

Vol. 1. No. 1 Society 1.1
One Science – Physics
 (revised)
 By Arthur S. Iberall

“How can I or anyone else claim that there is a set of principles, so embracing, that it can apply to all systems, simple and complex, living and nonliving, small and large? That arises because there is one science that is first among all the others. That science is physics -- the laws of motion and change in all systems.”

So said Aristotle, the Greek philosopher-scientist, 2300 years ago. We physicists believe that the reality of that promise has been amply realized by the further contributions made by Sir Isaac Newton, James Clerk Maxwell, and Albert Einstein. Is it now possible to expose those principles of physics to a social physics? Is it further possible to do it in such simple terms that its applicability and rightness will become adequately apparent? What would a social physics look like? Merriam-Webster defines society as “an enduring and cooperating social group whose members have developed organized patterns of relationships through interaction with one another.” Predicting people’s behavior isn’t as easy as predicting the behavior of a motor, say, or a radio. These mechanical devices were designed for a specific reason and come with user manuals. People don’t. They interact, they have emotions and needs. And yet, I believe if you stay with me, by the 3rd essay, you will begin to see how the principles of physics can be applied to any complex system, even one as complex as a society.

Forces are agents of change

Physics states that *forces* are agents of change, and change causes movement. Atoms, particles of dust, ping-pong balls, living cells, people, even stars – are all engaged in motion. When they move freely, we can imagine that there are no forces acting on them (for the moment, we will ignore gravitational and electrical forces). At some point in time, one of these items will collide with another. A force will arise -- a mutual mechanical force of collision. Such a force causes a change in motion. They each redirect their movement and continue again until they collide once more in new pairs.

This simple description contains principles of physics. While our intent is to provide a foundation by which we can describe the group motion of a society, we really want to examine what happens during the time of collision. And there are three equivalent views of such an effector of change.

In the most direct view, the action of a force is to change the motion; that is, to make the item accelerate. You push on a thing, it jerks forward by a change in motion.

In the second view, the effect of a force acting for a time is to change the motion more directly. Multiplying the amount (or measure) of that force by the measure of the time it acts is known as the *impulse*. The impulse changes the item’s momentum. *Momentum* describes how fast the item is moving (as opposed to acceleration, which is how fast the

Impulse = force \times time

Momentum = mass \times velocity

velocity changes). Momentum is the velocity of movement multiplied by the mass of the item (*mass* is how much matter it contains). Humans engage in this process all the time. If you swing a baseball bat or a golf club to a ball, the impulse changes the momentum of the struck object. Remember, the impulse is the collisional force multiplied by the time that force acted. If the object is massive like a big chair or big ball, the change in velocity is of lesser magnitude for the same impulse. You can try it yourself. Slap a ball against a wall and see how the impulse of your slap starts the ball moving. See then how the impulse from the wall changes the momentum of the ball as it bounces back from the wall.

$$\text{Work} = \text{force} \times \text{distance}$$

In a third view, the effect of a force acting through a distance is to change the *energy of motion* of the item on which the force acted. For example, pushing or pulling a box on the ground for some distance changes the box's energy. Multiplying the measure of the force and the distance through which the force acted is known as the *work* done on the item. The energy of motion is measured by the product of half the mass of the item multiplied by the velocity repeated twice.

$$\text{Energy} = \frac{1}{2} \text{mass} \times \text{velocity}^2$$

To summarize, physics is concerned with forces acting in space and time on masses of matter. That is from where the changes in motion arise. Now, we continue on to discuss the subsequent motion caused by the collision.

Three Measures are Conserved in Motion

The forces of collision come in pairs (one hits the other and the other hits the one), and as a result, the forces are equal and

opposite. This is Newton's third law of motion. And since the forces are equal and opposite, their effect on the pair of colliding particles is nil, or zero. Therefore, the paired aspects of their motion have not changed. Since each of the force collisions that occurred involved a distance of collision (the work done by the collision) and a time of collision (the impulse of the collision), we can state that:

- the pair of particles did not accelerate;
- the momentum of the pair of particles did not change; and
- the energy of the pair of particles did not change.

Also, there was no reason for the mass of the pair of particles to change. Thus, even though the independent motions of each of the particles in the pair did change, the composite measures of the pair did not.

From this analysis, we infer that there were three fundamental properties of the pair that did not change. Those properties are known as *the fundamental conservations of the motion of collision*. The three measures that were conserved were:

- the measures of their matter (before, during, and after the collision),
- the measures of their momentum, and
- the measures of their energy of motion.

As a result of the fact that three such conservations exist, we can determine the motion of the colliding pair of particles

due to collisions pair by pair. Watch any ball player, yourself or perhaps your skilled children, or any golfer, or any pool player. They are computing these properties of collisions each time they exert a colliding force on some object. While the mathematical expression of collisional forces and conservations is perhaps frightening, it doesn't take mathematics for a three year old to begin to demonstrate objective skills of performance in accordance with these principles. Nor does it in non-humans, for example, in a bat echolocating, a hawk swooping on its prey, or a monkey jumping from tree to tree.

Why does all this matter? Let us think for a minute how we can use these principles in studying various systems. In a gas, for example, we use it to describe one collision between two atoms or molecules; of course, there are billions of billions of billions of such particles. Or, in a galaxy, we would use it to study the billions of billions of stars interacting. Or, in a living organism, we would use to study billions of cells interacting. In these examples, there is more going on than just the effect of one pair of colliding particles. But here again, the principles of physics come to the rescue and tell us how to describe the multiplicity of all the pairs of interaction.

Atomisms are the Units at Any of the Nested Levels

In the most general sense, that multiplicity of all the pairs of interaction is known as the connection between the micro and the macro -- the little and the big, the local and global. For the micro game, we refer to the play as the resulting *kinetic or dynamic interaction* among atomisms. *Atomisms* are the

generalized description of atomic-like or atomistic "things": the things that banged into each other in interaction without necessarily getting destroyed.

The atomic doctrine was first developed by the classical Greeks who sought out the primitive particles or material substances that might arise with indefinite division of material objects. They could not fully decide how many such particles there were nor what those particles were. We know now that such atomistic particles come in nested levels, making up a complex hierarchy of such units. For example, we have a cosmos which comprises perhaps one or more universes. Within any such universe, there are galaxies. These galaxies comprise large collections of interacting stars and cold matter. In and among that matter, there are a variety of other intragalactic matter systems - planets, planetisms, clouds, and chemical systems such as geochemical and biochemical systems. Within these, there are atoms, ions, and molecules. The smallest level we know at the moment are the leptons and quarks, all in a so-called vacuum. According to our current demonstrations and understanding, the result of interactions among leptons and quarks is to produce the same or other leptons and quarks from the vacuum. At present, we can't find anything or things below them. At each level are the units – a cosmos, a universe, a galaxy, a planet, a human, an atom, a lepton. These are the atomisms of the nested level. At the level most interesting for us in this study, we wish to concentrate on the biochemical systems which include us and our societies.

Note that the macro-micro game among the atomisms and their organized field of play is much more extensive than any simple game that people play. Consider a game of baseball. We may consider one interaction to be a batter facing an opposing team of 9 players. In 9 inning turns, three players from each of the two sides up at bat in turn have to be put out, starting from play initiated by a pitcher who is manipulating the throw of a ball by the laws of physics. Thus a game, minimally, involves 54 playing interactions, in which every batter is put out in turn. But that is not the total play. Since the batters may score base hits rather than be put out, many more than 54 turns at bat are taken. It is more like 100-200 turns at bat that are taken. One hundred years have not exhausted the amount of drama this game can create. Yet that game is extraordinarily simpler than any natural atomistic system of field play. Nevertheless, physics can collapse the play of one of these mammoth field games to a relatively small measure.

Flow fields: Motion for a Field of Players

Imagine watching water flowing past a ship's propeller. You are looking at what is called in physics as a *flow field* – which is the result of the pair by pair motional interactions of water molecules. You can see flow fields being produced by fans, water pumps, and hair dryers. Also, by turbine-driven aircraft, reaction spacecraft, rotationally driven galaxies, nuclear reaction-driven stars. You see it in the flow in a river, the tides in the ocean. In more general terms, a flow field is a *field phenomena* – which is the organized play of a large ensemble of players interacting through an extended space-time field of motional action among them. A flow field is likely the most

common of all physical field phenomena. So how does one describe its general phenomena of motion?

Local Averages Provide Method for Quantifying Motion

In order to understand the more general motion of the entire field of players, we'll start by introducing an intermediate description of the local ensemble. Let us imagine a local space-time box in which a considerable number of interacting plays are taking place. Look at it as a small local ballfield or a portion of a street where a ballgame is going on. Namely, there are a considerable number of players in the spatial box which only occupies a small amount of space, and we are going to observe the motion in that fixed box over a considerable length of time. In addition, we are only going to examine the motion at certain intervals of time (e.g., every other inning, etc.).

What we get out of those discrete, intermittent observations are local averages, the statistics that every one who lives in that neighborhood knows. For example, every time we blink - making one of our intermittent observations - we can count how many particles are in the box. Or, as an equivalent measure, we can count how much matter (mass) these particles have contributed to the content of the box. Those counts give us one local measure -- the local density. Note that we will either have the number density or the mass density. Suppose you imagined the box to be one cubic inch in volume (1 inch by 1 inch by 1 inch), and you counted 10 particles in the box, or 10 grams in the box (the mass of a U.S. nickel about 5 grams). Then we could say that the

number density is 10 particles per cubic inch; or the matter density is 10 grams per cubic inch. If we kept counting the contents of the box at different observation times, each time perhaps finding a different number - say 10, 13, 11, 15, 13, 11, 13, 10 - we could count up the total 96 and divide that by the number of observations 8, and get an average, 12. This is a statistic. We would then say that the average density (number or mass) is 12 per cubic inch.

In the same way, we could get the average for the amount of momentum that is to be found in this local box. We get that average by adding up how much momentum each particle carries when we look at it. Then, similarly, we could find the average energy of motion in the box.

Conservations for the Local Group

We saw earlier that three measures -- mass, momentum, and energy – are conserved in pair by pair collisions. What about when we are observing local averages for a local ensemble of collisions? After all, we are no longer looking at just two particles. We have to extend our view to include the conservations across the group. Our local intermediate level of measures represents the local group conservations that are being carried on in the field of particles. In terms of physics, we can name these intermediate local measures:

1. **Density.** Corresponding to the conservation of number of particles or mass of particles, we have the local measure of density.

2. **Pressure.** Corresponding to the conservation of momentum, we have the pressure. Pressure represents how much momentum per unit wall surface per unit of time that the particles in any extended region will deliver through any imagined wall space.
3. **Motional energy.** Corresponding to the conservation of motional energy of a pair of particles, we have the motional energy of the local group. Since it measures the energy associated with the specific volume, it is called the *specific energy*.

For pressure, think of it as the atomistic "balls" being engaged in a handball game against some imagined wall. Cap off the flow through a hose or through a hole in a pressurized container or balloon, and you can feel the pressure mount. It is the force per unit area of the hole that you had to exert to barely seal the hole off.

As for local energy, there is again an easy physical way to see it. Put your finger into that field of atomisms, and feel its *temperature* with your finger. That is a measure of the energy that the atomistic things carry. Of course, if we want the true measure of the specific energy, then the temperature is not enough. The specific energy is contained in the measure of the motional energy every which way that the atomistic thing can move. Temperature is a common equal measure of that motional energy in any one way of moving -- what we call one *degree of easy freedom* to move. But we need to know how many degrees of easy freedom there are to move.

There are always at least three ways for a free body to move - forward-back, side-side, up-down. Any particle, however tiny, if free, can move in those directions. But a fair sized ball can also spin in three ways, which adds three more ways to move. If an item has internal parts, there are also ways of shaking or vibrating or rotating or associating those parts.

The upshot of all these ways to move is that specific energy can range from 3 to 12 times the measure of energy of motion beyond what temperature by itself might permit if there were only one degree of motional freedom. For example, see how fast a thermometer (which is a known system that can be taken as a reference) moves toward the last few degrees of the current temperature. The measure we are going after is the so-called *heat capacity*. This is a measure of how much energy you have to put in to something in order to raise its temperature, say, 1° C. That measure tells you how many degrees of freedom the energy could have. This is from 3 to 12 degrees of freedom.

In summary, we see that the atomistic group conservations, for a given ensemble of atomisms, can be represented by three local measures: density, pressure, and temperature.

The Relationship Among Conservations: Equation of State

These three local group averages for the three micro conservations are related in an invariant way. That relation is known as the *equation of state of the group or ensemble*. Let us think back to the little box in which we made the observations to determine the local averages. Think of many of

these boxes. In every one of those freely connected and equally accessible boxes, the same equation of state exists. It no longer relates to only one box, but to all such boxes. There are many ball games going on throughout the whole field region. However, the individual group measures may vary from place and time to place and time. We will come back to this concept.

Why are these local conservation measures connected by an equation of state? It is because, each time a new particle enters a box, it carries its number (or mass) count, its momentum count, and its energy count into the box. As long as these are the only conservational measures, then these three new fluctuations are connected just in the same way as the ones in the box already.

Now let us extend this analysis to larger items, such as baseball players. Suppose there are lots of ball games going on. Each game is occurring in its box -- the Yankees in Yankee Stadium, the Red Sox in Fenway Park, you name it. All these games – as well as the teams, players, rules, and managers -- are connected together into a league, and all the elements of play are, loosely speaking, comparably competent to continue playing. We want to know, not how to win one of the ball games, but how to manage it with enough competence to stay in the play. As we know, there is no manager who can win all the time. You don't win them all, or get a hit every time at bat, or even put out a batter at every turn. Professional baseball has many statistics, many of which are recited repeatedly by people, particularly boys and their older counterparts, from perhaps 8 years of age on up.

They know how many hits a player can average and how many games a pitcher has won. Fans are always second guessing the manager. What can physics tell us that these avid observers do not know?

Ballplayers are not just any human beings, they are drawn from a special pool of people who can learn and acquire a particular set of skills. They also apply the laws of physics to produce different statistical results, something a manager is acutely aware of. For example, with ballplayers, you need to select them and use them so that they average nearly one hit per five times at bat with perhaps one third of them capable of producing one hit per three times at bat. You have to have a pool of pitchers who can pitch enough strikeouts and not give up too many hits, and you have to have fielders who do not make playing errors with more than a certain frequency of play. These are mechanical tasks performable in rather narrow limits by only certain people. But they are also thermodynamic field tasks or processes: the ballplayer is converting mechanical energy from one level of the atomism to another, for example, transforming Wheaties to base hits and put outs, or transforming ball play to earned money, or from ball play to a variety of internal emotions, such as elation, satisfaction, and anxiety. All these processes are involved in managing a ball team.

And ultimately, whether we are looking at ball players or molecules in a gas or liquid, the players at any level in the atomistic hierarchy are engaged in a statistical mechanics-thermodynamics game with the same physics specialized for each of their games.

Local Measures are Connected

We have examined the local connected averages in a simple flow field - density, pressure, and temperature or specific energy. When do we pay attention to temperature and when to specific energy? If we have selected our molecular player, say water molecules rather than oxygen or hydrogen molecules, temperature would be our third local measure. If we mix up the molecular players, then we have to take into account the specific molecular properties of their specific heat. This would be equivalent to the problem of managing a mixed group of players - say baseball, golf, and tennis players. Their actions work differently and have different worth.

An interesting point to note is that these local averages are connected. This means that if you elect two of them, the third one is prescribed. What does that mean?

Let's start with density. To do this, let's take a closed empty rigid container with some particular volume, say one liter. Now put just a small amount of water in that container without any air. This is not as easy as it sounds. The easiest way to achieve this state without laboratory equipment is as follows: Start with a bottle which, of course, will have air in it, and put some water in the bottle. Begin to heat the bottle until the water boils out (you can use a double boiler to do this). If you put a flap on top of the bottle, perhaps hinging a cork as a cover, the water will boil out as steam with no air returning. When you have boiled all the water out until only steam remains, or boiled out some of the water until

whatever amount of water you want to leave in the bottle, you can then seal it with a cork or stopper. Now let the water cool off, and you will have succeeded in the proposed task. Other ways might require a very good vacuum pump, a completely collapsible balloon later jammed into a box, a carefully constructed piston and cylinder, or heat and a system of valves. The amount of water (as liquid water or steam) that you put into or left in the container determines the density of water in that container. Namely, if you divide the measure of the mass of water in the container by the volume of the container, that measure gives you the average density of water in the container. That is how you managed to fix the density.

<p>Average density = mass/volume</p>
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Next, let's fix the temperature. The easiest way would be to put the closed-off container into an oven or a refrigerator. Before doing this, put a thermometer into the appliance and adjust the temperature to the one you want the water to have. That fixes the temperature.

Now, what about the pressure? You can determine what the pressure is in the container by measuring how much force is required to hold the lid sealed. However, you cannot fix the pressure in the container. It is fixed by the fact that:

- (a) you filled the container with a specific number or mass of water molecules, the "things" you chose to manage, and
- (b) you fixed the temperature (the motional energy measure).

This fixes the pressure. That is the meaning of the equation of state for water.

Change the type of molecule and you would have another equation of state for the other molecules (the change in the equation of state would depend on properties of the molecule).

Phase of Matter Can Change As Well

Let's manage the contents of that bottle. For example, suppose we first made certain that the walls of the container were all held at the same temperature. How could we do that? By putting the container in a totally temperature-regulated bath – for example, a refrigerator or oven or a surround of gas or liquid (or even sand). After a certain amount of time, the internal temperature in the water will all be the same as the wall's temperature. But now we find a surprise. At high temperature, we find that all the water is evaporated and the contents are only steam vapor. Also, we find that as the temperature raises further, the pressure raises.

At sufficiently lowered temperature, we find a value at which steam starts to condense to droplets of water. The lower the temperature, the larger the pool of liquid droplets we find. Then - another surprise - we reach a temperature at which the droplets or pools of water freeze into a solid -- water ice. There still is a "steam" vapor, but its vapor pressure has been diminishing all the way with temperature (How do we know? Put in a surface much colder than the container temperature, and you will see that "steam" or vapor condensing. You see

such a process in the morning as the dew on the grass evaporates as soon as the surface warms up).

We can see that the equation of state for water or any other pure atomic or molecular substance can be rather complicated. Not only does the state of density, pressure, and temperature change, but also the phase of matter - gas, liquid, solid or combinations of these phases - can change with the state measures. We can manage to make pressure, temperature, and density do a versatile variety of things. Before refrigerators, for example, people used “ice boxes”, where a piece of ice was put in a box, and even though the ice melted, it would keep the inside of the box cool, for example, near 32 ° F. Another example: on a hot day, you can put on a wet shirt. As the water evaporates, it will cool you off.

To exemplify a little more versatility than we have so far shown for the equation of state, let us suppose that we raised the temperature of the water vapor to extremely high values. We would find that we could reach temperatures that would destroy the molecules. The high motional energy of the molecules banging into each other at high temperature would crack them apart, achieving a chemical reaction. The water molecules would change their chemical state and separate into oxygen and hydrogen. At another level, for example, eggs: you can burn the eggs you are frying. Or, we could add other ingredients to the water and cause it also to enter into other chemical reactions. So we see another aspect of an equation of state, the possibility for chemical changes in state. Chemistry, by definition, is the making, breaking and exchanging of bonds

between atomistic components; this will remain true even when we deal with societies.

Creating Flow Fields

But let us now get to a more dynamic game, one worthy of calling fluid dynamics (hydrodynamics, using the Greek stem for watery or fluid matter). What we want to do is to take the changeable equation of state, changeable from time and place to time and place, and manage it to do things in time and place. Let us start simply. In the surface of a closed rigid container, prick a small hole. The rest of the container wall maintains its temperature and pressure. The pressure falls near the hole. What happens? There is a flow of momentum out of the hole. In time, the contents of the container loses its contained momentum; that is, its pressure falls. Its temperature doesn't have to fall. We could continue to keep the walls warm.

This simple example demonstrates that by changing the equation of state measures between different regions of a matter field, it is possible to create flow fields, for example, flows of density, flows of momentum, flows of energy.

Transport Measures Characterize the Flow

The description of these flows are represented by equations of change. There are as many equations of change as there are conservations. In a simple flow field, we see:

- three local conservations (density, momentum, energy), and
- three equations of change, one globally (throughout the field) for each local pair by pair conservation. Namely, there is a flow of mass or number, a flow of momentum, and a flow of energy.

The description of these processes is very complex, so we will just touch on them. Suffice it to say that depending on the atomistic material and its temperature or pressure range, there are *transport measures* that tell one something about the rules of flow. Transport measures are known as diffusivities. A *diffusion* is the process of spreading out or scattering:

- There is a measure for how fast one kind of atomism may move among other kinds. That is known as the *mass species diffusivity* (each type or species of atomism can have a different measure).
- There is a measure for how fast momentum will flow. That is known as the *momentum diffusivity*. The more common name is the *viscosity* of the fluid substance. Water, because of its great fluidity and low viscosity, relaxes quickly and diffuses its momentum slowly. Tar, because of its small fluidity and great viscosity, relaxes slowly and diffuses its momentum quickly.
- There is a measure for how fast energy will flow. That is known as the *energy diffusivity*. Its common name is the *thermal conductivity*. It tells you something about how fast you will say “ouch” when you touch a hot surface.

Examples of Managing Flow

Let us now illustrate how to manage these processes independently. First, let us manage a flow itself, for example, the flow or diffusion of momentum.

Take a large container and pump it up with pressure. Suppose, first, that you keep the temperature of the container constant, or nearly constant. How? Leave it standing outside or put the container in a refrigerator or oven. Push a little amount of material into the container. For example, you can blow small amounts of air in, breath by breath. Or you can push a small amount of water in by using a pump or by pouring it in using the gravitational force. As you push the gas or liquid material in, you will begin to see the pressure rising. But think of using a very large container. It will take a long time to get the container or reservoir filled and the pressure high. But it will get there.

Now someplace in your reservoir, say near its bottom, make a hole, perhaps plug in a pipe and add a valve so that you have a hole that you can open and close. Here, then, you will see how the pressure in the reservoir creates a flow or diffusion of momentum from the hole, pipe, or valve. You are the manager of this system.

Is this real and practical? Of course. It is the way your city supplies water to every valve or faucet connected to its large reservoir. You don't win or lose in this game of managing such a flow supply, you just succeed in doing it.

Let's manage the flow another way, through temperature. This time fill up the reservoir, but don't pump up its pressure high. If, for example, you have water in the container, put the hole on top. Now heat the container so as to raise its wall temperature. Recall in the equation of state that with temperature rising, the pressure rises. After a while, the water is converted to steam and its pressure then creates a flow of momentum. That is, through manipulating the energy via temperature, we used the equation of state to transform that measure into pressure and then the pressure into a flow or diffusion of momentum.

Is this practical? Of course, it's the basis for the steam engine, also called the external combustion engine, because the driving heat came from outside and was applied to the container walls. Such a container is known as a "boiler". You likely have one in your house. It may be used in a combined fashion, partly used as a reservoir of pressure and partly as a reservoir for heat energy to give you hot water or steam flow.

This suggests a third way to create a flow or diffusion of momentum. This is by a process of *chemical conversion*.

This time, insert a mix of two substances, say liquid gasoline and air. With an igniting hot spot (high temperature) produced somewhere in the mix, these two different sorts of molecules may undergo a chemical process. As we mentioned, chemistry is the making, breaking, or exchanging and joining of bonds among atoms and molecules of all sorts. In the case of a simple fuel and oxygen, the chemical process is one of breaking and exchanging fractions of each type of molecule. But that process

gives off heat energy, and that heats up the old and new molecules. Then, as before, that raises the temperature of the materials. That raised temperature raises the pressure, because the density was fixed, and creates a flow.

Is this practical? Yes, it is what happens in each cylinder of an automobile engine many times per second. A small amount of fuel and air is pumped into the cylinder. It is sparked electrically to start a combustion. The fuel and air "explode", producing high temperature and pressure. That pushes the little cylinder container into a larger volume configuration via a piston-like motion. That spins the crankshaft and wheels. After each such explosion, the flow products are exhausted out the tail pipe. This device is called an internal, rather than an external, combustion engine, because the management took place among the players. (A Diesel engine doesn't use a heating spark to ignite the fuel. It just compresses the mixture enough which then explodes chemically).

Here is another way to create a flow of momentum. We place a series of blades mounted on a shaft, at an angle to the shaft. Now, if we turn the shaft (a mechanical motion), those blades will "grab" the air and force it into motion. This occurs because of a *flow boundary condition*. If we move a sheet of atoms or molecules past other sheets, the one sheet will drag the other sheet. This is due to a dynamic transport property of matter, in this case the momentum diffusivity or viscosity. To make this work fairly well, the sheet of molecules used for the drive was the surface of a solid, so that they remained united and stuck together. The molecules of the fluid that we

dragged the solid sheet past could not oppose that motion too strenuously, so they had to move. That created a flow or diffusion of momentum.

Is that practical? Of course, those blades may be a propeller or turbine in an airplane or a ship and they create the flow stream that makes the craft move. Here the momentum transfer was rather direct. When an entire ensemble of players are forced into motion directly, shepherded, that is known as *convection* rather than diffusion.

Let's look at a final example that appears to be made more indirect, and therefore, is a little more subtle.

Let's take two containers. Let's join them on a common smooth face, say by abutting them together. We will fill each container with a different molecular substance, say one oxygen and the other nitrogen, or one water and the other oil. We'll arrange to have the same pressure in both containers, as weak or strong as you want. To do this, we could open holes in both containers, suspend a weighted and tapered piston in each hole, and keep filling both containers till the same weight in each piston "floats". You see this example in a pressure cooker. The weight of the float, for a given area of vent hole, determines the "pressure" of which the float rises and vents material. We will also arrange the same temperature bath on both sides.

Now open a hole or a pipe between the two containers. With the same pressure and temperature on both sides, you might think that nothing will change. But it will. Substance 1 will diffuse into substance 2, and vice versa. Because of the

difference of materials, there will be matter or mass diffusion, which thus creates a momentum diffusion of each substance separately.

Is this real? Certainly. Every time you put milk or cream or sugar in your coffee, you see the process taking place without stirring. How do you think the water that rains on earth gets back into the atmosphere? Largely by that evaporative, diffusion, process.

Summary

In summary, an equation of state captures the relation among atomistic conservations. There are equations of change which you can manipulate from "outside" (at the walls) or "inside" (as a player) to manage and influence the play in space or time throughout the field. You can transform any one of the conservations, stationary (static) or changing (dynamic), into any of the other conservations, in a different static or dynamic form. That is the game of flow or field physics, and it provides us a set of starting tools to manage a society, an enduring and cooperating social group.