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Thermo-Gravitational Equilibrium

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Abstract: Acknowledging that what is currently defined as 'pressure' should not have reason to exist without the existence of a gravity field, the connection between thermodynamics and gravity can be easily made clear. Comprehensive *thermo-gravitational* equilibrium conditions may be defined without raising any doubt about the validity of the conventional *thermodynamic* and *gravitational* equilibrium conditions, being the latter ones consistent with the spontaneous tendency, respectively, towards *lateral* disorder and *radial* order, jointly resulting from the existence of the gravity field. Therefore, in a whole system subjected to its own gravity field, or in any isolated large fraction of it, a thermal gradient would be associated at equilibrium to the pressure and density gradients.
Keywords: gravity, thermal gradients.

INTRODUCTION

Looking at the atmosphere - that is, at that portion of the self-gravitating system Earth in which spontaneous phenomena patently tend to re-establish at once thermodynamic and gravitational equilibrium - it is easy to argue that processes considered in thermodynamics ensue from the existence of the gravity field. It happened that thermodynamics has been developed ignoring such an evidence, so that any 'traditionalist' would blame a skeptic who should raise a doubt about the 'external' role played by gravity in thermodynamics, maintaining that the state of a system is completely described by state parameters that are defined leaving out of consideration the gravity field. After all, the traditionalist can rely on the proven effectiveness of his premises, since they turn out to be fruitful enough to be judged true, or at least the most convenient.

I intend to show here that both the skeptic and the traditionalist are in a measure right and that we would get everything to gain by conciliating their points of view.

THE EQUILIBRIUM STATE OF A SELF-GRAVITATING SYSTEM

Let us consider the molecules contained in a volume element of a quiet region of the Earth's atmosphere. To keep up their room, these molecules (whose number remains substantially constant even if some of them continuously cross the ideal enveloping surface) have to withstand the action exerted from the ones surrounding the enclosing ideal surface. This action cannot be equal in every direction since it depends on the existence of Earth's gravitational field. The maximum inequality is the one between the 'upwards' and the 'downwards' directed actions. When dealing with small regions of the atmosphere, we may consider *reasonable* to disregard the above inequality. Even if such a simplification may disguise the very *raison d'être* of what we call 'atmospheric pressure' – that is, *the existence of the gravity field* - it turns out to be *convenient*, for it allows, among other things, to treat the reciprocal action between the molecules located within and outside the volume element – that is, the *pressure* - as a scalar quantity.

The state of the content of the ideal envelope does not change if, leaving its location unchanged, the action of the surrounding molecules of the atmosphere is replaced by the one exerted by the molecules making up the walls of an enough rigid and impervious material container. After all, as stated by Newton, "*the container of a fluid is the limit within which it is included, both the surface of the body – wood or glass, for instance – that contains the fluid and the surface of an exterior portion of the same fluid that contains an internal portion*" (1). If the container is made of wood, or glass, or of some other 'solid' substance, one may find attractive considering the pressure as an average effect of molecular collisions with the container walls thought of as a 'continuous' obstacle. When dealing with a small container, one may find it *reasonable* to disregard that the frequency of collisions on the top should be different from that on the bottom. The ensuing figure of pressure turns out to be *convenient,* for its definition, among other things, does not involve any connection with the gravity field.

When displaced across the equipotential surfaces of the Earth's gravitational field**,** the above *small* fractional system, consisting in a 'canned' atmosphere sample, preserves its original equilibrium state. Therefore, its state that originates from the existence of the gravity field seems to lose its dependence from gravity. During the displacement, if the gravity acceleration *g* does not change from place to place, even the disregarded slight difference between 'up' and 'down' ensuing from the gravity gradient remains unaltered; if *g* changes, its even more slight modification may be neglected.

On the contrary, a *large* fractional system, when displaced in a site where the gravity acceleration has a value different from that of its original location, could be characterized by a pressure gradient macroscopically different from the original one. The local increases and decreases of pressure, and then of temperature, occurring when *g* changes, would not allow the preservation of the original equilibrium state if the zeroth principle of thermodynamics (stating that in an isolated thermodynamic system two phases in thermal contact reach equilibrium at the same temperature) has to be considered valid also for a system endowed with a macroscopic pressure gradient at equilibrium. So, to justify the permanence of equilibrium, one could be reasonably inclined to believe that the equilibrium state in such a system must be characterized by the joint existence of a pressure, density and *thermal* equilibrium gradients, all changing gradually while *g* changes. The existence of this thermal gradient would not exclude the validity of the zeroth principle of thermodynamics within every layer of a self-gravitating system embodied by two not too distantly spaced equipotential surfaces.

Of course, the above conclusion should be in agreement with what occurs in nature and supported by experimental evidence. Unfortunately, most of the observable natural thermal gradients are currently explained as evidence of departures from equilibrium, while possible equilibrium thermal gradients in small isolated systems are apparently unperceivable and nobody seems to be interested in making investigations to ascertain their existence. Yet, it seems to be enlightening with what currently happens in our atmosphere. It is well known that there *temperature homogenization is prevented by the substantially adiabatic (i. e., isentropic, if we assume reversibility) character of transformations spontaneously occurring in air masses that occasionally are compelled* *to move up and down*. In short, looking at the atmosphere, we notice the spontaneous tendency to the restoration of an equilibrium thermal gradient.

Even if the far lower mobility of the molecules making up the so called ‘solid Earth’ does not allow fast achievement or restoration of equilibrium conditions, I am reasonably tempted to generalize the above spontaneous tendency towards equilibrium to the whole self-gravitating system made up of the Earth together with its fluid envelope. In an isolated and motionless self-gravitating system in equilibrium, every volume element containing the same amount of the same component should be characterized by the same *heat content*. Since any decrease of gravitational energy has to be compensated by an increase of internal energy, and vice versa, in a portion of the system characterized by homogeneous composition, even the amount of internal energy plus the potential gravitational energy per unit mass should remain constant whatever the distance from the centre of gravity (2). Therefore, in a self-gravitating system in equilibrium as a whole, for a portion *of homogeneous composition* we should have, independently from its location,

$$U_c = \text{constant}, \qquad [1]$$

and

$$U_c + U_p + U_g = \text{constant}, \qquad [2]$$

(where U_c and U_p are, respectively, the heat content and the internal potential energy, and U_g the potential gravitational energy, per unit mass).

Moreover, we will have homogeneity of the entropy S per unit mass where

$$S = \text{constant}. \qquad [3]$$

Condition [3] is the only one that can be valid for a whole heterogeneous system such as a self-gravitating system *made of phases of different composition* and will be considered here as the equilibrium condition for the whole system.

In agreement with the symmetry of the gravity field, we should expect a spontaneous tendency of the whole self-gravitating system to attain *lateral* isotropy, i. e. isotropy along each equipotential surface. Of course, the discrete nature of matter can allow nothing but a statistical isotropy, suffering from fluctuations in space and time below a certain scale. Actually, the statistical *lateral* isotropy results from a random distribution of material particles (and of aggregation of particles, such as crystal grains), of interactions among particles (and among their aggregations), and of motion of particles, giving rise to statistical homogeneity of composition, pressure, temperature, and internal energy over a certain scale that I will call the *significant scale*.

It is well known that in fractional isolated systems made up of fluid phases, temperature and pressure usually may attain and preserve with time lateral homogeneity, *together with lateral homogeneity of composition*. On the contrary, *during human observation times*, temperature and pressure may attain and preserve lateral homogeneity in many systems (especially those including ‘solid’ phases), even though the composition remains laterally non-homogeneous. Apparently, what occurs in the latter systems seems to support the assumption that gravity has no influence on the setting up of thermodynamic equilibrium. Actually, in these cases, what one perceives as a system enduring in its conclusive equilibrium state is a system out of equilibrium in which the spontaneous evolution towards equilibrium is still going on at a more or less imperceptible pace. After all, we have evidence that very long geological times rub out any difference in behaviour between solids and fluids, allowing, among other things, the spontaneous compaction of sediments through the upwards migration of fluids originally filling their pores.

Suitable mixing and unmixing of different components, reactions among them, phase changes, and reordering of matter, operate jointly to bring to equilibrium both a whole self-gravitating system and every fractional isolated system. Summing up:

- the equilibrium, as suggested by the isentropic processes we observe in our atmosphere, should be characterized by *homogeneity of entropy per unit mass* in the whole self-gravitating system,
- homogeneity of temperature, composition and pressure along every equipotential surface should be considered as a necessary equilibrium condition,
- a temperature gradient across the equipotential surfaces should accompany changes of composition and/or density.

In short, the intrinsic connection between gravity and thermodynamics can be made explicit just by substituting the tendency towards *thermo-gravitational* equilibrium condition to the tendency towards the *thermal* equilibrium condition of classical thermodynamics: in other words, considering the spontaneous tendency towards uniformity of entropy per unit mass *both along and across the equipotential surfaces of the gravity field,* instead of the tendency towards uniformity of temperature.

CONCLUSION

Undoubtedly, a number of processes can be still advantageously investigated and described considering as unrelated the tendencies to mechanical and thermodynamic equilibrium. Anyhow, the above discussion shows that the classical thermodynamic approach cannot be extended to too small fractions of a self-gravitating system (below the above defined ‘significant scale’, such as single crystals, or molecules, or clusters of few crystal grains making up a polycrystalline aggregate or of few molecules making up a fluid), and too large systems (exceeding the limits of a self-gravitating system). Moreover, any process of geological or cosmological duration, together with *all* those of shorter duration in which the joint tendency to thermodynamic and gravitational equilibrium plays a basic interlaced role (such as convection), may be conveniently investigated and described only by acknowledging that a self-gravitating system, and every isolated fraction of it, tends spontaneously towards the thermo-gravitational equilibrium above defined.

If the existence of an equilibrium thermal gradient will be verified by further evidence, the suggested approach could lead to huge consequences. Anyhow, it seems already well grounded on the recognition of unquestionable empirical evidence of the inseparableness of Chance and Necessity, expressed by the interweaving of the spontaneous tendency towards lateral disorder along every equipotential surface of the gravity field, and towards a well determined order in directions normal to the same surfaces, ensuing from the gravity gradient. Moreover, it involves the scaling down of the meaning of the word ‘*Welt*’ – that should not refer to the whole Universe but to every single celestial body thought of as isolated– in the Clausius statement: “*Die Energie der Welt ist konstant, die Entropie der Welt strebt einer Maximum zu*”(3).

Because of one of the simplifying premises inherited from classical thermodynamics – that is, the assumption that the principles of mass conservation and energy conservation are valid separately - the occasional or consequential nature of mass-energy transformations actually occurring even in a self-gravitating system, such as our Earth, remains a challenging problem to be solved. On the other hand, the revealed relationship between gravity and distribution of mass and energy in a self-gravitating system seems to give a hint of a possible relativistic approach that needs not concern us there. Perhaps one should consider the gravity field of a celestial body responsible for, or consisting in, a spontaneous tendency towards a local equilibrium curvature of the spacetime.

POST SCRIPTUM – It must be borne in mind that at present, to describe the equilibrium state of any volume element of a self-gravitating system, we are forced to have recourse to a sort of collage of intrinsically independent non-polar and polar mathematical quantities. One may expect that the inner connection betweeen thermodynamics and gravity will be hardly accepted until the lack of an organic mathematical description will persist.

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