Making Heat Work:
The Thermodynamics of Groups

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Abstract

Heat metaphors are often used to describe startlingly productive groups, and this metaphor fits well with the subjective experience of working in such groups. To date, however, the use of heat metaphors for groups has not been grounded in a broader understanding of thermodynamics. Moving beyond metaphor toward more systematic theory, this paper draws on analogies with physical thermodynamics to define group energy, temperature, heat, and work. Just as temperature shifts physical matter among qualitatively different states such as solid or liquid, groups operating in different temperature ranges transition among four characteristically different dynamic states: fixed, fluid, chaotic, and complex. Along with characteristic member experiences, each dynamic state has distinctive patterns of energy flow and group productivity. The probability of a group transitioning into and stabilizing in the different states is proposed to vary based on its temperature, its internal group structure, and the structure of opportunities and constraints in a group’s operating context.
Making Heat Work: The Thermodynamics of Groups

In an evening action in Normandy in 1944, Lieutenant Millsaps led a patrol of volunteers to attack an enemy line that had trapped an American battalion on a hill for three days. The wounded were dying for lack of plasma and water, and the soldiers who volunteered were in a "peculiarly desperate" state of mind. The cries of the wounded had so demoralized the able-bodied that Millsaps and the men welcomed the opportunity to get away (Marshall, 1947, p. 183).

The ad hoc collection of volunteers had a clear leader--the lieutenant--with a sergeant second in command. The goal was also clear and both aligned with the survival of the battalion (and by extension the volunteers) and in conflict with individual survival motives, as attacking the enemy would directly expose the men to grave danger. As soon as the enemy opened fire on the patrol, the newly formed group dissolved as the soldiers "broke and ran like dogs."

The two officers beat the fleeing men back using physical force, eventually collecting them together in a group again. After an hour of bullying and pleading by Millsaps, the group was ready to advance again. This time they charged "as if oblivious to danger" and succeeded in overrunning the enemy line despite taking casualties. Millsaps then lost control of the surviving members, who went collectively berserk. Having killed every German in sight, they "ran on into the barns of the French farmhouses where they killed the hogs, cows, and sheep. The orgy ended when the last beast was dead" (Marshall, 1947, p. 183).

This ad hoc group experienced dramatic changes over its short life. The group's collective dynamics repeatedly altered as the group formed, warmed to its task, abruptly dispersed, and then under internal and external pressure transformed into a superheated agent of destruction.

The Thermodynamics of Groups

Our choice of language in summarizing these events illustrates how easily temperature
metaphors describe collective action. Winning athletic teams are “on fire,” a successful new business venture is “hot,” and busy work cycles occur at a “fever pitch.” Widespread intuitive metaphors can be useful springboards for understanding phenomena, as the choice of language signals how such experiences are represented cognitively (Lakoff & Johnson, 1980). Ubiquitous metaphors of distance and space, for example, characterize relationships as psychologically close or distant. The spatial metaphor has offered considerable traction for understanding social life, providing conceptual and methodological tools in the form of social network analysis, for example (Wasserman & Faust, 1994; Wellman & Berkowitz, 1991). We believe temperature metaphors hold similar promise for illuminating some of the processes that underlie group productivity. The thermodynamic account of groups presented here offers a fresh perspective on why groups vary so widely in their ability to transform energy into productive work.

The elusive holy grail of group synergy (Larson, 2007), also known as the assembly bonus effect (Shaw & Ashton, 1976) has fired the imagination of many group researchers interested in productivity. Synergy is when group productivity exceeds what would be expected based on the abilities of individual members. Like the grail itself, however, synergy remains elusive. Claims of discovery (e.g., Michaelsen, Watson, & Black, 1989) are often followed by scholarly refutations (e.g., Tindale & Larson, 1992), and expressions of faith (e.g., Propp, 2003) countered by appeals to retain our skepticism (e.g., Pavitt, 2003). Groups researchers understand process losses better than gains, although some findings of process gains are robust for particular tasks and circumstances (Kerr & Tindale, 2004).

The temperature metaphor has appeared sporadically in literature on organizations, groups, and charismatic leadership (e.g., Gratton, 2007; Klein & House, 1995; Lipman-Blumen & Leavitt, 1999) as a way to think about unusual productivity. Hot groups (Lipman-Blumen &
Leavitt, 1999) and hot spots (Gratton, 2007) buzz with energy, creativity, and accomplishment. Groups may be set “on fire” (Klein & House, 1995) by charismatic leaders. As these cites indicate, we are not the first to connect productivity and thermodynamics. For the potential of this analogy to be realized, however, scholarship must move further along the continuum from engaging metaphor toward a testable theory with well-defined concepts. It also needs to develop a more comprehensive account of the different thermodynamic states available to groups, rather than focusing exclusively on the hot state (Lipman-Blumen & Leavitt, 1999). Gratton (2007) briefly notes the existence of other states, both cold and warm, but gives other states scant attention in contrast to the hot spots that are her main focus.

To that end, this paper draws systematically on the well developed field of physical thermodynamics to define analogous concepts of energy, temperature, heat, and work for human groups. We then integrate heat metaphors with scholarship that has proposed that groups, like other dynamic systems, operate in a small number of qualitatively different dynamic states (e.g., Campbell, Flynn, & Hay, 2003; Contractor & Seibold, 1993; Dooley, 2004). We believe unusual productivity – high or low – as well as more ordinary levels of productivity depend in part on how groups channel member energy in different thermodynamic states. Building on previous work (e.g., Arrow, McGrath, & Berdahl, 2000; Campbell et al., 2003; Stacey, 2001), we identify four such states: fixed, fluid, chaotic, and complex. As groups heat up or cool down they move from one state to another, altering the flow of energy and information, the complexity of interaction patterns, and the productivity of the group.

The thermodynamic theory presented here applies to interacting groups of people who coordinate their behavior to accomplish collective goals. The clearest application is to work groups, but the concepts are also relevant to larger organizations, friendship groups, families, and
short-lived ad hoc groups. Our goal is to create an integrative framework for understanding the mechanics and dynamics underlying the full range of group performance from dismal to astonishingly effective. After defining the core constructs and describing the thermodynamic states, we put the theory to work generating hypotheses and applying the concepts to a set of student project groups and an organizational case study.

The Postulates: Energy, Temperature, Heat, and Work

Energy, temperature, heat, and work are core concepts of physical thermodynamics. Energy is the potential for causing changes; temperature is the average kinetic energy of atoms as they collide. Heat is spontaneous energy transfer between two objects at different temperatures, and thermodynamic work is energy transfer that accounts for changes at the macroscopic system level. Physical thermodynamics explains the process and constraints of how energy is exchanged between physical systems as heat or work (definitions derived from Kondepudi & Prigogine, 1998; McKenzie, 1961). In this section, we define analogous concepts for group thermodynamics. The four postulates form the foundational assumptions for our theory. (Formal mathematical versions are available in the Appendix.)

Postulate 1: Group energy is current member activity plus potential member energy.

Energy. Physical energy is the potential for causing changes; group energy is a group’s ability to make things happen. The actions and interactions of members are the source of group energy, which we define as current member activity plus potential member energy. Current member activity includes any energy expended on group-related activity. Potential energy corresponds to familiar concepts such as member commitment: the willingness of members to commit time and energy to the group on an ongoing basis (Moreland, Levine, & Cini, 1993).

The Millsaps case can help illustrate these two components. Initially, Millsaps recruited
volunteers by tapping the men’s desire to escape their miserable circumstances. This was sufficient to get the group launched. The initial attack, however, revealed the fragility of the group, which fractured under pressure. When the men broke and ran, they were certainly behaving energetically—but as individuals, rather than members acting on behalf of the group. Low member commitment meant that group energy was insufficient to handle the demanding task of engaging the enemy. It fell to Millsaps and the sergeant to gather the men together and both redirect their energy toward the group and build up potential energy to fuel the next attack. 

Postulate 2: Group temperature is the average intensity of member energy.

Temperature. Physically, temperature is the average kinetic energy of atoms within the substance being measured. It is an intensive property, such that small and large objects can have the same temperature, even though the larger object has more total energy. For groups, we conceptualize temperature as the average proportion of each member’s total available energy and engagement that is devoted to the group. The higher the average engagement and energy of its members, the higher the group temperature. An important distinction here is between member energy and individual energy. The multiplicity of social identity means that a person can be in a group context while acting in service of another membership or identity not relevant to the group.

In the Millsaps group, the energy expended by the individual soldiers as they ran away was high, but their group identity had been supplanted by the more primal identity of frightened individuals fleeing danger. Once Millsaps and the sergeant had gathered the men back together, they set to work warming up the group to support the second attack, during which the intensity of group activity spiked dramatically. By the end of the case, the group had potentially achieved 100% engagement, as the soldiers continued in an intense orgy of collective (over) killing.

Postulate 3: Group heat is the rate of spontaneous change in energy levels in other systems attributable to the group.
**Heat.** Physical heat is spontaneous energy transfer between two objects of different temperatures. While temperature is the property of an object, the energy flow of heat occurs between objects. The relational nature of heat may explain in part why it has been such an attractive metaphor for group dynamics. In our conception, the primary "objects" of interest are the group and its members. Internal group heat flow occurs when the energy levels of members change spontaneously based on their interactions in the group. An intrinsically motivating group task (Deci, 1972), for example, promotes internal heat flow: the change in member energy level attributable to engagement in the group, experienced by members as feeling energized (positive heat flow) or drained (negative heat flow) by the group. Heat can also flow to non-members who interact with, observe, or hear about group activity. For example, sports fans may experience a surge of excitement when watching their team play. When outsiders or other observers feel a "warming" effect of contact with the group, they are experiencing external heat flow.

In contrast to physical heat, which requires the conservation of energy, group heat can increase the arousal and activity of members without requiring that the heat received be simultaneously deleted from the heat source. All members can be energized by one another, resulting in a net gain in group energy, or all members can feel mutually drained by one another, a net loss. In that sense the mutual transfer of energy in groups is more like the mathematics of information, as information is not depleted by sharing.

**Postulate 4:** Group work is the expenditure of group energy on group products and on increasing group productive capacity.

**Work.** Mechanical work is transfer of energy by physical force. Thermodynamic work is more general. In defining group work, we propose a broad concept that includes energy exerted to create group products and energy exerted to build productive capacity via adjustments to
group resources and structure (learning and development) and temperature (morale building). These correspond to McGrath's (1991) group functions of production and group well-being.

The efforts of Millsaps and his sergeant to reform the group and prepare them to fight effectively boosted productive capacity for the second attack. Effort devoted to member support, the third of McGrath's (1991) functions, counts as work if it improves group productive capacity or if member support is, in fact, a primary purpose of the group. In contrast with the spontaneous flows of heat, work involves a deliberate expenditure (outflow) of energy. The efficiency with which this energy is transformed into completed work is one of the factors that differs in the four group thermodynamic states, to which we turn next.

Group Thermodynamic States

**Proposition 1:** Groups can operate in at least four qualitatively different thermodynamic states: Fixed, Fluid, Chaotic, and Complex

In the physical world, temperature, a continuous variable, is associated with qualitatively different states of matter. Water, for example, is liquid over a broad temperature span from cold to hot. Below this range, it freezes; above this range, it boils off into steam. The differences between states are sufficiently profound that we use different words for them: Ice, water, and steam or vapor. Qualitatively different states of matter are characterized by structural properties such as density and thermodynamic properties such as temperature and heat capacity (Kondepudi & Prigogine, 1998; McKenzie, 1961). Although temperature clearly is associated with different states of physical matter, it is not a one-to-one mapping. Water vapor, for example, exists at a range of temperatures that substantially overlaps with the temperature range of the liquid state. This makes it possible, for example, for sublimation—a direct transition from ice to vapor—to occur with no intermediate liquid phase. As with water, we propose that qualitatively different thermodynamic states occur in groups, and that these are associated with group temperature but,
like water, in an overlapping rather than discrete mapping.

The structural differences among different states of matter give rise to different dynamic behavior: Water flows easily but sticks together; vapor dissipates; ice fractures under pressure but does not flow. Fundamental differences in dynamic behavior can also be characterized more generally and abstractly, however, without reference to underlying states of matter. We draw on both sources—physical thermodynamics and the study of dynamic systems more generally—in characterizing groups. Based on an extensive examination of dynamic systems using computer simulations called cellular automata, Wolfram (2002) identified four fundamental classes of dynamic behavior, and our four thermodynamic group states—fixed, fluid, chaotic, and complex—correspond to these categories. After briefly describing the Wolfram dynamic classes, we characterize the states in more detail for human groups.

Mathematicians and other scientists who study dynamic systems have long distinguished between activity that diminishes over time and activity that continues in a regular rhythmic pattern. If a stone is thrown in a still pond, for example, the patterned ripples of water quickly diminish until the surface of the pond is still again. Similarly, the stone comes to rest and stops moving. Both illustrate how activity and change dissipate as the system returns to a fixed state, called the fixed point attractor. Wolfram calls this Class 1 behavior. A group in the fixed thermodynamic state shows an analogous tendency to lose energy and move toward stasis.

Systems may also exhibit rhythmically patterned movement. The swinging pendulum in a grandfather clock and the orbit of the moon are two physical examples. The system continues to change from moment to moment but these changes are smooth, regular, and repeat over time. The pendulum goes up, goes down, and shifts from left to right, following a repeating pattern—a periodic attractor—with minimal deviations. Wolfram calls this Class 2 behavior. Repeating
patterns are common in biological systems that have cycles linked to the day-night cycle or the progression of the seasons. When a group is in the fluid thermodynamic state, activity is dominated by predictable, repeating cycles.

Chaotic behavior—studied and characterized in the 1960s and 1970s for physical systems such as weather and turbulent water—seems highly disorganized and random but was found to have pattern embedded in it. Wolfram calls this Class 3 behavior. In chaotic systems, a small change anywhere in the system can sweep through and affect distant parts of the system—the "butterfly effect" popularized by mathematician and meteorologist Lorenz (1963). This means that new information that emerges anywhere in the system is rapidly transmitted to other components. In sharp contrast to the predictability of Class 2 dynamics, the underlying order that governs the behavior of systems in Class 3 dynamics is much harder to detect. The behavior of individual components, while not random, is not predictable beyond a very short time horizon. When a group is in the chaotic thermodynamic state, the behavior of group members is similarly unpredictable, not only to other members but even to themselves.

The complex behavior that Wolfram calls Class 4 is the most recently characterized dynamic state, described as existing at the edge of chaos by Langton (1991). The complex state combines the repeating patterns of Class 2 with the novelty of Class 3 behavior to generate dynamic behavior that includes both orderliness and surprise, predictability and unpredictability. Class 4 behavior is common in biological systems, which exhibit both patterns and novelty in those patterns over time. Groups in the complex state generate patterns that recur (like the predictable rhythms of the fluid state) while they also continue to morph and change, with some patterns fading out (as in the fixed state) as new ones emerge.

In the next section, we describe in more detail what the four group thermodynamic states
are like, including the phenomenology of member experience, the patterns of energy and information flow, and the productivity of the group.

Proposition 2: The four group dynamic states are characterized by different:
(a) member experiences of the group
(b) patterns of energy and information flow within the group
(c) functional relations between group energy inputs and group outputs

Class 1 Dynamics: Fixed State. Fixed state dynamics drain member energy while generating little in return. The experience of fixed state dynamics is like touching metal on a cold day: whatever energy people bring to the group is rapidly depleted. Interaction is effortful and yields disappointing results. Gratton (2007) contrasts the excitement and energy of hot spots with the lassitude and exhaustion of people trapped in what she calls the big freeze, and what groups researchers and therapists have long referred to informally as the “stuck” state (e.g., Berg & Smith, 1995). In the chill of the fixed state, negative feedback loops damp down and close off energy flows, and hence temperature—the intensity of member activity—stays low. Like physical solids, groups in a fixed state are relatively unresponsive to pressure, either from members or by outsiders. Extra effort is required to get anything done because the only spontaneous transfer of energy (heat flow) is negative. Members may experience strong emotions, but the emotional energy does not get channeled into the group. Effortful repression of thoughts and feelings can contribute to the chilling effect. Information is trapped in individuals or small pockets within the group rather than circulating freely.

Groups fall into a fixed state when members lack motivation, when the internal structures needed to capture and channel energy are inadequate, or when flows of energy and information among members are blocked by internal or external constraints. Among the chilling influences Gratton mentions (2007, pp. 39, 159) are the structures of corporate bureaucracy and a competitive mindset that encourages people to hoard rather than share information. If conflict
(or the desire to avoid conflict) inspires members to withdraw from one another, this blocks action. When groups stay stuck in a fixed state instead of dying a natural death as members abandon them, it is generally either because members are not free to leave or because they have withdrawn into subgroups that retain some energy and activity.

*Class 2 Dynamics: Fluid State.* In a group that has warmed to its task, group activity has a rhythm and flow that make it seem fluid. Members experience group work as satisfactory, orderly, and predictable, like the smooth laminar flow of water in a canal. Productivity is related in roughly linear fashion to member input, minus process losses due to coordination costs, incomplete alignment with member motivation (Steiner, 1972), and the friction of conflict. If members increase their efforts, more gets done, and if they slack off, so does group productivity. The flow of coordinated collective work facilitates the spontaneous energy transfer of group heat, which makes it easier to do tasks together than alone, and allows groups in the fluid state to achieve weak synergy (Larson, 2007), outperforming what an average member might accomplish. A wide range of group temperatures are consistent with fluidity, which corresponds to what Gratton calls the “business as usual” state of midrange temperatures (2007, p. 6). We suspect that the majority of groups studied in the published literature were observed operating in the fluid state. Fluid dynamics are a good fit for linear models because input-output relations approximate linearity most closely in this state.

Tasks that group members care about, routines that define familiar patterns of action, and a clear structure of norms and roles should all help a group attain and maintain fluid dynamics. Effective coordination supports behavioral entrainment, which promotes the positive affect (Kelly & Barsade, 2001) associated with the fluid state. Information will tend to be exchanged among members who coordinate closely, but will not diffuse rapidly through the group. As is
the case with fixed dynamics, negative feedback loops help stabilize fluid dynamics, so that when members stray from group routines, the corrective responses of other members bring them back into coordination. Positive feedback loops can operate either when members encourage one another to build enthusiasm for a task, or when conflict escalates. If the checks of negative feedback fail to check these spirals and keep them in bounds, this can trigger a phase transition to another state. Drastic changes in the group or its embedding context that disrupt its rhythms can also create turbulent pockets of disorganized activity. Turbulence, in contrast to smooth flow, belongs to the realm of chaotic dynamics.

Class 3 Dynamics: Chaotic State. In a chaotic state, group activity lacks the predictability of fixed and fluid dynamics. Uncoordinated member activity and disorganization mean that even high levels of energy devoted to work generate scant progress on collective goals. Information disperses very rapidly, and small events can trigger disproportionately large and unexpected responses via positive feedback loops that amplify like the screech of feedback from a poorly positioned microphone. Members will experience this state as confusing, frustrating, overwhelming, stressful, and/or exhausting; it will not be boring. In contrast to the fixed state, which is tiring because it is uneventful and boring, the chaotic state is tiring because it is hard to make sense of whatever is happening and to figure out what to do.

In the study of physical matter in motion, the activity of liquids and gases shifts between smooth flows and turbulent flows based in part on velocity, the speed of flow. In groups, this would correspond to the volume of energy flowing through the system as both heat and work. For a work group, a high work load increases the intensity of activity, heating up the group. A group that is able to coordinate smoothly at a typical work load may tip over into chaos when the pressure ramps up and members can no longer stay entrained. The loss of coordination and high
uncertainty contribute to the negative affect (Kelly & Barsade, 2001) associated with chaos.

Velocity or temperature is not the only factor that promotes turbulence, however. The chaotic state, like the fluid state, can span a wide range of temperatures. The experience of group members will be more intense the higher the temperature. Cooler chaos is like swirling fog; warmer chaos is generalized disorder; hot chaos is like churning rapids.

Viscosity—the resistance of a fluid to flowing (Winterton, 1997)—is a structural characteristic that affects the propensity of liquids and gases toward smooth or turbulent flow. High viscosity helps flow stay smooth even at higher velocity, while low viscosity—hyperresponsivity to any kind of pressure or influence—lowers the threshold for turbulence. In groups, the closest analogy to viscosity is cohesion, the classic variable for describing the “stickiness” of a group. This suggests that factors that weaken cohesion should also predispose a group toward the chaotic state. A sudden disruption may also dislodge the group from its usual routines, disconnecting people from one another (loss of social cohesion) and from their familiar tasks (loss of task cohesion).

When chaos sets in, normal routines and roles fail to organize the behavior of members, as attempts to get things done are partial, disrupted, and incomplete. Alignment is fleeting, so members tend to “bounce off” of one another rather than coordinating effectively. In this state, a strong boundary can help hold the group together as members seek a new path toward order and productivity. If the boundary fails, the group may dissolve, temporarily or permanently. Chaotic dynamics also clear the way for new patterns (Freeman, Kozma, & Werbos, 2001) to emerge, making the turbulence of chaos a gateway to the complex state.

Class 4 Dynamics: Complex State. The complex state corresponds to the extraordinarily productive groups described as hot (Gratton, 2007; Lipman-Blumen & Leavitt, 1999). Along
with the edge of chaos term, this high energy state has also been called *positive turbulence* (Gryskiewicz, 1999). A balance of order and disorder allows for both stability and flexibility. High spontaneous energy flows make even very hard work seem effortless rather than exhausting, so members experience the complex state as exhilarating and energizing. The Millsaps group shifted into this state during its second attack, as the soldiers morphed into a self-organized swarm of highly effective killers. Their behavior after completing their main task (routing the enemy) shows they were still flush with excess energy.

In the complex state, highly energized members have a strong effect on collective group behavior. Members’ openness to the input of others makes energy contagious, allowing groups to quickly reorient around a new idea or direction. As in the chaotic state, positive feedback loops amplify divergent ideas but the ability of the group to maintain a coherent focus channels the boosted energy into the surprisingly productive work of strong synergy (Larson, 2007).

The complex state generates a form of collective flow (Gratton, 2007, p. 1) or Zone dynamics (Campbell et al., 2003) in which strongly interdependent action both triggers and maintains members in a shared zone of heightened group performance. When tasks are strongly interdependent, members’ need to be mindful of one another promotes *heedful interrelating*, a characteristic of *collective mind* (Weick & Roberts, 1993). The deeply satisfying experience of collective flow arises from complex behavioral entrainment.

A variety of structural features have been proposed to help groups enter the complex state. Lipman-Blumen and Leavitt (1999) found that hot groups had very active communication, flat structure and fluid roles. Gratton (2007) identified a cooperative mindset, boundary spanning, and igniting purpose as features that promote the emergence of hot spots within organizations. When strong cohesion allows members to express conflict publicly and productively rather than
keeping it a private experience (O'Connor, Gruenfeld, & McGrath, 1993), then friction can becomes a source of heat. Networks of relationships that span the group boundary promote the flow of resources into the hot group (Gratton, 2007) and more open boundaries also promote turbulence in organizations (Gryskiewicz, 1999), which can fuel either chaotic or complex states.

High diversity, which in low energy states should predispose groups to fixed dynamics, becomes an asset in the complex state, increasing differentials among members. High variability is a hallmark of the complex state. In physical matter, uniformly high viscosity corresponds to the fluid state and uniformly low viscosity promotes chaos. Materials with variable viscosity, however, become more or less fluid in response to pressure and temperature. This variable response corresponds to the threat-rigidity effect by which groups adjust the permeability of their boundaries (Staw, Sandelands, & Dutton, 1981). The high energy, connectivity, and productivity of the complex state suggest the closest analogue in the physical world is plasma, an ionized gas sometimes called the fourth state of matter (Merlino & Goree, 2004). The high electrical conductivity of plasma promotes tightly coupled collective behaviors in which each particle interacts simultaneously with many others. Just as plasma-based technologies generate light very efficiently, with minimal waste heat, complex dynamics channel member energy into productivity more efficiently than the other dynamic states.

Putting the Theory to Work

This section articulates hypotheses connecting thermodynamic state, temperature, and structure. We report briefly on a pilot study that took some first steps toward addressing the problems of measuring group temperature and classifying thermodynamic states. We also discuss the impact of organizational structure and conflict on thermodynamics.

Hypothesis 1a: Fixed state dynamics will have the coldest range of temperatures, and complex state dynamics the hottest, with no overlap among these two ranges.
Hypothesis 1b. The temperature range for fluid dynamics will overlap that of the fixed state but cover a warmer range.

Hypothesis 1c. The temperature range for chaotic dynamics will overlap that of fluid and complex states, but cover a cooler range than the complex state.

These hypotheses can be tested using a cross-sectional design and measuring temperature and state across multiple groups of the same general type and size. Another approach would be to sample state and temperature repeatedly for the same group or groups longitudinally. For groups of markedly different types and sizes, however, the hypothesized gaps and overlaps might not hold, with the fixed temperature range for one group overlapping the complex range for another group. In short, we view generality across group types as an empirical question.

We are still in the early stages of tackling the measurement problems of classifying states and measuring group temperature, a requirement for any test of these hypotheses. A global classification of group state can be elicited by having members (or observers) complete a checklist of features for a specified period of interaction. For groups whose work requires lots of discussion, the conversation can also be used to assess both the group temperature and the dynamic state. Word generation rate divided by the number of members present provides a rough indicator of temperature (average intensity of member energy), based on the assumption that more lively conversations indicate more intense member involvement. The group state can be classified by coding structural features of the conversation after breaking it into threads by examining the content or by direct analysis of a continuous stream of speaker turns (e.g., Pincus & Guastello, 2005). The complexity of interaction can be measured via structural coding for measures of order, repetition, variety, and the length of coherent strings.

Our characterization of the thermodynamic states suggests that along with overall measures of complexity, particular structural features of the conversation should be relatively
common or rare in different states. Groups in a fixed state should have a high incidence of short and repetitive conversation strings, as contributions to the conversation go unanswered or receive responses that discourage further discussion. Groups in the fluid state should have a high incidence of repeating patterns with longer strings than those typical of the fixed state. Groups in the chaos should have a high percentage of novel patterns with very little repetition. Groups in the complex state should have high incidence of longer, more complex interaction strings involving multiple members, with a balance of repetition and novelty.

Pilot testing suggests that these features do correspond to group temperature, group performance indices, and a global assessment of group state. Wise and colleagues (2009) examined three classroom groups that met ten times over the course of a semester. Two observers watched the first three weeks of videotaped interaction for each group and identified the most typical dynamic state using a checklist of features. One group was classified as predominantly fixed, one as predominantly fluid, and one as having predominantly complex state dynamics. Transcripts of the conversation were coded for structural patterns, and word production rate per member was used as an index of group temperature.

The group with the worst task performance (as measured by grades on group projects) had the lowest word production rate and the smallest number of interaction chains that involved three or more group members. Observers had classified this group as being in a fixed state. The group with the best task performance had the highest number of interaction chains involving three or more group members and an intermediate word production rate. This group had been classified by observers as having complex dynamics. The group observers classified as fluid had intermediate task performance, the highest word production rate, and the highest number of repeating conversation patterns.
Hypothesis 2: Temperature change will result in a change of state only when it moves a group across a transition zone, the location of which may differ for different groups.

Changes in a group’s temperature may or may not trigger a shift in group state. Just as liquid water may be cooled from 90 degrees to 10 degrees C with no change in state, the intensity of group activity can vary while the qualitative dynamics remain the same. However, a smaller change of temperature that takes a group across a transition zone should shift the group into a different state, just as cooling water from 10 to -10 C freezes it. For groups, the location of these transition points will differ across groups, and the location may also change over time for the same group. The success of rowing crews, for example, depends on the ability of crew members to stay in tight synchrony and not respond to any momentary deviation from the rhythmic attractor of perfect fluid collective motion (Snook & Polzer, 2003). A major goal of training, therefore, is to extend the range of temperature (intensity of effort) at which a crew can row together with without tipping into chaos as the rhythm is lost.

The pilot groups described above (Wise et al., 2009) varied from week to week in their rate of word production. The fixed state group, for example, produced substantially more words per hour some weeks than others. Yet the increased temperature had no notable impact on their conversational structure or performance level. Hypothesis 2 suggests that this is because the change in temperature failed to push the group through its transition zone.

Identifying when groups shift from one thermodynamic state to another should be possible using both objective measures such as the structure of interaction chains and subjective reports by group members about their experience in the group. Knowing the threshold for transition from one state to another is of particular value for group leaders or supervisors who seek to manage performance by stabilizing the group in one of the two more productive states—
fluid and complex. Hypothesis 3 identifies some factors that should affect the range of
temperatures at which such states are accessible.

_Hypothesis 3: Charges in the internal structure of the group (composition, norms, cohesion) or
the external structure of incentives and constraints in the group’s embedding context can alter the temperature range for each state._

Group and organizational structure are potential levers that can be adjusted to manage the
likelihood of a group experiencing different dynamics. The thermodynamic suggests that
structural changes designed to improve productivity are most likely to be successful when they
expand the accessibility of fluid and complex dynamics, while confining fixed and chaotic
dynamics to narrower temperature bands. Below, we reanalyze a previously published case of an
organizational restructuring (Morrill, 1996) to illustrate this link between structure, temperature,
and thermodynamics.

The case of toy company Playco was originally written as an illustration of how
organizational structure affects conflict management. We use it to illustrate how a change in
structure can shift both the typical temperature at which a set of groups operate and how that
temperature maps to thermodynamic states. The thermodynamic lens also highlights the
paradoxical nature of conflict, which can both chill and heat groups.

In the mid 1970s, Playco restructured its executive ranks from a unitary command system
organized along functional lines to a matrix model, in which product teams included executives
from multiple functional areas such as marketing, sales, and finance. Executives used words such
as “staid,” “laid back,” and “bureaucratic” to describe the dynamics before the restructuring.
Conflicts were handled behind closed doors and people kept to themselves (Morrill, 1996, pp.
180-181). These descriptions suggest a cool temperature range with predominately fixed
dynamics in interactions among executives. The restructuring was an attempt to invigorate upper
management (p. 182) during the challenging business climate of the 1970s recession.

In theory, the matrix created multiple reporting lines to both functional superiors and team heads. In practice, the result was both a sharp increase in activity (temperature) and a shift from the fixed realm into chaotic dynamics. As recalled by a vice president, "nobody knew who to report to or who was responsible to whom" (p. 182). Executives struggled to redefine their jobs amidst the confusion. In the first year of the matrix, 55 memos were issued attempting to clarify reporting lines and responsibilities, many of which were contradicted by the flurry of 58 memos issued the following year. The flurry of memos both illustrates the heightened activity and indicates repeated attempts to emerge from the stressful unpredictability of chaotic interaction.

Eventually, a new order did emerge—based not on the memo blizzard but on the bottom-up reorganization of the executives into a tribal culture of honor. Like warlords in a failed state, executives assembled rival “gangs” or “crews” and formal differences in rank lost their meaning (Morrill, 1996, p. 184). Instead, executives earned status via ritualized confrontations as conflicts over project-related decisions were worked out via public “duels.” The new system was characterized by a frenzy of activity and dense interaction among highly engaged executives, who relied on gossip (described as a core function of the communication network, p. 186) to track dynamic changes in reputation. From the thermodynamic perspective, the crystallization of new order was a second, bottom-up restructuring that allowed the already invigorated but formerly very confused executives to emerge from chaos into the complex state.

In the complex state, high levels of spontaneous energy flow, channeled through appropriate structures, get tasks accomplished in a way that is energizing rather than draining. The emergent structure consisted of a set of rules, rituals, and a status system that promoted rather than dampered conflict, replacing negative feedback loops with positive feedback. The
strong emotions and arousal provoked by public conflict fueled intense engagement and the culture of honor channeled this energy into (mostly) productive task-relevant debate. Conflict was transformed from a private experience that disrupted interaction into a major heat source that helped keep Playco in a hot complex state.

An exemplar duel among members of a product team illustrates the dynamic. The issue under dispute was the appropriate target dates for the development of some new products. R&D executive West and marketing executive and project team leader Harris, supported by sales executive Holmes, developed competing plans. As recounted by Morrill (1996, pp. 200-202), feverish activity ensued as both teams carefully prepared for the duel, and the duel itself was well attended by executives eager to see who would prevail. At the end of the confrontation the loser (Harris) tore up her copy of the losing plan and the two sides ritualistically shook hands. By transforming decision making on key issues into a high stakes spectator sport, Playco ramped up both internal and external heat flows, ensuring that people would pay close attention out of intrinsic interest. Information about duels and their outcome circulated spontaneously to those not present in the form of gossip, transmitting information and energy beyond the group’s boundaries with no need for the effortful work of generating memos.

The Playco case includes several features that other writers about hot groups and hot spots consider critical. Lipman-Blumen and Leavitt (1999) identify active communication, flat structure and fluid roles as key features. The emergent order at Playco included all three. For Gratton (2007), cooperative mindset, boundary spanning, and igniting purpose facilitate the emergence of hot spots. The cross-functional teams institutionalized boundary spanning. The igniting purpose that drove the duels, however, appeared to be as more about attaining and defending status than a shared concern for Playco success. The public duels also departed from
Gratton's ideal of a cooperative mindset and instead illustrate the more individualistic motivation of competition and aggressive, which in Gratton's view drains energy and freezes up the system. From a thermodynamic perspective, anything that promotes dense interaction and supports the spontaneous circulation of energy can be a source of heat. What matters for performance is whether the spontaneous friction of conflict is captured and channeled into productive work.

Concluding Remarks

We had three goals in writing this paper. The first was to fuse our ideas about group heat and structural dynamics into a more coherent thermodynamic account. After many cycles of heating and cooling our ideas, we hope the material is sufficiently tempered to be useful. The second goal was to plumb the potential of thermodynamics as an analogy to group dynamics. Although the differences between physical matter and social entities require adjustments in the metaphor, the potential is far more evident to us than the limitations. If the paper succeeds in persuading some readers of this potential, it will help achieve our third goal of widening the circle of collaborators working to develop and apply thermodynamic group theory.

We believe group thermodynamics has potential as a general account of how dynamics, structure, and productivity are related. We believe the approach can help explain paradoxical or mixed results by pointing to the nonlinear relations that are ubiquitous in thermodynamics. Conflict, as we have noted, can both heat and cool groups. And structural features such as diversity can have very different effects depending on the group temperature. It can be an obstacle to smooth interaction in cooler groups, harming productivity, but help fuel creativity and complexity in groups that have warmed sufficiently to enter the complex state.

Practitioners will, we hope, find group thermodynamics to be a useful conceptual tool for thinking about interventions in terms of energy, heat, and dynamics. Sometimes large
interventions with groups have little apparent effect because the resulting change in group
temperature does not shift the group across the threshold to a different state. At the transition
zones, the absorption or release of energy associated with transitions (called latent energy in
physical thermodynamics) suggest that changes in energy input should be related in a nonlinear,
step-level fashion to both group temperature and productivity. Even close to a transition point,
sustained energy transfer may be required to move a group from the fixed to the fluid state. In
contrast, a small intervention can be highly effective in releasing a tremendous amount of
productive energy if it helps a group emerge from chaos into the new order of the complex state.

Going forward, we plan to pursue tool development, data collection, and theoretical
extensions. Developing reliable measures is the most pressing agenda item. The study of
physical thermodynamics made huge advances after the invention of the thermometer
(Kondepudi & Prigogine, 1998; McKenzie, 1961), and we hope the group thermodynamic
approach will also gain more traction once a group thermometer is available. Classifying
thermodynamic states should prove less challenging, just as the differences between ice, water
and vapor were readily apparent long before the temperature of water could be reliably assessed.

Whether we have accurately identified all the group thermodynamic states, whether they
are distinguishable from each other in precisely the ways we have described, and whether the
hypothesized links to temperature, structure, and productivity are correct are of course empirical
questions. Both cross-sectional and longitudinal designs will be needed for a full investigation.
For longitudinal work, we find Campbell and colleagues’ (2003) proposed mapping of order,
chaos, and complex states to group development models to be a very promising foundation.

Computational modeling (implemented using the equations included in the Appendix) can
be used to explore the web of proposed relations among energy flows, group structure,
productivity, group state and other variables. The outcomes of computational tests can help adjust the theory. Modeling results can also guide researchers in choosing particular subsets of relations to target for empirical tests using archival, experimental, or field study data (Zacharias, MacMillan, & Van Hemel, 2008). We also plan to articulate the multiple mechanisms of energy transfer as a next step in theory development and an important aspect of thermodynamics for practitioners.

We close by acknowledging our debt to Leavitt and Lipman-Blumen for introducing us to the hot groups metaphor, to Gratton for extending this metaphor to the varying temperatures within a single organization, and to colleagues too abundant to enumerate who have been working to integrate the insights of dynamical systems, chaos, and complexity theory into a more fundamental dynamic understanding of groups. We hope that our integration of the temperature metaphor with group dynamic states will give scholars and practitioners a more powerful set of tools to build theory and accumulate relevant data to explain the underlying mechanisms of the heat engines that allow groups and organizations to be productive.
References


Appendix

Postulate 1: Group energy includes current member activity and potential member energy.

\[ gE = \sum_{i=1}^{n} ma_i + \sum_{i=1}^{n} mpE_i \]  
[Eq. 1]

where \( gE \) stands for group energy,

\( ma \) represents current member activity,

\( mpE \) represents potential member energy,

\( i \) represents each member and \( n \) the total number of members in the group.

Postulate 2: Group temperature is the average intensity of member energy.

\[ Degree \ g = \frac{\sum_{i=1}^{n} \left( \frac{mE}{mE_{max}} \right)}{n} \]  
[Eq. 2]

where \( \theta g \) indicates temperature for a group,

\( mE \) indicates member energy, which includes current member activity (\( ma \)) potential member energy (\( mpE \))

\( mE_{max} \) represents the maximum energy available from a 100% engaged member

\( i \) represents each member, and \( n \) the total number of members in the group.

Postulate 3: Group heat is the rate of spontaneous change in energy levels in other systems attributable to the group.

NOTE: Group heat includes is separable into internal group heat (\( igQ \))—the rate of spontaneous change in the energy levels of members attributable to group membership—and external group heat (\( egQ \))—the rate of spontaneous change in the energy levels of non-members and other external systems attributable to the group.
\[ igQ = \frac{\sum_{m=1}^{n} (\Delta iE)_m}{\Delta t} \]  
[Eq. 3a]

where \( igQ \) indicates internal group heat flow,
\( \Delta iE \) represents spontaneous change in individual energy
\( i \) represents each member, and \( n \) the total number of members in the group,
the subscript \( im \) refers to that portion of spontaneous energy change for a specific individual attributable to their membership in the group, and
\( \Delta t \) indicates the time period measured.

\[ egQ = \frac{\sum_{k=1}^{j} (\Delta jE)_k}{\Delta t} \]  
[Eq. 3b]

where \( egQ \) indicates external group heat flow,
\( j \) represents each external system,
\( k \) the total number of nonmembers or other external systems,
the subscript \( jg \) refers to that portion of spontaneous energy change for a specific system attributable to involvement with the group

**Postulate 4:** Group work is the expenditure of group energy on group products and on increasing group productive capacity.

\[ gW = gE_o + gE_{\Delta c} \]  
[Eq. 4]

where \( gE_o \) is group energy expended on group productive output (products/services),
\( gE_{\Delta c} \) is group energy expended on improving the group’s capacity to turn member effort into acceptable group output, and
\( \Delta c \geq 0. \)
Author Note

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