Collective Phenomena
1978, Vol. 3, pp. 9–24

PHYSICAL BASIS FOR COMPLEX SYSTEMS—SOME PROPOSITIONS RELATING LEVELS OF ORGANIZATION

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(*Received November 25, 1977*)

Complex systems in nature may be hierarchically linked by five statistical mechanical propositions. A scientific scaffold is thereby established that provides linkages from fundamental particles through all organized levels to cosmology.

INTRODUCTION—SOME PROPOSITIONS ABOUT SYSTEMS

The body of pure physics is extended to complex systems found in nature by the following level bridging propositions.†

1) A deterministic continuum description of homogeneous matter must include dissipation for consistency. In this sense, mechanics implies thermodynamics.

2) An ensemble of interacting atomistic entities (henceforth to be referred to as atomisms) at any organizational level acts like a continuum, at an appropriate space-time scale.

3) A fluid-like continuum at any organizational level becomes dynamically unstable locally at some sufficient scale of stress, creating a spectrum of patterned structures of superatomisms that are freely mobile in broadly extended media.

4) The physics of interacting superatoms, including their internal processes, appears as ad hoc at their level, even though derivable in principle from the physics of the lower atomistic level. However the Liouville theorem and the existence of a distribution function for the translational degrees of freedom in an ensemble of these superatoms is directly transferred from the lower level.

5) The dissipative nature of a continuum, as required by Proposition 1, implies fluctuations at a lower level of organization.

These propositions link the hierarchical systems found in nature, and imply a statistical mechanics–irreversible thermodynamics for each level. Earlier presented only as a conjecture,[1] the physical framework for natural systems was represented by the notion that they were organized into successive levels of atomisms (A) and continua (C). An ensemble of atomisms forms a continuum. The continuum becomes dynamically unstable and forms a superatom. The line . . . –A–C–A . . . ends when it becomes singular at either end.

PRELIMINARY REMARK

Statistical mechanics, since the theoretical attack begun by Clausius and Maxwell, has been regarded as a study of the relationship between the molecular-atomistic nature of matter and the macroscopic nature of matter in bulk[2] regarded as an ensemble of such interacting atoms.† But if we assume that there is a deeper reductionism implicit in the corpus of physical law, then the application of a statistical mechanics to other levels of discerned behaviour‡ is in order.

† While largely described in a classical spirit, these propositions are essentially neutral with regard to quantum effects.

† The word atom will refer interchangeably to atom or molecule.

‡ Including the hydrodynamics of fluids, planetary atmospheres and lithospheres, biological organisms, human societies, ecology, stellar atmospheres, galaxies.

Such an extension was clearly foreshadowed by Einstein's theory of Brownian particulate motion, in which gross cellular fragments of material already can be seen to share the underlying atomistic motion. A rationale is offered for the extension of statistical mechanics of interacting atoms or superatoms to all levels of organization.

JUSTIFICATION FOR THE PROPOSITIONS

Proposition 1: On the Necessity of Thermodynamics for Continuum Fluids

The connection between Newtonian mechanics and thermodynamics has generally been made by considering systems of particles interacting through conservative force fields. The equations of motion for such systems lead to unique, time reversible, microscopic solutions satisfying the conservation laws of mass, momentum, and energy. In this particle picture, the macroscopic or thermodynamic phenomena of dissipation, irreversibility, and the Second Law emerge from probabilistic, statistical, or information-theoretic arguments.

A complementary view of the connection is provided by considering continuous fluid media. The conservative force field of the interacting particle picture is replaced by an elastic pressure field, p, which is a definite function of the density ρ or volume v (per unit mass), $v = 1/\rho$. The pressure is derivable from an elastic internal energy function e (per unit mass) which also is a function of the volume v.

$$p(v) = -\frac{de(v)}{dv} \qquad e(v) = -\int^{v} p\,dv$$

The Newtonian equations of motion, in Eulerian form, are then a set of nonlinear partial differential equations which are direct expressions of the conservation of mass and the conservation of momentum, and from which energy conservation may be derived. The only forces arise from pressure gradients.

A study of the solutions of these equations leads to a number of conclusions.

1) A Newtonian conservative mechanical description of a continuous fluid is necessarily incomplete, except for the case of a Hooke's law medium, one in which the pressure p is a linear function of volume v.† In a nonlinear medium, a disturbance propagates with speeds that vary with the disturbance amplitude. Solutions then become singular at places where different amplitudes arrive simultaneously, and threaten to become multivalued. This has been known since the time of Stokes.[3]

2) Single valued solutions can be pushed through the singularities by allowing discontinuities or shocks to build up. The motion of the shock fronts is determined by applying mass and momentum conservation across the fronts. It is then found that energy (here, the sum of kinetic and internal elastic) is not conserved across the shock front. Thus, in the Newtonian conservative description of a continuous field, the conservation laws of mass, momentum, and energy cannot all be satisfied across a shock front. This has been known from the time of Hugoniot[4] and Rayleigh.[5]

3) Two kinds of shocks can arise in the solutions of the equations. In a "normal" shock, energy is lost as fluid flows through a shock front. In an "antishock", energy is gained. Only normal shocks are generated directly from continuous initial conditions. Solutions containing antishocks exist following discontinuous initial conditions such as those used in shock tubes and those that arise from a collision of two normal shocks, a situation that can generally be expected to evolve from smooth initial conditions.

At all such times that solutions containing antishocks can be generated, it is also possible to continue the solution using only normal shocks. At such times, then, the solution becomes not unique and Newtonian determinism is lost. These notions have been discussed by von Neumann,[6] P. Lax,[7] and others.

In summary, Newtonian mechanics fails when applied to continuous, homogeneous, nonlinear media. Solutions become singular. When solutions are pushed through these singularities using mass and momentum conservation, then energy is not conserved. Solutions generally become nonunique.

A minimal way out of these difficulties can save energy conservation and determinism (uniqueness),

† The motion of a Hooke's Law medium is the superposition of noninteracting harmonic acoustic waves. The Hamiltonian separates into the sum of oscillator terms, one for each mode. This is the continuum equivalent of the particle picture case of a set of noninteracting particles. In both cases, there can be much motion, but nothing is happening or changing. Each particle or each phonon (acoustic mode) performs its own inertial motion. Structure and process do not arise without interactions. Nonlinearity is required.

without yet becoming involved with the detailed mechanisms responsible for the failure of the Newtonian description. These detailed mechanisms are discussed below in connection with Proposition 2. They are described by "smoothing" terms added to the equations of motion in order to prevent formation of singularities.

The minimal extension of the Newtonian description that satisfies all three conservation laws of mass, momentum, and energy, requires that the internal energy function, e, must depend not only on the volume v, but also on a new nonmechanical parameter s, one that is conserved along the continuous portions of a solution, but is not conserved across a shock front. That is

$$e = e(v,s)$$

Along a smooth part of the solution, the s value for a piece of moving fluid is constant and the internal energy varies only due to pressure forces (as work). Thus the derivative $-\partial e/\partial v$ is still the pressure. The other derivative of the energy function, $\partial e/\partial s$ is another new nonmechanical variable, T. The differential relations are then

$$de = -p\,dv + T\,ds$$

$$p = -\frac{\partial e(v,s)}{\partial v} \qquad T = \frac{\partial e(v,s)}{\partial s}$$

In order that solutions also be deterministic, following uniquely from initial conditions, it is required that antishocks be disallowed. All allowed solutions then contain only normal shocks, and mechanical energy is only lost across shocks, never gained. The loss of mechanical energy, as a unit mass of fluid crosses a shock front, is

$$\int T\,ds = \langle T \rangle\, \Delta s.$$

where Δs is the change in s across the front and $\langle T \rangle$ is a T value intermediate between T values on both sides of the front. Thus, the condition of mechanistic determinism, uniqueness, is equivalent to the conditions

$$\langle T \rangle \Delta s > 0$$

across a shock front. It follows that no two T values can have opposite signs, for if they did, the possibility that $\langle T \rangle = 0$ would always arise, and the above conditions would be violated. Thus, the parameter T must satisfy either $T \leq 0$ or $T \geq 0$. Selecting the sign of T such that it is nonnegative,

$$T \geq 0$$

it then follows that

$$\Delta s \geq 0$$

where equality holds along continuous portions of the solutions and the inequality applies across the shock fronts.

In this minimal extension of the Newtonian description of a continuous fluid, the satisfaction of the First Law, energy conservation, demands the introduction of the nonmechanical parameters, s, entropy, and T, temperature. To satisfy uniqueness, mechanistic determinism, demands the nonnegativity of T and the dissipation and irreversibility expressed by the increase of entropy.

Proposition 2: Interacting Atomisms Form a Continuum

The Proposition is a classical statistical mechanical theorem in the case of atomisms that quickly equipartition energy among internal and translational degrees-of-freedom, although there is considerably more obscurity in the proof for atomisms that exhibit long-range interaction as well as short-range collisions.[8,9]

In order to provide a constructive justification for this Proposition, the assumption has to be made that the ensemble of atomisms interact through their own mobility or their own action-derived processes, are long lived, essentially interchangeable as far as interactions are concerned, and are exposed to a reasonably stationary or slowly changing spectrum of external potentials. The salient metrics of concern are the collisional interaction time, the average energy associated with translational collisions, the measure of the internal time delay cycle, the average energy associated in total with the internal degrees-of-freedom, and the translational propagation velocity.

a) If there is no fluctuating time delay internally, the stress tensor of one portion of the ensemble on the other can be defined in terms of the momentum exchange. The Navier–Stokes formalism of the hydrostatic pressure, and a deviator stress defined by means of the transport measure of momentum diffusivity goes through. The hydrostatic pressure will have two components—one from the short-range collisional process, and the other from the longer-range interactional process.

The limits to the continuum description are spatial and temporal—insufficient size (or number) to the ensemble as compared to the mean free path; insuf-

ficient exposure time of the ensemble to external forces as compared to the translational time.[10–12]

b) Even if there is appreciable fluctuational time delay internally, the proposition can still be pushed through as a normal physics. The measure of the internal delay in action (fluctuational energy × internal time delay) relative to the translational action (fluctuating energy × translational time) is the ratio of bulk to shear viscosity. These two transport coefficients and their ratio can be defined for the ensemble.[8,9,11–13] The deviator stress state within the Navier–Stokes formalism can be extended to include a dilitational term that expresses the time delay into internal degrees-of-freedom.

c) The more obscure physical extension is to the case in which there is a very large amount of action tied up internally compared to translationally. Namely the internal processes have long time delays, to the point that these processes are often regarded as thixotropic, memory based, or even "free will". A description in terms of external momentum exchange, as an equation of external motion, hardly reveals any of the character of change in the ensemble which is all substantially internal. Thus it is not normal physics.

In a normal system, the stress tensor is the macroscopic variable that measures the effects of momentum interactions among atomisms on the momentum transfers in the ensemble. In these systems, the stress tensor is to be replaced by a new kind of macroscopic tensor variable which plays an analogous role. That is, this tensor measures the effects of atomistic interactions (generated by internal actions) on the ensemble action modalities.†

We call the physics for such factory ensembles, which maintain their ensemble charactertistics in long-lived fashion, homeokinetic, in recognition of a prior use of the notion to describe the actions of the complex living system.[14] In biology, the principle of homeostasis—the maintenance of the interior milieu of a cell or of an ensemble of cells (the living organism) independent of the external vicissitudes (as an impulse spectrum presented by the environment)—is a fundamental dogma.[15,16] The principle of homeokinesis—that the only mechanisms by which that internal regulation could take place is by the mediation by inhibition or release from inhibition of an extensive collection of internal oscillators (thermodynamic engine cycles)—was offered as a central conjecture as to the mechanism of regulation. Its experimental basis has become increasingly secure in biology, and it is intrinsically recognized in social phenomena (e.g., the characteristic mechanisms making up components of the business cycle).

In order to probe at the essential reliability of the homeokinetic notion for the ensemble physics of internally complex atomistic systems, we first note that the maintenance energy for the internal state must come via the gateway of external translational interactions, however weak. Mass, mass species, energy must so be derived and distributed among the members. Thus they are not immune to or independent of the physical constraints imposed by the outer world.

Secondly we note that at the highest frequency seen by the ensemble—the spectrum associated with the translational gate—our first Proposition holds. Namely there will always be a dissipation theorem applicable after a number of translational interactions so that the high-frequency tail end of any action spectrum will resemble isotropic noise, e.g., thermal or isotropic turbulence. At such a scale, one "moment" of impulsive collision is like another.†

The high-frequency attenuating roll-off assures one that the slower changing ensemble will be subject to the mathematical existence conditions for a Fourier spectrum, namely the field variables are constrained to be bounded functions of limited variation and can be so described by a Fourier spectrum. More to the point physically, in a unitary physical causal sense, it effectively isolates the universe of dynamic effects seen by the ensemble.

If we excluded purely linearly elastic modes of coupling (see footnote in Proposition 1), then the internal degrees-of-freedom within the atomisms must be nonlinear and at least piecewise fluid or plastic. The internal system may be in a part a bag of water, bone, a gel, metastable states of vapor, etc. The prototypes to keep in mind are the ensemble of atomisms making up the earth's atmosphere (with the emergence of the hubbub of weather), a living cell, or the members of a living society. In the latter two cases, the hubbub that makes up the biochemistry or the "sociochemistry" of life is found.

What one finds and expects to find in their Fourier spectrum is a cascade spectrum of modes of action.

† There is no great mystery to the character of internally complex atomistic systems. They are factories, dealing in fluid, plastic, and elastic processes.

† A street cleaner in any industrial area can assure us of the truth of this view at the end of each day. It remains equally true when the streets are biological conduits, the factories are cells, and the cleanup phagocytitic.

There is first a very slow mode of evolution and self-assembly by which the ensemble is brought together. But for this Proposition we are not concerned with the physics of evolution, only with the ongoing life characteristics of autonomously operating ensembles. After initial start up, ultimately the ensemble approaches a near equilibrium with its external potential sources.

Weather becomes driven by the mechanics of the earth and sun, e.g., starting from long term 10^5-year dynamic aspects of the earth's orbit relative to the sun,[17] one ultimately descends to the noisy stationarity of the yearly cycles of revolution of the earth around the sun, on to earth's daily rotations. There is a descent in process scale in which the large motions of the atmosphere are coupled to the small motions, but nevertheless exhibit a considerable degree of independence from simple statistical correlation. Dissipation ultimately takes place into the smallest, high frequency, size of ensemble motions. Except for the complexity of detail, one has little doubt that these internally complex motions are subject to physical laws of change, albeit in piecewise form, whether spatially or temporally. Each process domain requires identification of particular boundary value problems of considerable mathematical complexity.

The living system, e.g., cell, exhibits a similar hubbub of process. The near equilibrium scale of time must be viewed for at least as long as a generation, and the energetics involved in metabolism must be tied, through an extensive web, to the sun. But then one finds a similar cascade spectrum. Each member of the ensemble, as an example, is born, grows, has a probability of reproduction, dies. It utilizes metabolic "engine" processes which are thermodynamically degradative, by which it extracts required repair materials and energetics. There is a characteristic turnover of materials.[18] There is a characteristic repertoire of modal behavior, whether cell, mammal,[19–21] or human.[14] The chains of causality are not hard geared, but Markovian-like. A cascade spectrum emerges, ultimately dissipative, in the descent to the high frequency small scale. Ultimately, whether in a man or in society, in the mature stage of life, one "day" becomes much like another.

In summary, a gross scaling mesh for continua is presented in Table I.

Proposition 3: Instability of Mobile Continua—Production of Mobile Macroscopic Atomisms

Proposition 2 provided a rationale for expecting that an equilibrium distribution will be achieved for a bounded ensemble of atomistic entities.

But now we ask about the continuum so formed. Is its homogeneous extension possible without end? In the case of fluid-like (gas and liquid) or mobile continua, an indefinite extension is not possible. By virtue of mathematical-physical properties of the ensemble motion, nonlinear stability issues ultimately force a convective process on the ensemble and some large-scale patterned motion ensues. We can offer the following elementary rationale.

The Reynolds number Re is defined by

$$\mathrm{Re} = \frac{V}{\nu/D}$$

where

D = a characteristic dimension of a field,
V = a characteristic (convective) velocity,
ν = kinematic viscosity (i.e., its momentum diffusivity).

It will be recognized that the numerator is really a convective velocity sweeping into the field which has

TABLE I

μ	λ	β_s	τ_t[a]	τ_l[a]	τ_t/τ_l	Type of field
$\neq 0$	$=0$	$1\,p_0$[b]	$\varepsilon\tau_0$[b]	0	0	Structureless molecule—sparse proximity
$\neq 0$	$\neq 0$	$1p_0$	$\varepsilon\tau_0$	$\varepsilon\tau_0$	1[b]	Structured molecule—sparse proximity
$\neq 0$	$=0$	Np_0[b]	$\varepsilon\tau_0$	0	0	Structureless molecule—close neighbor mobile proximity
$\neq 0$	$\neq 0$	Np_0	$\varepsilon\tau_0$	$\varepsilon\tau_0$	1	Structured molecule—close neighbor mobile proximity
$\neq 0$	$\neq 0$	Np_0	$\varepsilon\tau_0$	$N\tau_0$	N	Structured molecule with memory—close neighbor mobile proximity
$\neq 0$	$\neq 0$	Np_0	$1\tau_0$	$N\tau_0$	N	Structured molecule with memory—close neighbor poorly mobile process (plastic-solid, gel, geo-, bio-chemical)
$=0$	$\neq 0$	Np_0	0	$N\tau_0$	∞	Elastic solid (i.e., its interior is "frozen" out)

[a] The measures of translational and internal relaxation times are given here as μ/β_s, λ/β_s; β_s is the adiabatic bulk modulus, μ is the shear viscosity, λ is the bulk viscosity.

[b] The magnitudes ε, 1, N are small, of unity order of magnitude, or large compared to the observer's scale. The observer provides a τ_0 time scale, and p_0 pressure scale. Further detailing of processes and numerics requires development of the specific kinetics appropriate to each compartment.

some gradient either in space or time over that field.† The denominator is a diffusional velocity. While in the elementary hydrodynamic case, viscous (momentum) diffusion may be the dominant dynamic process, clearly any other diffusive process may be dominant in other cases (e.g., electrical, thermal). So as a generalization we write a generalized Reynolds number

$$\mathrm{Re} = \frac{V\,(\text{convection})}{V\,(\text{diffusion})}$$

The general issue is whether the energy associated with the convective velocity that sweeps into a field can be internally absorbed into the underlying atomistic internal energy. If not, then the field becomes unstable, and some *new* inhomogeneous patterning emerges (i.e., at Re greater than or equal to one). That patterning leads to superatomistic "structure"‡ or large scale "fluctuations". Mathematical-physical instability has developed a higher ordered atomistic structure within the continuum.

In the case of plastic-solid continua, a similar "homogeneity breaking" theory, albeit at a slower time scale, produces dislocations.

The competition producing the instability, a convective process versus a local diffusive transport or propagative process, is usually self evident. The particular choice of a unity measure for the stability transition

$$\mathrm{Re}_{\text{critical}} = 1$$

is of course somewhat conventional, and requires detailed investigation in each case. To illustrate in the known molecular cases, the issue of such an instability is roughly established at specific measures near 1 for the flat plate boundary layer (intersection of the laminar sublayer and the von Kármán logarithmic velocity distribution[22]), drag on a sphere (deviation from Stokes law), a Bénard cell formation, Taylor cells, Oceen's logarithmic law for drag on a cylinder; or for propagative instabilities in such phenomena as cavitation, combustion, nucleate boiling, or cloud formation. The point to the Proposition is to develop an appreciation that it holds for all levels of continua (out of subatomistic) organization.

The quantized structure thus developed as an instability is not automatically an autonomously sized superatom, prepared to conduct an independent systems' existence. It may be confined by walls. The merit of modern hydrodynamic stability theory (Landau,[22] Ruelle and Takens[23] and the topological conjectures[24] and experiments that these views have provoked (for example, see Ref. 25 for an experimental study) is that it has suggested that driving any continuum field into the domain beyond a first instability (e.g., by increasing whatever gradient might have driven the convection in the field) will provide a number of branching instabilities, bifurcations, field superatoms of ever-diminishing size. This sequence of separated singularities will end in what is commonly seen as "noise" when viewed at very large field scale, namely a distribution of quantized entities small enough to have an autonomous life. These are superatoms. That is, when a sufficiently high ordered atomistic instability is reached, whose size is no longer governed by its boundaries, then the Proposition applies. As illustrated in the case of flow between parallel plates (or tubes), the scale for the production of the superatoms of turbulence is not measured by the plate separation $\mathrm{Re}_{cr} = 1000$, but by the local boundary layer $\mathrm{Re}_{cr} = 1$.[22]

But we wish to pursue the conjecture beyond the more normal hydrodynamic range. As recent contributions have suggested[22,24] via the organizing measure of order parameters, there is increased recognition that phase transitions may be governed by the same or a similar concept.

For the general applicability of our Proposition it would seem clear that it applies equally well if constructed on the basis of the ratio of convective to diffusive velocities, momenta, or energies.

Examples may be developed to illustrate the richness of this Proposition. Note all that the Proposition states is that when the translating velocity, momentum, or kinetic energy which is transporting some systems' process property (e.g., mass, momentum, energy) into a region exceeds the velocity, momentum, or kinetic energy which atomistic entities can absorb, some change in status (state,

† Namely variations in velocity over the field will have the nominal range 0 to V, for there are no unstabilizing effects in a uniform translational velocity field.

‡ Further there is a priority ordering of how that convective energy is absorbed. At low values, it is absorbed into rotational momentum (associated with turbulence); at higher values with phase change or chemical association change; at still higher with "stable" nuclear moiety changes (nuclear chemistry); at still higher with "fundamental particle" (nuclear fragmentation) changes. But for the moment, confining ourselves to the weakest changes which do not destroy the existing continuum, rotational momentum develops. We find persistent macroscopic vortices energized as superatomistic formal "structures". To name a few, Bénard cells, Taylor's vortices between rotating cylinders, pipe turbulence, atmospheric air mass movements, ocean currents.

phase, dynamic macrostate) must take place as a criterion of relative stability. The Proposition relates to a macrosize domain (containing many atomistic entities) at which a new ordered status will then appear.

In this form, the Proposition may appear "obvious", yet obscure. Namely it may be regarded as stating that the total energy of an ongoing system (regardless of how it makes up its losses to keep going) appears as the sum of kinetic and (internal) potential energy, and that the field system becomes unstable when newly brought-in kinetic energy exceeds the organizable energy of the existing field. Examples are possible currently within the nuclear domain, the cosmological and the galactic domain. But beyond such useful "hydrodynamic" speculations, it may be more interesting to provide a few unexpected examples.

Example 1: Condensation of a liquid phase. A first-order phase transition is examined to indicate how a process, ordinarily treated as static, may be viewed as a dynamic instability; showing that thermostatic and irreversible thermodynamic relations are causally connected by their common source of atomistic fluctuations.

The stability theme is not completely original. The elementary "thermodynamic" argument used by Maxwell to establish the location of the gas-liquid equilibrium isotherm for a van der Waal gas can be regarded as a stability argument in the double minimum potentials associated with the macroscopic continuum phase. In fact such cubic force relations were used by Poincaré to illustrate the problem of dynamic stability. The present argument will take a "cellular" thermodynamic form, thereby establishing a uniform connection from the macro to the micro-domain.

So consider now two derivations of the Clausius–Clapyron relation, one a standard macroscopic thermostatic derivation; a second via a local scale dynamic instability, using the Reynolds number criterion on the energy requirements to maintain a condensation process. In the thermostatic derivation, a reversible Carnot cycle is operated from saturated liquid to saturated gas, between their adiabats and between two neighboring isotherms. Complementary expressions in the p-v plane and the T-s plane gives the desired relation (briefly, constancy of the chemical potential results in constancy of Gibbs free energy).

In a dynamic instability view (probed at via condensing fluctuations) imagine a collection of cells, each with one average particle (i.e., a near ideal gas configuration). In the center of that collection, imagine a cell which can hold a collection of molecules that make up a minimum liquid "cell" (the coordination number involving a central molecule with a shell of all of its near neighbors). This dynamic model requires attending to those "gas" cell molecules which are competent to move inward to condense in the "liquid" cell. The first concern is with the fluctuating process that can both "condense" a liquid droplet shell and then "evaporate" it reversibly. Finding two such possible states furnishes the basis for the dynamic stability argument.

Such number density fluctuations take place in many regions of the gas. However some stability threshold is finally reached whereupon shared energy is converted to binding, and such droplets begin to condense and persist statistically with long life.

As gas-liquid equilibrium is approached, the momentum change that can convect the gas molecules from their cells into the central liquid cell take place in a constant pressure–constant temperature milieu. By the Reynolds number criterion, the p-v energy convected into the cell must be equal to or greater than the kinetic energy of measure T that the liquid cell can absorb internally for the instability transition (to liquid) to take place. The equality is a necessary condition for the formation of a liquid phase (i.e., as liquid cells, one by one).

But the notion of a hydrodynamic instability and its consequent production of new superatomistic forms is generally associated with shear flow fields. The accounting of the process of such formation by momentum seems quite transparent. Prandtl, G. I. Taylor, von Kármán and Landau have provided such rationale for the process at the formative boundary layer. In essence (turning the argument around), the transition from a turbulent jet represents the convective "condensation" of its turbulent fluctuations competent to furnish the viscous dissipation of energy of the shear field that is conducted through a newly added fixed bounding wall via a boundary layer.

One difficulty, to be found at every turn, in trying to deepen the application of pure physics to complex systems is with transport via the dilitational process. It is not convincing to simply call upon the bulk viscosity as the general cover for this form of transport. What seems to be required is some identification of the specific hydrodynamic processes

buried internally. The obscurity is no less true in this case of thermostatic condensation, or change of phase. It is essential to the spirit of this paper, therefore, that a constructive model of condensation as a dynamic stability process be offered. A stability argument has to apply just as well to a radial or dilitational field as it does to a shear field. In the shear field, eddy momentum is transported to support molecular momentum transport. In dilitation, external process action (energy × time) is transported to support molecular action of association.

A hydrodynamic model. 1) A single fluctuation cycle of condensation and subsequent slow evaporation on a nucleating center can be treated as a near equilibrium flow process. The hydrodynamic model that will be appealed to is a psychrometric process in which the nucleating center is viewed as the psychrometer, and the *incoming* stream of condensing molecules makes up the hydrodynamic field. By this process, temperature and condensing liquid number density fluctuations can be related to a hydrodynamic instability condition for condensation and binding rather than of inflow and equally rapid efflux.

A psychrometric process is an adiabatic saturation at constant total pressure in which the heat and mass transfer within a convecting flow field (free or forced) take place via the same boundary layer. The evaporative mass transfer is driven by the concentration or partial pressure difference. The inwardly driven heat transfer is forced by the temperature drop—stream to "wet bulb"—which develops to drive the evaporation. The countercurrent flow process is scaled by the latent heat of evaporation l.

If the hydrodynamic transfer field is axially long (reversible adiabatic, or thermodynamic, saturation), then the psychrometric constant (the ratio $\Delta p/\Delta T$ for the dual process) depends only on the initial temperature and initial degree of saturation. It is computable as a thermostatic potential difference. It does not depend on dynamic parameters, e.g., the Reynolds number, of the flow field.

However, if the saturating segment (the psychrometer proper) is axially short, then a discrete adiabatic saturation step takes place, whose psychrometric constant is a hydrodynamic resultant and not equal identically to the reversible adiabatic saturation.

2) A hydrodynamic argument involving a dominant transport mechanism, essentially makes two statements. The assignment of a Reynolds number scales competing dynamic processes, i.e., convective and diffusive, and its critical value *scales* the minimum intrusion of convection at which a homogeneity breaking form appears in the field. Formal identification of the dynamically coupled processes *then* relates causal gradients and fluxes of the coupled process, as a function of the dynamic scaling. Some details of the psychrometric process are appended, most compactly by a similitude argument.[38]

The critical Reynolds number applied to the inflowing vapor molecules scales the field at gas mean free path length "D" $= \nu/C$. However the psychrometric "boundary layer" is so thin (one condensing molecular layer d) that a short line result holds. From its theory, an appropriate psychrometric constant can then be computed.

[Detailing the two implications of the hydrodynamic argument: A local Reynolds number of 1 implies a near equilibrium scale for the hydrodynamic process by which local superatomisms will appear de novo to break up any homogeneous field. Implicitly, it is a facet of Proposition 5, in which loss in a continuum field implies underlying fluctuations which may be viewed as atomistic; or a facet of Proposition 1, in which interacting fluctuations have to be lossy. Thus Re $= (\text{"}D\text{"}\ V/\nu)$, applied to homogeneous gas where $V = C$, implies a scale "D" $= \nu/C$, the gas mean free path (it is made up of a lossy diffusion coefficient ν, and a propagation coefficient C), which is approximately a near equilibrium process measure. It is not the measure of a single atom, but an ensemble average of a stream of atoms. However it represents no superatomism, only the fluctuational scale of underlying atomisms, because all such fluctuations are taking place in a homogeneous field. Thus a second competing hydrodynamic process has to be found which can quantize the field at an internally complex scale. In this case, in what was a "homogeneous" gas, now a psychrometric process is visualized around a nucleating center. Since this is taking place in a near ideal gas vapor, V still equals C, and "D" $= \nu/C$. But now "D" is a superatomistic scale, a homogeneity breaking isolated entity. It is a new inhomogeneous form that has more permanent stability at the transition than the prior homogeneous fluctuations. The field now has higher internal order. The Reynolds number transition thus always provides a scale for the new quantization process—in this case condensation; in a boundary layer, "condensation" to the second "phase" of a laminar sublayer.

But then exploration of the flow regime, via its

dependence on a relevant dynamic parameter (the Graetz number) which depends on the Reynolds number and the transport path geometry, shows that the psychrometric process of condensation is a short line, and thus a hydrodynamic exchange process whose psychrometric constant can be computed. That constant, practically, is nearly the same as the reversible adiabatic saturation, over the entire range of phase equilibrium.]

3) The psychrometric constant relates the partial pressure (or density concentration) difference fluctuation in condensation, to the temperature fluctuation, as a constant chemical potential process (constant Gibbs free energy), which really is all that is required to derive the Clausius–Clapyron result.

The point to matching the thermal fluctuation to the latent heat, which need not be pursued in greater detail, is that sufficient energy has been extracted from the nucleating center so that a quantum mechanical process of binding (involving the symmetry of the wave function) may now take place. The total ensemble had to provide the inborne conduction balance. Thus the reversible fluctuation of a temporary ingathering has been converted to a more "permanent" delayed process of condensation of liquid cells in the ensemble.

What the Reynolds number criterion did was to offer the near equilibrium atomistic scale of the process, in this case the mean free path in the vapor phase. Since that same test applied to the gas prior to condensation, the question will no doubt arise as to the difference between the gas fluctuation and the liquid condensation.

Consistent with Proposition 1 and Proposition 5, atomisms are dynamically scaled in the gas phase at v/C dimensions. In fact that scaling is the essential macroscopic measure of the *mean free path*. Starting from their initial appearance in ensembles, the atomistic fluctuations remain homogeneous.

But now we identify, apparently by the same stability measure, the appearance of a new force system and a new inhomogeneity—psychrometric condensation—which starts out at the same scale as the gas fluctuation, but it is a different hydrodynamic process. The condensing influx velocity C is not the same as the evaporating efflux velocity; whereas in the gas fluctuation, the influx and efflux velocities are the same.

As a final comment, in shear fields, the flow velocity grows continuously with forcing gradient, and thus a specific point can be transparently noted at which Re approaches Re_{cr} (=1). In internalized processes, the transition from a "fluctuational" velocity to a locally oriented velocity occurs discontinuously for the transition to $\mathrm{Re}_{cr} = 1$. In each unexplored case, a deep study of potential competitive physical mechanisms is required to decide *a priori* on any new emergent forms. The most vivid pictures to keep in mind are: in a shear field, the rising smoke plume of a burning match and the various ways its form might be upset; in a dilitational field, life starting up in a primordial fluid and the various selection of chemical paths by which such process entrainment might have taken place. Physical science no longer feels any embarassment for treating such births as the cosmos, stars, or meteorological storms, whereas there still may be uncertainty with regard to the basic modeling of galaxies, planets, life, and fundamental particles.

Example 2: Formation of settlements in society. A social physics has been approached in the following spirit:

First, for the social organization of Paleolithic man, as his superatomistic structure:

1) Among mammals, daily metabolic requirements have been shown to vary with body weight;[26] also the average daily roaming of mammals has been shown to vary with body weight.[27] The range relation depends on the animals' diet, differing for plant eaters, animal eaters, or omnivores. The characteristic of the space roaming pattern for a particular primate can be seen in Ref. 28.

2) Mammals exhibit a characteristic number of behavioral modes, approximately nine in all.[19] These are characteristic of and associated with their evolved central nervous command-control system. Some of the more specialized character of primate social organization has been described.[21] The increased complexity of human behavior, stemming from his more evolved primate brain has also been identified.[14]

3) The social behavior governed from the human brain leads to a division of labor. A complexion count in the spirit of the Boltzmann relation for entropy permits an estimate of the number of people, bound together by social ties, that can survive operationally.[29] This is the extended family, which we have referred to as the unit bonding group. The number is of the order of magnitude 25–50. This *a priori* estimate checks against the Ethnographic Atlas,[30] which describes the sizes of all known isolated cultures. (Cultures, the Atlas points out, are isolated at the time scale of 1000 years, or space scales of 200 miles).

This grouping has furnished an "elastic" hard sphere "noninteracting" model of Paleolithic hunter-gatherer societies. The expected range (daily walking

range) and the implied character of isolation seems to agree with population densities and isolations found during the past few million years of the Pleistocene Age, with its waxing and waning ice ages. Also, the magnitude of an Einstein diffusion velocity can be sensed, namely a diffusion of culture at a rate of one roaming range dimension per generation (checked for the diffusion of agriculture, metallurgy, and pottery). This is approximately 20 mi/20 years, or 1 mile per year.

Compare now this earlier organization with the subsequent post-Neolithic modern society, as a new superatomistic structure:

Given that earlier organization, apparently stable for a few million years, yet involving considerable evolutionary change from hominid to homo to homo sapiens, how might the change to modern man as settled agriculturist (i.e., in his precipitated bound form rather than his freer "ideal gas" form) be accounted for?

One current theory, a Marxian theory, has been advanced by R. B. Lee (see Sahlins[31]). As an alternative we have been inclined to test the physical Proposition in the following spirit. We do not attempt to make a deterministic calculation of the moment of transition, nor do we assume that it took place instantaneously (e.g., in 1000 years). Rather, as with other stability transitions (e.g., laminar to turbulent flow) we are considering the relative stability of two forms, one of which replaces the other. Given a social field continuum made up of Paleolithic extended familial atomisms, could one estimate a condition for the new formation of superatoms by a hydrodynamic stability criterion, which ensued when the physical field boundary potentials changed? Namely when a warming temperature ramp, a glacial retreat, the advantaged appearance of certain flora and fauna that were domesticable and that could enter into a symbiotic fixed life state with man occurred? It is the computation of some characteristic of the condensed stability requirement of such fixed settlements that we wish to attempt. So we require

$$\mathrm{Re} = \frac{V\,(\text{convect.})}{V\,(\text{diff.})\{1 + \lambda/\mu\}} = \frac{DV}{\nu\{1 + \lambda/\mu\}} \geqslant 1$$

The denominator has been augmented by $1 + \lambda/\mu$ to indicate that it is energy both in translational and long time delayed internal motions that can be absorbed in the local domain.

Let

$$D = D_0\sqrt{N}$$

D = the diameter of the large fixed social superatom.

D_0 = diameter of a single culture. We select $D_0 =$ 40 miles, twice the nominal daily walking distance

N = number of such cultures bound in the superatomistic constellation. They are required, in constellation, because the new variable of value-in-trade unstabilized the field and required convective trade among the fixed settlements

$$\frac{\lambda}{\mu} = \frac{\Delta E_\lambda}{E_\mu}\,\frac{\tau_\lambda}{\tau_\mu}$$

This is an approximate model. It states that the viscosity ratio is equal to the ratio of action—the product of energy and time in the socially involved modes.[13,32]

E_μ = equilibrium daily energy available to the human, e.g., 2000 kcal/day.

ΔE_λ = energy which may be tied up in and released in internal modes. One may assume that its *a priori* magnitude is of the order of the total energy available through the translational gate. Namely, what is taken in each day is nearly all dissipated through all modes of activity. A very minor amount is taken up by repair activity. Thus $\Delta E_\lambda/E_\mu \approx 1$

τ_μ = the equilibrium human time constant. This would likely be of the order of a day. Action modes are substantially discharged in a day (e.g., sleep, wake, seek food, social activities).

τ_λ/τ_μ = the number of day units that individuals in a society tie up their more ancient customs and beliefs when exposed to a new theme, before adapting or changing. One surmises this to be of the order of a generation (i.e., 7000 days/day).

ν = translational viscosity. Expressed as a diffusional constant *based on the atoms.*

$$\mathrm{Re} = \frac{\sqrt{N}}{1 + \tau_\lambda/\tau_\mu}\,\frac{V}{\nu/D_0}$$

V = the translational (convective) velocity by which men, goods, animals are transported into or around the constellation. While forced marches are of the order of 25 miles per day, the transportation velocity in a simple post-Neolithic society, basically walk-

ing between settlements to conduct trade, would be more like a fraction of that velocity, e.g., 5 miles per day. On the other hand v/D_0 is of the order of 1 mile per day. Thus:

$$\mathrm{Re} = \frac{\sqrt{N}365 \times 5}{7000}$$

The criteria for stability (Re = 1) requires that N be of the order of 16 communities. Because of the $D = D_0\sqrt{N}$ relation, the region in which the constellation is bound is of the order of a few hundred miles.

We have compared these crude estimates with the first trading constellations known (see Refs. 33 and 34). A reasonable agreement seems to exist. Thus the application of physical notions to society is not so far fetched.

Such a computation is not unrelated to similar stability computations in cosmology, or in galactic formation.

Proposition 4: Atomism Physics Below Implies Atomism Physics Above

Subject to the restriction of the last Proposition, that the superatomism above is cast autonomously into a field in which it is free and not bound by wall constraints, then we can move directly to these autonomous superatomisms from the atomistic level below; we can learn that the same mechanics holds at the upper level that held at the lower level.

So we will assume the existence of a level of atomisms which effectively act like point particles and interact via a Newtonian Hamiltonian. Liouville's theorem for the conservation of the density of systems in phase space follows by a standard argument.

$$\frac{\partial f}{\partial t} + \sum_{i=1}^{n} \left[\dot{x}_1 \frac{\partial f}{\partial x_1} + \dot{x}_2 \frac{\partial f}{\partial x_2} + x_3 \frac{\partial f}{\partial x_3} + \dot{p}_1 \frac{\partial f}{\partial p_1} + \dot{p}_2 \frac{\partial f}{\partial p_2} + \dot{p}_3 \frac{\partial f}{\partial p_3}\right]_i = \frac{Df}{Dt} = 0$$

The critical step to note is that within this bounded phase space, it is generally found that some particles in the system nearly share the same local average position and momentum when examined at frequent intervals within an extensive epoch of time. Aggregate the density of systems by time averaging those correlated degrees-of-freedom (i.e., replace the correlated variables $(x_1\, x_2\, x_3\, p_1\, p_2\, p_3)$ for the q, r, s, t ... particles by new barred variables, their summed average). This partitioning effectively segregates or aggregates all those particles whose motion is coupled. Conceivably no such aggregation could exist, or an indefinitely large or changing number could exist. We will assume that in common experience, systems may generally exhibit a few fairly permanent types of such associated aggregates. For example, suppose that one such association has been found.

For this critical aggregation step, we will assume that there is a finite period, an average cycle time, over which the motional correlation essentially repeats. There is an associated spatial extent, an average aggregate size.

The aggregate averaging will produce m discrete aggregated entities

$$m < n$$

whose phase space is now quantized in space and time. Liouville's theorem will continue to hold for the new distribution, $\bar{f}$, for these m structured "particles".

This may be noted by expressing the original distribution in terms of barred variables and relative variables y_i. We then have to dispose of terms like $\dot{y}_i\, \partial f/\partial y_i$ by smoothing over the quantized space-time scale; that is, by integrating over this scale these extra terms average out to zero. Thus what we have "proved", in a sense of showing its plausibility, is the ensemble equivalent of Newton's law for center of mass motion of a system of particles. Namely for a complex atomistic entity (elementary particle, atom, molecule, biological cell, organism in a society) that retains internal structure, the Liouville theorem for the conservation of system density in aggregate phase space applies exactly in the same form as for point particles that are structureless, but only for a quantized time scale in which the time quanta are the average periods over which the internal "warbling" motions are cyclic.

Note that this holds true whether the internal motions are coupled with losses or not (i.e., whether a Newtonian Hamiltonian truly exists or not). The problem revolves around conditions for the sustained cycle. If the motions are internally lossy in their exchanges, as may be expected from Proposition 1, then the cycle can arise as a nonlinear limit cycle. If not they may arise from a "pure" quantum mechanics.

Thus, recapitulating, over many cycles of internal motion, Liouville's theorem holds for the translational center of mass degrees-of-freedom of the aggregate particles

$$\frac{D\bar{f}}{Dt} = \frac{\partial \bar{f}}{\partial t} + \sum_{i=1}^{6m} q_i \frac{\partial \bar{f}}{\partial q_i} = 0$$

where the sum extends over the translational displacement and momenta degrees-of freedom q_i. The distribution function $\bar{f}$ may be viewed as continuous, but only if accompanied by an underlying quantized time constant associated with internal structure.

It is then possible, as by all further treatments, to develop the Boltzmann equation, or equivalent, and integrate over the collisional integrals to obtain the equations of change for the summational invariants—of mass, energy, momentum, individual mass species, and the like. (For living species we must add one new summational invariant—one for population number, since living systems live and die instead of possessing "permanent" particles. For modern human societies we add another new summational invariant—one for value-in-trade—since in exchanges the notion of "value" is conserved in each transaction.)

As a final comment, we will apply this Proposition to the common central example of a random process, the Gaussian distribution. We argue that the Gaussian distribution, for physical phenomena, arises as a Maxwellian distribution for dilute degrees-of-freedom embedded in an interactive ensemble, and is not to be considered as random process "noise". In contrast, true random unconnected noise, i.e., white noise, consists—by definition—of an indifferent ensemble of oscillators of all frequencies with random relative phasings. There literally is no connection between the oscillators.

We recall that the line of argument that leads to the Maxwell distribution is Newton's laws implying the Liouville theorem which, for dilute concentrations, implies the Boltzmann equation which, at equilibrium, implies the Maxwell distribution.

The fluctuational scale is the usual kT when the translational energy of the milieu is thermal as in Brownian motion. If the translational fluctuating scale of the milieu is larger, then the fluctuational scale of the dilute ensemble is higher. Richardson demonstrated this for the distribution of bed load particles in a turbulent stream.[35] The transfer of Liouville's theorem level by level, and a consequent appearance of a Maxwellian distribution at every dilute level is the likely source for all so-called Gaussian distributions for translational degrees-of-freedom of physical systems which are immersed in force bound continua.

Proposition 5: Continuum Above Implies Fluctuations Below

Proposition 1 demonstrates the existence in a fluid continuum of an energy component that is not macroscopically mechanical, that cannot be accounted for as the sum of macroscopic kinetic and elastic energies. Insistence on a mechanical accounting of energy then implies the existence of lower level motions with zero mean value.

The scale of such "fluctuations" can be described only by going beyond the minimal extension of Newtonian mechanics given by Proposition 1, and including in the equations smoothing terms which prevent the formation of mathematical discontinuities. The simplest smoothing term, from the mathematical point of view, is that which corresponds to viscous drag. The resulting minimal thickness of a shock front may then be regarded as the fluctuational scale.

The arguments presented here imply the existence of lower level quantized structures. That these are in fact subatomisms is suggested by more detailed arguments.

FINAL REMARKS

Philosophically, we believe we have provided a physically conceived weldment for a hierarchy of complex systems in nature, with consequences generally coherent with most many-bodied processes. The Propositions place the burden on physics, at each level, to identify the internal process and determine wherefrom an emergent scaling arises. Obviously the internal processes tend to remain coupled throughout all scales, but the macroscopic continuum mechanics of each higher level can smear the details over in the lumped form of transport coefficients and processes. Thereby a satisfactory decomposition into atomistic (kinetic) physics and continuum physics (thermodynamics) is achieved level by level.

The net effect of our Propositions is to provide a formal recognition of an "intuitive" wisdom that there seems to be interaction from dei ex machina above and below. We identify the mechanisms from below with their basic atomistic fluctuations (illustrated at different levels as nuclei, atoms, cells,

individual organisms, social constellations, turbulent air masses, rivers, lakes, earth plates, or galaxies). In their hidden variable covariations, they make up the gross formed or mean status of the macroscopically isotropic and homogeneous "material" systems above. We identify the mechanisms from above as the convective stresses which provide organizing competence. We can understand that in the larger cosmological picture our processes from above are to be related to the big cosmological processes creating the big bang (or to the hand of God). Thereupon, s and T explicitly descend, level by level, from above. But also, they can be formally constructed and identified from below. Order, time, topological relation thereby remain uniquely correlated in our universe.

On the Long Lived Hierarchical Character of Systems

In summary of the hierarchical character of nature, seven primary levels seem to exist in the sense of a flow of authority (e.g., as by order parameters), isolation, and nesting (each less inclusive one contained in the superior level)

cosmos
galaxies
stars-planets-comets-solar systems
reactive fields
atoms-ions-molecules
"permanent" nuclear particles
fundamental particles

"Explanation" for the existence of these seven levels would be the function of a physics of evolution, which is not our present concern. Explanations of form and functional process within each of these levels seem to be currently well within the scope of normal physics. Explanations for levels beyond, e.g., cosmic origins above or negative oceans below, currently would still verge almost on the philosophic. The level of reactive materials is included because within galactic substructures, there are a considerable number of different kinds of atomistic and extended domains that are both reactive.† Thus reactive fields will comprise subfields of the stars-planets-comets level above and other galactic fields, e.g., dust, and gas clouds.

† For reactive, we literally imply, in its broadest sense, the notion derived from chemistry of the making, breaking, and exchanging of bonds.

If we require detailed attention to the processes of concern to man, we must focus more microscopically on planetary processes. The planet can exhibit many inhomogeneous forms of reactive matter. This will depend on its material constituents, proximity to a parent star, and the triple point temperatures of its constituents. Thus on planets, under favorable conditions (e.g., earth) we find

planets
planetary atmosphere—hydrosphere—lithosphere
geochemical-physical—biochemical-physical
reactive fields

If we attend with more detail to life forms on earth:

biochemical-physical reactive fields on earth
ecology
species
cells—colonies—organisms
organelles

And if our focus is on ourselves:

species, man
ecumenes
polities†
settlements‡
bonding groups
men

† Polity, or political organization begins when there are man-made, or mind-made rules that regulate the fluxes in the social system. The variables in flux are matter (to be used in the trade among settlements), energy, population, value-in-trade. The most precise notion that seemed to characterize the polity—as a connected field of settlements—was whether it threw up such man-made impedements (or aids) to diffusion or convection of these variables any different for members of its own settlements or for "foreigners". Just as in liquids or solids, where—differing from gases—the diffusions of mass, momentum, energy are not very simply related, the diffusional barriers to various material, and men may differ in the social polity.

‡ While man's brain likely evolved into its modern form about 40,000 years ago, making a full range of abstraction possible, including the symbolisms of speech at rapid neural rates, for most of the life of the species man operated with mobility as hunter-gatherer with a social bonding group organization not highly dissimilar to other primates. But with the retreat of the glaciers in northern midlatitudes about 10,000 years ago, man and a number of other species mutually domesticated each other, and man became bound into place, into agricultural settlements. *Then* that particular brain could evolve new notions fitting this new earthbound circumstance. Namely man could develop patterned forms for this new life style. It is the extension of social form past a simple Neolithic agricultural settlement, in the urban trading or manufacturing or religious settlement, that arises from the unique characteristics of the human brain.

The notion of hierarchy and connectivity is represented by the fact that a nuclear moiety (we exclude the fundamental particle level because of its short life) may enter into any of the named associations but find itself bound by ever-increasing complex rules of "authority"† (not that it is necessarily aware of those rules). Notice that some branches are alternate or parallel paths in the hierarchy, e.g., the nuclear moiety may be bound in a planet, or a star. This arises from the heterogeneity of the energy-matter-space-time manifold. We tend to assign time and space continuous properties, but matter-energy nonhomogeneous properties.

It goes without saying that both scope and focus seem so awesomely complicated at every level in every region. Yet we note that we are never faced by more than a small number of interacting levels. The overseer always seems to be faced only by king and by peasant. *That* is our key notion.

Now the smallest of particles of matter may cohere by the strongest attractions; and compose bigger particles of weaker virtue; and many of these may cohere and compose bigger particles whose virtue is still weaker and so on for diverse successions....

Sir Isaac Newton.

A Few Historical Notes on the Question of Reductionism

Physics, according to Aristotle,[36] is concerned with motion in systems, including living systems. Yet the promise of a universal formal science of motion was not forthcoming until Newton. The Enlightenment was largely founded on the notion that it could harvest and utilize the fruits of the Newtonian organic scheme to build a science for all of nature, including life, society, and even mind.[37]

The experience of the 19th Century proved that the Newtonian scheme (the laws of motion plus universal gravitation) were not sufficient to deal with the intractible complexity of nature, life, and social organization. And so the 19th Century counter-dialectic produced a fragmentation in both ideology and science, each splinter developing its own philosophic notions. A central theme common to the fragmented natural, biological, mental and social sciences was an awareness of the problem areas that involved history and evolution, in addition to a regularity of motion that the Enlightenment attributed to Newton and to Cartesian clockworks. The challenge was mounted by the well known dissents of Lyell, Darwin, Spencer, Marx, Freud.

Physics in turn collapsed its scope, in the main to specialized invariant motions—of heavenly bodies, of motion in the small, of flow of fluids and deformations of solids, of new motion-creating force systems, e.g., the electric and magnetic. Yet within the 20th Century, physics has reacquired some sense of its general applicability. But the notion that it might put forth its claim, once more, of being *the* universal science has been avoided. All such broadened applications of physics have been viewed by physicists as "engineering", "metaphor", or "myth". In the light of our propositions, we ask that physicists once more review the more general applicability of their science to complex systems' phenomena at all scales.

The acceptability of such reductionism would hardly seem to be an issue any more among physical scientists (see for example, Ref. 39), only its detailed application. Hopefully these propositions may cast some "constructionist" light on the physical path.

† We take recourse again to the Landau notion of governing order parameters.

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$$\lambda = \frac{\rho}{kT}\int_0^\infty \langle \sigma^{xx}(0)\,\sigma^{xx}(t)\rangle_0 dt$$

for the bulk viscosity, which depends only on the diagonal components of the stress tensor $\bar{\sigma}$. If the stress can be represented by a single overall relaxation time, then

$$\lambda = \tau_\lambda \beta$$

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Graetz number (>100) the normalized psychrometric constant is given by $a_3 = (S/P)^{2/3}$ where

$$a_3 = \frac{1}{(\rho C_p)_0} \frac{ml}{RT_1} \frac{\Delta p}{\Delta T}$$

For the case of the condensation on a nucleating center, the process is assumed to take place at Re = 1. It was pointed out that in practical psychrometry, minimal values of Re = 500 have to be used to avoid conduction errors (from thermometer stem and wicking), but if carefully designed, much lower values of Re could be used with no significant change in the psychrometric constant. Namely a lower limiting transition Re depends on avoiding conflicting force systems that interfere with the psychrometric process. In nucleating condensation, it is the prevention of an ingathering condensing stream itself (namely fulfilling conditions for a psychrometric field) which can interfere with the process. If there were no specific gradient forcing the hydrodynamic process (this particular cell), then only an undirected diffusion would take place. Thus some minimal dynamic criteria must be applied, and in a stability sense Re = 1 is suitable for spheres, cylinders, and thin layers, and for consistency with the theory (as opposed, say, to a free convective field process).

$$\mathrm{Re} = \text{“}D\text{”}V/v = 1$$

By kinetic theory, $V = C$. Thus $\text{“}D\text{”} = v/C$, the gas mean free path for the ingathering “stream”. For atmospheric vapor parameters, “D” is of the order of 500 Å. It is the “dimension” of the process domain over which the common heat and mass transfer process co-mingle. On the other hand, the “length” of the transfer field is only of the order of the molecular diameter d where the actual psychrometric process takes place. (The condensed molecules form the wetted wicking.) Thus as applied to the nucleating center, the Graetz number of the fluctuating process can now be estimated. The Prandtl number for the vapor and the Reynolds number of the process are both of order unity.

$$Gr = P \frac{\mathrm{Re}\,\text{“}D\text{”}}{\text{“}L\text{”}} \approx \frac{\text{“}D\text{”}}{\text{“}L\text{”}} \approx \frac{v}{Cd}$$

At normal temperatures and pressures, assuming d = 3Å, the Graetz number is of the order of 150, the short line result. Thus $a_3 = (S/P)^{2/3}$, representative of a dynamic psychrometric process. 2. However, the vapour values for S and P, both near unity by elementary kinetic theory, lead to the *same* result as in the case of thermodynamic saturation, $a_3 \approx 1$. It was pointed out that the real test of a unity constant of proportionality in the $a_3 = c(S/P)^{2/3}$ scaling relation is the limiting case of a pure substance evaporating into its own vapor at its critical point, where its heat of vaporization approaches zero. It was shown that the condition is satisfied. Thus $a_3 \approx 1$ can be expected to hold for S/P of the order of unity, as well as at unity, a generalization applicable over the entire range of phase equilibrium. It is only the novelty of the psychrometer that may be unsettling. The same example offered as a macroscopic illustration, would not be unsettling if presented as a model for the dew point.

39. P. Anderson, *Science*, **170**, 393 (1972).