0^c \frac{dv_0}{dt} = -\frac{du_0}{dt} > 0 \quad (1)$$

where p_0^c is the proper hydrostatic (or radiation) pressure, v_0 is the specific volume and u_0 the specific internal energy. Therefore, before applying the first law of thermodynamics, a local observer, co-moving in non-adiabatic, non-uniform expanding universe (with local small volume and velocity perturbations from a uniform expansion rate) must add $\dot{w}_{ad}^{cosm}$ to du_0/dt to make the proper internal energy appear conserved in isolated systems; that is, the general mechanical term in the first law of thermodynamics is decomposed into $\dot{w}_{ad}^{cosm}$ with mechanical work $p dv_0/dt$ due to local volume perturbations. When this is done I find that the first law of thermodynamics (written here for conservative forces $\vec{F}_k$ and non-adiabatic processes with real, viscous, non-elastic fluids and negligible special relativistic effects) must take the form

$$\begin{aligned} \frac{d_1 u_0}{dt} = & -\dot{w}_{ad}^{cosm} - \frac{1}{\rho} \bar{\pi} : \text{grad } \vec{v} = \frac{du_0}{dt} + \frac{1}{\rho} \text{div } \vec{J}_q + p \frac{dv_0^L}{dt} \\ & - \frac{1}{\rho} \sum_k \vec{F}_k \cdot \vec{J}_k = \frac{du_0}{dt} - \frac{d_e u_0}{dt} \geq 0 \end{aligned} \quad (2)$$

where $\bar{\pi}$ is the viscous stress tensor, $\vec{v}$ is the centre of mass velocity vector, ρ the total density, $\vec{J}_q$ the total heat flux, and $\vec{J}_k$ the diffusion flux of component k ($k=1,2,\dots,n$, where n

represents total number of chemical components present). $d_1 u_0/dt$ therefore results from "internal" processes while $d_e u_0/dt$ (as defined by equation (2)) represents energy interactions with the surroundings (it might therefore be positive, negative or zero).

Thus in small isolated expanding regions with real, viscous media, a dynamic equilibrium can be established when

$$\dot{w}_{ad}^{cosm} = \left(-\frac{1}{\rho} \bar{\pi} : \text{grad } \vec{v}\right)_{ad}^{cosm} > 0 \quad (\text{that is, in non-equilibrium}$$

$$\text{processes } -\frac{1}{\rho} \bar{\pi} : \text{grad } \vec{v} > \dot{w}_{ad}^{cosm} > 0). \quad \text{The positive viscous}$$

dissipative term (which may be approximated by $(\mu/\rho)\Phi_v$, where μ is local Newtonian viscosity and Φ_v the dissipation function) represents irreversible degradation of mechanical to internal energy while the reversible $\dot{w}_{ad}^{cosm}$ becomes irreversible as far as space keeps expanding. Consequently, in terms of internal energy (rather than entropy) equation (2) is analogous to classical formulations of the second law⁶. Equation (2) can also be recast as

$$\rho \frac{d_1 u_0}{dt} - \text{div } \vec{J}_{u_0} = \rho \frac{d_1 u_0}{dt} \geq 0 \quad (3)$$

which is analogous to the balance equation for entropy but where $\vec{J}_{u_0}$ represents flux of internal energy due to thermal, mechanical and external energy exchanges (that is, the flux $\vec{J}_{u_0}$ arises from the term $d_e u_0/dt$ in equation (2)). An entirely new and entropy-free thermodynamics can thus be constructed if one independently defines a scalar temperature (for instance, by the product of the pressure of radiation and the squared (4,4) component of the metric⁴). Furthermore, one is no longer dependent on a number of postulates inherent to classical formalism; for example, the existence of entropy and its properties, and the so-called Loschmidt paradox.

In the actual universe the effects of the expansion are mainly concentrated on very small non-expanding regions in which they penetrate through a large number of intermediate stages involving non-expanding material bodies. Therefore a direct estimation of $\dot{w}_{ad}^{cosm}$ from the dynamics of real, non-uniform, cosmological models is not yet possible. Nevertheless, whatever scale one chooses for a thermodynamic analysis we must first examine the universal scale (that is, isolated systems do not exist, cf. Mach principle). The addition of $\dot{w}_{ad}^{cosm}$ takes into account the actual mechanism by which local energy is eventually "lost" in the universal "sink" of intergalactic expanding space, thereby giving rise to the "arrow of time"¹. The theory I have postulated immediately suggests a possible explanation for the serious contradictions inherent to statistical formalism of entropy increase in large portions of our non-equilibrium expanding universe^{4,7}.

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