A NEW THEORY OF THE INORGANIC WORLD

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Translated by Michel Slubicki

It is, in fact, a new theory of the inorganic world R. Fr. Ad. Laray offers us in these two slim volumes, for which MM. Gauthier-Villars publishing house has loaned its shining fonts.[1] This theory is inspired by, but not simply modeled after, all that the great philosophical systems have expressed for the past three centuries. Descartes's system, Leibniz's and Boscovich's have each provided something to Fr. Laray, but he improves the theory of the inorganic by synthesizing them, and by adding new theories. He succeeds at putting together a system like no other, belonging to him, and only to him.

As with all thinkers who have probed to the very bottom or core of their ideas, Fr. Laray is extremely clear. It is fashionable these days to deem profound only that which is obscure, as if one were turning Boileau's famous epigram upside down and claiming that a well-articulated thought cannot be expressed clearly. This fashion was imported here by a philosophy born in the vicinity of the fog of the Baltic Sea; it was unknown when thinkers were breathing only the air of the Mediterranean. Thank God, there are people who refuse this new fashion and Fr. Laray is one of them. His definitions are presented in a clear and crisp manner; his deductions follow one another with method and order; he is not aiming at achieving a literary effect; he says just and only just what must be said in order to be understood. In other words, he thinks that reason is better served by a geometrician's style than by a novelist's.

Fr. Laray has another quality, quite rare these days. He is not only a philosopher, but also a theologian and a scientist. As a theologian, he knows how, without ever confusing the domains of natural truths and revealed truths, without using the latter in a book devoted to the former, he knows, I say, how to use the light

[1] R. Fr. Ad. Laray, *Essai sur la synthèse des forces physiques* (Paris, 1885); *Complément à l'Essai sur la synthèse des forces physiques* (Paris, 1892).

faith has given him to clarify the labyrinth of rational metaphysics. One good example are the limits he carefully sets to some very general propositions, endorsed by many philosophers, which are in opposition to the Church's dogmas of Incarnation and Transubstantiation. But again, this theological influence is reduced in Fr. Laray's work to what is required to treat in a fair manner both the rights of revealed truth and those of reason. Never is a revealed truth going to be the basis for a deduction that would lead to a truth belonging to the scientific domain. Faith is for him only a kind of barrier that marks the precise limit where one leaves the solid terrain of natural truths to fall into mistakes that happen to be heresies.

But Fr. Laray is not only a theologian, he is a scientist as well. That is what makes this work valuable. How many of those books have we seen these past years wherein an writer, ignorant of the most elementary scientific knowledge and informed by reading some half scientists or popular magazines, offers nevertheless a complete explanation of a universe he has never really looked at! Fr. Laray is not that type; not only is he a subtle observer, but he is a scientist who deserves the name. He is not afraid to subject his mind to the strict discipline of mathematical physics, and he understands—a rare quality—that before one is set to explain the laws governing the universe, one has to know them.

I should say that all these reasons produce the particular worth of this work. In fact, the systems of philosophers with no real scientific knowledge tend to remain very vague when the explanation of the universe is in question. They formulate general statements, far from the laws astronomers and physicists do study. This explains why astronomers and physicists walk past without interest and without looking up toward that cloud which pretends to shed some light upon their work. But Fr. Laray develops his own system to its ultimate scientific consequences. From his system he seeks to find the fundamental laws that govern celestial mechanics, physics, and chemistry. He wants to accomplish this task not with loose arguments that let in what is needed but leave out whatever causes difficulties. On the contrary, his logic is so tightly organized that one can be sure that nothing is to be found in the conclusion which was not in the premises, because he uses the logic of mathematical analysis.

The logic of mathematical analysis is a very good and secure method, because it is based upon principles that are clearly and honestly open to discussion by metaphysicians, while its ultimate conclusions can be subjected to the criticisms of physicists. Such is the characteristic of all the explanations of the material world, which have influenced the development of the physical sciences, from Descartes to Boscovich. But this method has unfortunately one defect, which can be held more against our century than against the method. I am concerned that philosophers will not read Fr. Laray, because he uses mathematics, and that scientists will not read him, because he talks about metaphysics. It would be difficult to write for scientists an abstract of Fr. Laray's books in which all metaphysics is eradicated; but it may be possible to write for the philosophers an abstract free of algebraic formulae. This is what I shall try to do here. I will develop the arguments without discussing them; I will tread upon metaphysics, which is not my usual terrain, under the guidance of Fr. Laray. I intend to follow the road he indicates and do not wish to criticize his information. For a traveler who doesn't know the terrain, criticism would surely be dangerous, and blatantly tactless.

I. FR. LARAY'S THEORY

1. Space

Space is a *substance* that exists in itself, independently of all bodies. This substance is absolutely incapable of any effect. It is passive, and this trait makes space the bottom step on the ladder of substances.[2]

> We would like to classify the substances as follows:
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> In the highest place, the purely active substance, the only God, a pure act.
> In the lowest place, the purely passive substance, real space.
> In between those extremes, all the other substances, both active and passive at various degrees.
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> But is a purely passive substance simply nothingness? Absolutely not. Nothingness is neither passive nor active. In order to feel something or to do something, one has to be, and the ability to contain bodies would not fit nothingness.

Real space is essentially finite and this differentiates it from the ideal space which geometricians study and also what Fr. Laray calls the *imaginary space*.[3]

> The imaginary space, as indicated by its name, is the representation of real space indefinitely enlarged by the imagination. If one were to try to travel to the limits of the world with the resources of the mind alone one would see them constantly eluding one's grasp. That fact alone proves that we can conceive of the possibility of a space growing constantly. Our imagination does for the universe's dimensions what it did for man's height when it represents a giant whose head passes the top of the trees, above the clouds, above the moon, reaching the sun and the stars. Imaginary space has no more reality that that fantastic giant.

Real space is divisible to infinity:

> Nobody will object to ideal space, the triple abstract dimension, the object of geometry, being indefinitely divisible. But this passage from the possible to the actual does not affect the essence

[2] Laray (1885): 8.
[3] Ibid: 7.

> of the problem. Thus actual space must be endowed with the same proprieties which are necessarily included in the idea of space.[4]

2. Atoms

Matter is made of a very large, but limited number, of atoms. An atom is constituted by a simple and active substance called a *monad* which is located in a finite part of space. The monad, not being made up of parts, can occupy a finite portion of space only by being entirely present in every single point of that space. The space that it occupies, when it occupies it, is closed to and impenetrable by any other material monad. But a monad does not always occupy the same space at the every instant; at different instants, a monad can occupy different portions of space; this is when it is in motion.

> For us, the atom is made of a real space and a monad, as man is made of a body and a soul; and the monad is present within the whole volume of that space, like the soul, which according to many philosophers is present to the entire body. This presence, in both cases, is the presence of an activity. Like the soul communicating life to the body, the monad communicates impenetrability to the space it occupies. But, if the soul is always united to the same body, the monad, as soon as it moves, stops being united to the same space and makes in succession different spaces impenetrable. With this relation, the difference between the monad and the soul is not as wide as it appears at first because the human body is not made of the same identical elements at the various stages of its life.[5]

This system is very distinct from the Cartesian one: extension is not the essence of matter; all matter is extension, but not all extension is occupied by material monads; so that absolute vacuum, impossible in Descartes's system, is possible with Fr. Laray; and not only it is possible, but it does exist, because the monads are in contact only by accident.

He also distinguishes two kinds of atomism. For some atomists, the atom is a simple being without extension, a *material point*; for some other atomists, the atom has extension, but it is a compound whose parts are united by a link which no created action can break up. Fr. Laray wants the atom to be simple being, but like the others he wants the atom to have an extension.

Fr. Laray's system has some traits in common with the scholastic system, but should not be confused with it.

> We could indicate that our system and the scholastic one have much in common. Our monad is the active principle of the atom, which the scholastics used to call a substantial form; our real space

[4] Ibid: 7.
[5] Ibid: 14.

> could respond to their primary matter, and our atom would find itself constituted, according to their language, by the union of matter and form. But contrary to their opinions, we claim that matter cannot exist without form and that form does not come from matter.[6]

Finally, Fr. Laray's system should be differentiated from those of some contemporary metaphysicians who identify material monads and souls:

> We have insisted on the comparison between man and atom because it seems to us it helps clarify the idea we have of the material element. Nevertheless, now we feel the need to say that we do not establish any natural proportion between the monad and the human soul. Similarly, both divine nature and human nature are simple but nobody would because of that very reason put them on the same plane.[7]

In many ways, Fr. Laray's doctrine is close to Leibniz; Fr. Laray does acknowledge the similarities between his monad and Leibniz's. But his is different from Leibniz because of an essential character: for Leibniz, monads do no interact; one monad's modification cannot be the efficient cause of another monad's modification; there is only one efficient cause which is God; and when we think we are establishing a cause/effect relation between a modification within a monad and a modification within another one, in actuality we are only witnessing a manifestation of the harmony the creator has pre-established between the evolution of the internal states of the various monads.

For Fr. Laray, on the contrary, a monad can be the real cause of the modifications that take place within another monad; it is a true secondary cause, whose activity stems from the first and creative cause, but a truly efficient cause nevertheless. This is how a material monad can be the cause of changes in the motion of another material monad, what we call the first one exerting a mechanical action upon the second one.

Fr. Boscovich has formulated a system of physics which also borrowed from Leibniz the conception of the monad, but which also gave to the monads the possibility of interaction. Two material monads could exert upon one another some action in order to get closer or farther from one another action whose magnitude is proportional to the nature of the monads and their distance from one another. And these actions are nothing else than the elementary actions, which the physicists since Newton have used to explain all natural phenomena.

For Fr. Laray, on the contrary, two material atoms cannot exert a mechanical action upon one another whenever there is the slightest distance between them. In order for two material atoms to act upon one another, there should be a

[6] Ibid: 15.
[7] Ibid.

contact point between the volumes they occupy; it is only then, when each monad communicates its impenetrability to the volume it occupies, that this monad is going to be in contradiction with the impenetrability communicated to its own locus by the other monad, and then the activity of the two monads begins to play out and each of them causes changes in the other motion. Two atoms can exert a mechanical action upon one another only at the moment they are in contact.

This is the main point in the theory of the world Fr. Laray presents us with. This theory, indeed, was born out of the desire to explain universal gravity without conjuring up an actual action at work between separated material atoms. A first attempt was made in that direction by George Lesage, from Geneva; Fr. Laray had already modified and improved the theory of *out-of-this-world corpuscules* of Lesage in a book published in 1869 and called *Constitution of matter and its motions*, *nature and cause of gravity*, but that was one of the first sketches, heavily edited since then, of the book under review now. We will get back to this point when we are done with the full exposition of Fr. Laray's system.

3. Properties of Atoms

When a material atom is not in contact with another material atom, its monad produces an impenetrable spherical volume, invariable in magnitude, and whose center moves *along* a straight line at constant speed.

Things change when, during its motion, an atom collides with another atom. During the time the contact takes place, the surface of each atom is distorted; but, as Fr. Laray agrees—and this is one of the fundamental hypotheses of his system—each atom keeps an invariable volume. It is this invariability of the volume occupied by each atom that constitutes for Fr. Laray the invariability of the mass of this atom; the mass of an atom is then, by definition, a quantity in proportion to the volume of the atom.

A second hypothesis that plays an fundamental role in Fr. Laray's system is the following: the impact of the atoms upon one another modifies their motion according to laws which are similar to the ones studied in any treatise of mechanics under the entries of laws of collision of perfectly elastic balls; from these laws it follows that the projections upon three rectangular axes of the quantity of motion and of the *force vive* of all the atoms which constitute the inorganic world are four quantities that keep indefinitely the same value.

The mathematical laws of the collision of elastic balls are thus the foundation of all the explanation of the physical world; so we won't be surprised to see Fr. Laray devoting numerous pages to the subject; there are, in these pages, some new problems that are very elegantly and simply solved.

4. The Eon

The inorganic world is a product of three kinds of matter existing at the same time: the eon, ether, and matter properly speaking.

> The *eon* or *primal fluid* is made of the most elementary atoms, whose volume represents the minimal amount of actualized matter within the creation. We call it *fluid*, because its elements are susceptible to give way to the action of any force with the greatest ease; but it is different from any other kind of fluid because these very same elements have no unifying link between them. Their kinship is a product of the equality between form and volume, but their motions remain totally independent from one another. We will call it *primal fluid*, because we will look at it as the origin of all physical phenomena, as the universal mover or at least as the agency of transmission of all the motions.
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> Let's consider it first in a static state and, in order to do so, let's move to the origin of the creation to witness its sublime performance. After having produced and limited the immense sphere of the world, God creates a large population of eonian atoms and spreads them over its vast extension. Their number is so amazing that each millionth of cubic millimeter has billions of them, and their minuteness is such that this multitude occupies only a very tiny part of space.
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> Consequently, the eon's density is extremely low.
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> [. . .] We have considered the eon and its atoms at rest and because of their inertia are incapable of leaving that state of stillness by themselves. At the origin of motion as at the origin of being, God's special intervention is needed. We see Him throwing the eonian atoms, with the same motion and in all directions by an action of His almighty will. This divine impulse, the only instantaneous force, because it is the only infinite one, communicates to these eons in the very first moment an enormous speed which we can estimate, if required, at many million times the speed of light. So marvelous a velocity makes up for the smallness of the volume and picks up the magnitude of the product of mass by speed or the quantity of motion. This quantity represents the kinetic force laid down by God at the origin in each atom of eon, and because of that, it can be called cause of motion.
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> [. . .] Nevertheless a difficulty presents itself if we travel to the limits of real space. What happened to the speed of an atom having reached these limits? In our system, it cannot move over: because it is made of a localized monad, and there is no possible location outside real space. Therefore, having reached the limits of the created universe, the atom must reflect itself, as if confronted to an insurmountable obstacle and, during the time it changes shape, a force and an elastic energy starts to grow within it that compensates for the loss of force and kinetic energy.[8]

We have quoted the very words of Fr. Laray, because the introduction in physical theories of this primal fluid or eon, is one of the most innovative and fruitful part of his system; Fr. Laray saw clearly—which does seem to have been observed before—that, for those who deny the mutual action of two distant atoms, ether cannot be the explanation of all transmission of force at a distance; the properties we assume ether has, the elasticity notably that we request in the theory of

[8] Ibid: 61–62.

light, cannot be explained without action at a distance, unless one assumes there is a fluid even thinner than ether, and that fluid is the eon.

5. The Ether

> Ether is, like eon, a fluid made of spherical atoms perfectly elastic and uniformly spread over space at the moment of creation.
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> The specific difference between these two fluids being that the volume of eonian atoms is much smaller than the volume of atoms of ether. We acknowledge that the atoms of ether occupy a volume capable of containing thousand, perhaps million of atoms of eons, keeping their distance from one another.
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> Let's imagine an atom of ether placed in a space in which the eonian atoms are rapidly crossing in all directions. These atoms will collide with the atoms of ether and set them in motion according to the laws of collision of elastic balls; but, because of the magnitude of its volume, an atom of ether cannot be impacted in a certain direction by an atom of eon without an other atom of eon impacting it very shortly thereafter in an opposite direction with the same force; thus surrounded in all directions by eonian current of equal force, the atom of ether will remain still in space, or, to be more precise, will only feel imperceptible quivers.[9]

Will it be the same when two atoms of ether come face to face? At first, it seems that the answer is no: both atoms cut off some eonian currents which should have gotten to the other one; this last one will then receive less impact on the side which protect that screen than on the other one; the eonian current will thus push the two atoms of ether toward one another which will look as if they were attracting one another. In reality, this last reasoning forgets something: the eonian currents which reflect upon the first atom the impact on the second one; or:

> for all current cut off on one side there will be on the other side a reflected current in the same direction which will replace it; therefore the simultaneous presence of two atoms will not disturb their balance [. . .] One can apply the same reasoning to any number of atoms, and, further down we can conceive at the origin the ethereal fluid uniformly spread in space and enjoying an actual balanced state, in spite of being in an ocean wherein currents activated by tremendous speed keep crossing one another.[10]

But if two atoms of ether remaining still in the bosom of the eon exert no apparent action upon one another, it is not the same thing, in general, when one of these atoms, or both of them, are in motion. In that case, the impulses each atom receives from the eonian atoms are not equivalent in every side anymore; the eonian currents tend to either precipitate both atoms toward one another or move

[9] Ibid: 83.
[10] Ibid: 84.

them away from one another; an *apparent* force of attraction or repulsion is born from their interaction.

Fr. Laray studies carefully and in detail this apparent force, which cancels itself with two atoms remaining still in relation to one another; which, when the two atoms move away from one another, tends to bring them closer; which, conversely, when two atoms are getting close, tends to separate them, in sum, a force that always tend to destroy the effect of a disturbance brought about to the map of the atoms of ether.

Thus, not only are the atoms of ether *elastic atoms* that bounce back on impact, but ether is furthermore an elastic medium, which reacts against the disturbances affecting its state. These are the dual meanings of the word "elastic" which are quite distinct and which should not be confused. The elasticity of atoms of ether is an intrinsic and essential propriety of these atoms; on the contrary, the elasticity of the etherial medium is not an intrinsic propriety of that medium; it owes its propriety to the presence of the eon. The eonian atoms are equally elastic, but the eon itself, considered as a medium, has no elasticity.

This theory of the elasticity of the ether is, in Fr. Laray's work, one of the parts which deserves the most attention from people interested in natural philosophy.

The essential characters of the elastic force have always being a problem for those who intend to explain all natural phenomena with the actions of attraction and repulsion exerted at a distance in between molecules.[11] The elastic force does not act within the medium when in a natural state; it only acts when one imposes a distortion to some part of that medium, and it always behaves in such a way as to react against the distortion, so that it changes at the same time. How can we reconcile these characteristics with the existence of a molecular attraction always working in between atoms and which is only dependant from their mass and their distance? Fresnel, Cauchy, and Poisson have tried to base a theory of elasticity of solid bodies upon the hypothesis of molecular attraction; in spite of the magnificent results they have reached, their theory is contradicted by experience and should be considered wrong.

Navier, the founder of elasticity, and Lamé, who has done so much to forward this part of physical theory, did not accept the notion of molecular attraction understood the way Boscovich did. For them, two atoms at rest in relation to one another in a balanced medium exert no action upon one another; their mutual action is initiated only when one atom is being displaced in relation to another; a gap in between the two atoms induces an action of attraction between them; to bring them closer, will induce a action of repulsion. This hypothesis, as

[11] We are taking the liberty to refer the curious reader eager to explore this question to our *Cours d'hydrodynamique, d'élasticité et d'acoustique* (Paris, 1891), particularly to ch. III from book IV.

one can easily see, is very close to the consequences Fr. Laray deduces from his system.

Worth of attention in its principle, the theory of the elasticity of ether Fr. Laray proposes is even more worthy of attention in its consequences; in fact, this religious scientist bases upon this theory the explanation of a very strange property, very paradoxical, that opticians have been attributing to ether in order to explain the effects of polarized light. According to them, ether cannot transmit a *longitudinal* vibrating motion, that is to say, a vibrating motion that would make the molecules move in the same direction as the propagation. Fr. Laray shows that this paradoxical property of the ethereal medium stems from the constitution he attributes to it.

6. Matter Proper

The eonian atoms and the ethereal atoms are not the only kinds of atoms which take part in the constitution of the inorganic world; what we commonly call *matter* or *bodies* has as an element Fr. Laray calls, using a familiar name, a *chemical atom.* But the chemical atom is not at all akin to the eonian atom or the ethereal atom; it is not anymore a simple being whose activity produces, at each separate instant, a certain amount of volume impenetrable to the other atoms; it is a real organism. A fairly big number of ethereal atoms, each made of a monad and of the space that a monad makes impenetrable, are gathered under the aegis of a monad of another nature. The object of the activity of this last monad is not to make impenetrable a certain portion of space, but to maintain a determinate form to the gathering of ethereal atoms it presides over, to bring back, using an elasticity of a new kind, the entire group to this very form when external actions disturb them. With this form of activity, distinct from the activity of ethereal monads proper, but compatible with them, the superior monad adds itself to them without being an obstacle to their existence.

> We will define the element of the simple bodies, or the chemical atom: *a group of ethereal atoms, presided over by a monad which is in charge of keeping its shape and its volume* [. . .].[12]
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> Without any doubt, according to its etymology, the atom is not breakable, cannot be divided into smaller fragments; but, even though the element of the simple bodies can if need be, be subdivided, since it is a compound, we can admit that it is naturally indestructible and that no created force is capable of subtracting the component atoms from the empire of the monad that hold sway upon them. It is de facto indivisible. It exists only under that condition, and the breaking of the

[12] Laray (1892): 1.

links which brings its diverse parts under the aegis of the dominant monad would be, like the splitting of the body and soul in a living being, the destruction of the individual.[13]

This dominant monad, which maintain together the ethereal atoms of which a chemical atom is made, is thus "a kind of mineral soul, close to the vegetative and sensitive ones of the scholastic, but from a much inferior order, since it is not a principle of life." It is indeed *the queen of the monads* Leibniz had set aside for the conservation of any organism.[14]

All eonian atoms are identical; it is the same with the ethereal atoms; on the contrary, we admit that chemical atoms can display a great variety. What is that number exactly? It is equal to the number of really simple bodies there are in nature, but how many truly simple bodies are they? Chemists as of today count 70 simple bodies, and the list is getting longer. Every day some new metal is discovered on our planet or is assumed to exist on other planets. Many people, it is true, think that not all these bodies are indivisible; some, with Dumas's son, fancy that they all are compounded, that there is only a unique simple body that does exist, and that it might be hydrogen. In such a case, as only one kind of eonian atom and one kind of ethereal atom actually exist, only one kind of chemical atom would exist; the primal constitution of matter would be remarkably simple.

With the chemical atom, the constituting ethereal atoms are very close to one another so that no atom of ether can penetrate in them; but the eonian atoms, much smaller than the ethereal atoms, can slip in the interstices.

The impacts the eonian atoms or the ethereal atoms tend to put make the constituting parts of the chemical atom into motion. But the queen-of-the-monad then reacts, and a part of the impulse received by one of the atoms constituting the chemical atom is then transformed into a vibrating motion that animates the whole construction. We will see which role Fr. Laray gives to these transformations of motions in his explanation of heat and attraction.

7. Heat

The eon is a very subtle fluid, of homogeneous density, whose elements move in every direction at high speed. A chemical atom, in the bosom of this fluid, will thus be attacked from all sides by

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13 Ibid: 20.

14 "We have admitted," says Fr. Laray (1892, 4), "only two kinds of simple atoms and even one would be enough, the eonian ones. The ethereal atom would then become a group of atoms presided over by a monad of second order, and our present group of ethereal atoms, which is the chemists' one, would be presided over by a monad of third order."

currents, which will get inside by the means of superficial pores, and will cross it in all directions. The ethereal atoms will then receive a multitude of impacts and we will have to look for the effect it produces.

The chemical atom is apt to transform the particular motions of the elements it is made of, but these very elements, how can they move since we saw that an ethereal atom remains in balance inside the eon? Yes, of course, but then we were assuming the ethereal atom to be either isolated and impacted evenly in all directions by the eonian currents, or surrounded by other atoms which are remaining at rest and this ethereal atom is sending back on average as many reflected currents as it is stopping the direct ones. This equivalence between stopped currents and reflected ones was roughly correct, because of the supposed homogeneity of the ethereal fluid and the relatively considerable distance between its elements. But, it is not the same thing, if in spite of the atoms of free ether, we consider the atoms associated to form a chemical group. The eon, it is true, insinuates itself very well inside that group; nevertheless, the circulation is not free enough in there for each of its elements to be impacted by currents equivalent in all directions. The impacts felt by the various associated atoms will not balance out, and it will receive very diverse impulses. The lead monad will react, as we have explained it above, in order to coordinate and transform these internal motions.[15]

This mechanism will explain to us: heat, the attraction chemical atoms exert upon ethereal atoms, and the attraction chemical atoms have to one another, that is to say gravity.

Let see first what is, according to Fr. Laray, the nature of heat.

We use the word *heat* for lack of a better term able to encompass, within its meaning, the whole set of radiations, calorific, luminous, and chemical we have differentiated in the sun's spectrum. We know that these radiations are differentiated only through their wavelength, and, if our senses or our instruments are more sensitive to some rather than to others, that does not constitute a difference in nature. Since all bodies emit calorific radiations, we thought that the word *heat* [. . .] was more appropriate to designate the whole radiations [. . .] Therefore, the word heat will cover the whole of the vibrating energy propagated by ether.

So, for us, heat objectively considered, is made out of the vibrating motions of the ethereal atoms, whether these atoms are independent or are associated in order to form chemical groups.[16]

Thus, neither the translative motions nor the rotative ones can constitute what heat is. Their *force vive* is apt to transform itself into calorific energy, but until that transformation takes place, heat does not exist. Similarly, the vibrations of material elements that result from the unified oscillation of their center of gravity, such as sonorous vibrations, are not heat. Their own energy is very distinct from the calorific one which is essentially constituted by the particular vibrating

[15] Laray (1892): 20.
[16] Ibid: 26.

motions of the ethereal atoms and not from the whole set of motions of chemical atoms.

> To determine the origin of heat, is thus to precisely determine the circumstances where these kind of motions begin. As we have seen above, the eonian currents, while crossing a compounded atom, communicate vibratory energy. We have thus noticed that heat is produced within the bosom of the chemical group; and we have seen which part is assigned to each productive agent of the phenomenon.
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> The eon brings up the necessary vivid force; the ethereal atoms constituting the chemical group sheltering that force under the form of vibrating energy, and it is the leading monad of the group which operates the transformation and regulates it.

We do not follow Fr. Laray here down to the various consequences that he infers from this way of looking at heat. The curious physicist may look up the *Abstract on Kinetic Gas Theory*[17] to find out how these consequences fit with the very known laws of thermodynamics. They will see how Fr. Laray has been led by his own ideas on heat to deliver a new theory of the relationships of the specific heat of the gas fully attuned to experimental data; how, further more, he has tried to verify his own principles with curious radiometric experiments. But all these questions would take us out of the general outline we are trying to write here.

8. Action of the Atoms on Ether

Gravity

The eonian currents that cross a chemical atom lose there some of their *force vive*. This *force vive* transforms itself into a *force vive* of vibrating motions for the diverse atoms of ether that constitute the chemical element, that is to say heat. They come out weakened, not that the atoms which are compounding them are less numerous, but because they walk at a slower speed.

Let's put an atom of ether next to a chemical one. On the side that looks at this chemical atom, the ethereal atom is affected only by enfeebled eonian currents; on the other side, it receives the impact from the currents that retain their entire intensity; the impulse they communicate to it is more powerful than the impulse it feels from them. It will be pushed toward the chemical atom, and thus a chemical atom will seem to attract the ethereal atoms around it.

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[17] Communiqué à la Société française de physique, publié dans les *Annales de chimie et de physique* in 1892, and joined as an appendix to the *Complément à l'Essai sur la synthèse des forces physiques*.

We say "around it," because the chemical atom will be protected from the collisions with the eonian atoms only the ethereal ones are not too distant. So the force of attraction we just talked about will cease to be felt at a very short distance from the chemical atom. The ethereal atoms located out of that range will not feel any effect from the chemical atom; those closer will get near to its surface, and around a chemical atom the ether will condense in order to form a sort of atmosphere.

Fr. Laray is thus led, by the logical development of his system, to assign to chemical atoms an attractive action upon ether, an action very similar to Cauchy's, an action that Briot was referring to explain the dispersal of white light into a spectrum of the diverse colors.

When two chemical atoms get close to one another, each of them slows down the eonian currents that cross them, and in so doing, an apparent attraction is being born in between the chemical atoms, analogous to the attraction a chemical atom exerts upon an ethereal one, but spread further away.

But if going through the pores of a chemical atom enfeebles the eonian currents, the very same currents going through the innumerable openings which the chemical atoms forming a body leave between themselves will enfeeble them as well; they will leave in the body a part of their *force vive* as vibratory motion, that is to say heat, and if, when they come out, they come across a second body, they will be too weak to sustain the assault against the currents which impact on the other side at full speed. This second body will then be pushed toward the first one; he will seem attracted by it.

This apparent attraction obeys, Fr. Laray proves, the laws of universal gravitation. These laws are at least for this attraction a first approximation; universal gravity is explained without introducing any action at a distance. We have seen that, in the chronological order of Fr. Laray's research, this result came first; we can be assured that its importance is not last.

9. Cohesion

But the eonian atoms are not the only atoms able to affect the chemical ones in their motion; the ethereal atoms are able as well to affect the chemical ones whose fabric is too tight to permit those ethereal atoms to get inside. These repeated impacts initiate a pressure capable of making the different chemical atoms hold together and produce what is ordinarily called *cohesion*. It is with the study of cohesion and also with the study of *chemical affinity* that Fr. Laray concludes his second volume. Of the theory of chemical affinity we will say nothing, not only in order not to swell the review too much, but also because what links this theory to Fr. Laray's complete system seems loose to us. In spite of all that, we would hope that what we have said so far of this Eudist scientist, this member of the Congregation of Christ and Mary, will inspire readers to find out for themselves what we have omitted.

II. IS AN ACTION AT A DISTANCE POSSIBLE?

Now that we have sketched the general outline of Fr. Laray's cosmological system, let's go back to what constitutes the corner stone of this system: the impossibility of an action at a distance.

The motion of planets is explicable as if the sun and the planets attract one another according to the laws discovered by Newton. Is it possible that this action of attraction of material masses separated from one another be at the same time an inherent property of these masses, a property which then it would be useless and impossible to explain? Should we, on the contrary, declare it metaphysically impossible for a body to have the ability to move at a distance some other body, to consider universal gravity as an apparent force, and explain it only by evoking the actions exerted upon one another of particles in direct contact?

It is this last option Fr. Laray supports.

> It is utterly impossible that a body would act wherein it is not located and that the sun for example, could move the earth [. . .].[18]
>
> [. . .] In fact, activity is an ability of the substance, and action is nothing but this ability at work. But his ability cannot be separated from the substance in which it is located, and the action cannot be separated from the ability, which enacts it. So an action separated from the working substance, an action at a distance, is utterly impossible.[19]
>
> In other words, an action is a mode of being of the active substance. And the modes of being are inherent to the subject they modify; therefore they cannot exist outside of it, at a distance.

It is strange how utterly different the views of philosophers are about this issue.

Until Descartes, it was not difficult to look upon the property a body has to exert an action at a distance upon another body as a primary and inherent quality of bodies.

Gilbert, in his *De Arte magnetica*, published in 1600, does not hesitate to consider the property to attract iron at a distance as an essential property of the magnet. Copernicus looks at the mutual attraction material particles have for one another as primary quality given to these particles by Providence. Kepler in his celebrated introduction to the treatise of *Stella Maris* where for the first time the tides are explained as a struggle between the attraction from the moon and the

[18] Laray (1885): vi.
[19] Ibid: 3.

attraction from the earth upon the waters of the sea, Kepler, say I, has no problem with providing the moon with a *virtus tractatoria*.

But Galileo, in his *Dialogues on the System of the World* laments that Kepler, in order to explain high tide and low tide, makes use of an occult quality, and what had seemed very natural to Descartes's predecessors will look absurd to Descartes and his successors.

For Descartes, as it is well known, the essence of matter is extension; all the properties of any part of a body must come from this essence, and this essence consists merely in being a part of the extension. But extension cannot act, nor can extension have a propensity; a part of the matter cannot act upon another part in order to modify its motion; it cannot tend toward or move away from another part. Any action, any propensity of this kind, must be looked at as a figure of speech, a fiction. The effects attributed to it are not an explanation: they are what have to be explained.

Where does this explanation come from? From the essence of matter itself, identical to the extension it occupies; the extension occupied by a part of the matter is thus essentially impenetrable for another body, because there cannot be a same essence for two different bodies. Let's consider two bodies moving toward one another. If their motions remain the same, at some point their impenetrability will be violated or a same region of space would belong to both bodies; at the very moment a violation of the impenetrability starts to occur, that is to say, at the precise moment when two bodies are in contact, their motion will be modified: that is what constitutes the *impact*.

What are the laws, which preside over this modification of the motion of two bodies? What are the laws of the collision? Descartes tried to enunciate them; his statements were later deemed unacceptable. As Leibniz had pointed out, he admitted the conservation of the quantity of motion, instead of assuming the conservation of the three components of this quantity; he did not think about the *force vive* being constant; Nevertheless, one should not deny that the introduction of the quantity of motion in the theory of impact was a first step toward the form this theory had taken since.

It is therefore to the impact the diverse parts of matter have with one another that one must go for an explanation of the phenomena physics studies. Descartes does not stop at this general observation; he goes into details; he undertakes to prove how the laws of impact are enough to explain gravity, the different effects of light, the tides, magnetism, etc. Everybody knows, at least in its general outlines, the famous theory of the vortex, which he thought could explain the whole system of the world.

This attempt at investigating, down to the last detail, a universe the study of which was in an incipient state makes us smile today when we read the *Treatise of the World, or Light* or the book called *Principles of Philosophy*. Pascal had already said, "One must roughly say: it is done by figure and motion, that is true. But to say which ones do it and make the whole machinery up, that is ridiculous; that is useless, uncertain and painful." But if one can find the attempts Descartes made "to make up the machine" of the world futile, one cannot deny the immense help he brought to physics; by teaching that it is ridiculous to refer any new effect to a different virtue of the bodies, that to name a propriety was not to explain it. Descartes truly paved the way for theoretical physics; and whether one would like to believe or not in the reality of Kepler's *virtus tractatoria* Kepler ascribes to the moon and the earth as well, nobody regrets the *virtus dormativa* Moliere's doctors attributed to opium.

And, if Pascal finds useless, uncertain, and painful the attempt to make up the machine of the world, he carefully retains this useful and practical consequence of Descartes's system, the refusal to explain every natural effect by inventing a new propriety, a special virtue. Like Descartes, he thinks that any valid explanation is the one which uses nothing but figure and motion, and he showers his merciless irony upon these philosophers who "dare to say that bodies want to go down, that they aspire to their center, that they run away from their destruction, that they are afraid of the vacuum, that they have inclinations, sympathies, since all these proprieties can only belong to minds." He did in fact better than make fun of these philosophers by explaining the effects which were currently attributed to a horror of vacuum, he provided a sample of the scientific method physics would follow thereafter.

Even if we agree that the material universe is mechanical, Pascal thought that the building of such an apparatus was not worth "an hour of pain." Scientists in the 17th century did not share that view. The illustrious physicist, Christian Huygens, attempted to explain natural phenomena with figure and motion only. To Huygens we are indebted with *A Discourse on the Cause of Gravity*, presented at the Académie des Sciences of Paris, and later published at Leyden in 1690, following his famous *Treatise on Light*. The following pages from the preface Huygens placed before the discourse can help us appreciate to what extent he was on Descartes's side.

> Nature acts in such a secret and invisible manner, by bringing toward the earth the bodies called heavy, that with all the attention and the work we can muster, our senses cannot discover anything about it. This is the reason why philosophers from previous centuries looked for the cause of this admirable effect inside the bodies themselves, and they attributed it to some internal and inherent quality which made the bodies either go down toward the center of the earth, or to an appetite of the parts to be united with the whole, which was not exposing the causes, but assuming some obscure and not yet understood yet principles. One can forgive those who were content with those kinds of solutions; but one cannot forgive Democritus and his followers, since they had undertaken an explanation of everything by the means of atoms only, with the exception of gravity, which they have attached to earthly bodies and to the atoms themselves without explaining its origin. Amongst modern authors and restorers of philosophy, many have thought something should

> be postulated outside of the bodies in order to be the cause of their observed attractions and escapes; but they did not go further than the first philosophers when they postulated, e.g. some subtle and heavy air, that by pressing upon the bodies makes them go down. This already assumes a gravity, and it contradicts the laws of mechanics to assume a liquid and heavy matter pushing down the bodies it surrounds. On the contrary, it should make them go up, as they have no weight by themselves, just as water makes an empty vessel go up when it is thrown in the water. Others assume spirits and material emanations that clarify nothing, since we have no idea how something that is immaterial can put a material substance in motion.
>
> Mr. Descartes acknowledged much better than those who came before him that one will never understand physics except by principles which do not exceed the power of our mind, such are those which depend on bodies and their motion, apart from other qualities. But since the biggest difficulty we are facing will be to show how so many diverse things are done with only these principles, here Mr. Descartes did not succeed in many particular subjects he examined, gravity being one amongst others. The reader can make up his mind after some remarks I have made upon what Descartes wrote, and I could have said more about it. But I have to admit that his endeavors and his views, in spite of being wrong, helped me pave the way for what I have discovered on that subject.
>
> I do not think he is above any doubts neither that there nothing to object to in his writings. It is exceedingly difficult to go so far with researches of this nature. I still believe that if my main hypothesis is not the true one, there very little hope one could come across one and still remain within the boundaries of the true and sane philosophy.

So, even though Huygens does accept the theory of vortex as Descartes presented it, he remains firmly within the boundaries of Cartesian philosophy. Nothing is more revealing than the first sentence of his *Discourse*, which can be looked upon as a very clear presentation of physics according to Descartes:

> In order to find an intelligible cause to gravity it should be looked upon how it is possible, in the nature of bodies made out of the same matter, which have no quality or inclination to get close to one another, but only differences in magnitude, figure and motions; how, as I said, is it possible that many of these bodies tend to go directly toward the same center and remain assembled there together.

We will not go into details regarding the mechanism of gravity Huygens proposed; it will be enough to have emphasized, in this geometrician from the Low Countries, how Cartesian he was.

In between the moment Huygens was giving his speech (*Discourse on the cause of gravity*) to the Académie des Sciences of Paris and the moment he had it printed in Leyden (1690), the immortal work of Newton appeared (1687), *Philosophiae naturalis principia mathematica*, so that Huygens could write an addition to his discourse to refute Newton's objections against Cartesian physics and set against a Newtonian theory of the figure of earth a Cartesian one that experiments had condemned already. Newton's book was to become a new starting point in the evolution of physics.

Newton's position in the discussion concerning the reality of action at a distance can be characterized as followed: in a great number of cases, the motions of the bodies are the same as if they were exerting an action at a distance, upon one another, some action being attractive and some repulsive: not only does universal gravity provides an account of all the motions of the celestial bodies, but furthermore of other parts of physics that must take into account other attractive and repulsive forces: electric action, magnetism, molecular attraction and repulsion, and repulsive action of matter upon luminous corpuscles.

Should these actions at a distance be looked upon as essential and primary properties of matter? Should they, on the contrary, be explained by figure and motion of the particles that make up ether? The second option is highly probable.

But the explanation of the real mechanism that would provide an account for action at a distance construed as real remains extremely difficult. It is therefore proper method to begin with the study of actions at a distance and their effects and it will be only later on, when physics will be more advanced, that the study of which motions and which impacts convey these actions will be done.

In any case, the goal of the physicist is reached when he has succeeded in bringing an extensive class of phenomena under the consideration of some actions at a distance, under precise mathematical laws; the explanation of these forces and of these laws that govern them is the metaphysician's task.

Such is actually Newton's own thinking, which some quotations below will illustrate. Consider the closing paragraph of the *Optics*:

> Bodies act one upon another by the attraction of Gravity, Magnetism, and Electricity [. . .], and make it not improbable but that there may be more attractive powers than these [. . .] How these Attractions may be perform'd, I do not here consider. What I call Attraction may be perform'd by *impulse,* or by some other means unknown to me. I use that Word here to signify only in general any force by which bodies tend toward one another, whatsoever be the cause.

Then, further down:

> To tell us that every Species of Things is endow'd with an occult specific Quality by which it acts and produces manifest Effects, is to tell us nothing: But to derive two or three general Principles of Motion from Phenomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd: And therefore I scruple not to propose the Principle of Motion above-mention'd, they being of very general Extent, and leave their Causes to be found out.

Though Newton left out of his theoretical exposition of this inquiry into causes, he does not despise it. Numerous passages in his work or in his letters show him preoccupied by the cause of gravitation and looking for this cause in the motion of the ether. But, if he thinks of the research into causes as useful, he clearly separates it from physics. The purpose of physics is not to tell us about the causes of the effects we are witnessing around us. Its goal is more modest; it is about first gathering the facts into the form of laws, which is the object of experimental physics, then about reducing the laws to a small number of general principles enunciated in the clear language of mathematics, which is the object of theoretical physics. Above experimental physics, above theoretical physics, there is a science that has to find out the true causes of the principles of theoretical physics. But this science is not physics anymore; it is a part of metaphysics called cosmology.

Pascal and Galileo had made use of that distinction already which Newton claims for himself and uses in his treatises.

Newton's contemporaries did not understand him.

Some of them, obstinately attached to Descartes's ideas, were convinced that any "intelligible" physics could only consider "bodies made up of the same matter, in which one does not consider any quality or inclination to get close to one another, but only differences in magnitude, figure and motion." So they could not admit the value of the kind of physics Newton advocated; for them, there was no difference between these general principles of motion Newton was proposing without looking for their causes, and the occult qualities of ancient physics wherein Toricelli's experiment was explained by a horror of vacuum or by moving lightness. "I am coming back to what I have put forward," said a Cartesian[20] discussing Newton's principles:

> and I have concluded that, following the method of that great geometrician, nothing is easier than to develop the mechanism of nature; should you like to provide an account of a complicated phenomenon, if you expound it geometrically, you have done it all. What remains is a problem for the physicist that depends for sure either on some primordial law or on some particular determination.[21]

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[20] De Gamacher, *Principes généraux de la Nature appliqué au mécanisme astronomique et comparés aux principes de la philosophie de M. Newton* (Paris, 1740).

[21] In an article on *Théories physiques*, published by the *Revue des Questions Scientifiques* (1992) 2nd series, 31: 139–77. I have insisted upon the distinction stressed by Newton between the goal of theoretical physics and the search for causes; in the *Bulletin Philosophique* (1892): 653–55, a knowledgeable author thought he had to warn his readers against the "venom of skepticism" my doctrines seem to contain. "It is not out of love for metaphysics, says he, that Mr. Duhem leaves it alone; he despises it; he does not allow that foreign plant on his own domain. He thinks that physics should neither accept the yoke of metaphysics nor impose its own. Thus, this is not about an agreement that each science should mind its own business. Philosophy, regretting to have neglected the physical world, had started to study the physical sciences in order to be in harmony with them. Science, runs away and refuses to cooperate with philosophy. But is it still science when

Others, also misunderstanding Newton's thinking, took as an explanation the principles the limits of which the great geometrician had recognized so well, and they believed that universal or molecular gravity was the true and ultimate cause of physical phenomena. It was not long before the progress of the *physics* Newton had created paved the way for a triumph of a *metaphysics* which wrongly claimed to be his. We will meet later this school of which Laplace and Poisson are the most illustrious members.

Leibniz had certainly at first embraced Cartesian doctrines. But starting with its principles, he did not accept them blindly, rather he corrected them. In his *Theoria motus abstracti* and *Theoria motus concreti*, he does not agree with the conservation of the quantity of motion as taught by Descartes and replaces it by the conservation of the projection of that quantity onto any axis; he adds to it the conservation of *force vive*. But, if the developments of his mechanics are quite different from Descartes's, the foundations upon which they lay are the great French philosopher's ones: "It works roughly," says Leibniz, "through figures and motions." In his *Theoria motus concreti*, following Descartes's and Huygens's bold example, he tries "to tell why and how to build its machinery," and he tries to explain things in a purely mechanical fashion, by the motion of an ether, light, gravity, elasticity, magnetism, etc. He thought that to admit a force such as an action at a distance would be going back to a physics of occult qualities that had been painfully disposed of. All his life, he kept rejecting the reality of Newtonian attraction, and his opinion upon that question seemed to fit his system wherein monads are incapable of real actions upon one another. His metaphysics, however, would bring his successors to look at action at a distance as the true explanation of natural phenomena. Let's explain how that development took place.

For Leibniz, there was no real direct action of the monads upon one another. When two monads seem to act upon one another, it is in actuality because the perceptions of one of them unfold in harmony with the perceptions of the other, a harmony pre-established by the sovereign wisdom and sovereign power of God.

But it is not only the perceptions of two monads in contact that have a pre-established harmony between them. This harmony exists between the perceptions of two monads whatever the distance might be, because the perceptions of any

it relinquishes knowledge about things in themselves and their causes?"—I beg my opponent scientist for his forgiveness, but I think he misunderstood me; by looking for delimitation between positive science and metaphysics, I intend to despise neither of these sciences, and I think I am facilitating their agreement more so than if I were confusing their objects and their methods. My opponent scientist notices that his ideas have been favorably received by some scholastics; it is indeed one of the glories of Aristotle's philosophy to have acknowledged that each science has its own domain and its own independent methods, and that harmony does not require confusion, quite the contrary.

one monad reflect, more or less distinctly, the entire universe; and the distance between two monads is nothing else but a certain relation between the perceptions of these two monads.

So, any mutual action of the monads is a purely fictitious one, an effect of the harmony pre-established by God between the internal development of these two monads. In this respect, there is no distinction to be made between two contiguous monads and two distinct ones.

In Leibniz's system,

> The ordinary ways of speaking are doing well. Because we can say that the substance whose disposition provides a reason for change, is in an intelligible manner the one which should be thought of *acting* upon the others—so that one can judge that it is that very substance the other ones have been linked to by God since the beginning according to His decrees.

According to this principle, how will the conclusions we have reached be translated but as such: the monads act upon one another at a distance and when they are in contact as well; they act even whatever the distance might be which separates them.

It is true that the action Leibniz speaks about is a purely fictitious one, an effect of the harmony pre-established by God. But let's give to each monad the power Leibniz denied them to cause in an efficient manner, albeit indirectly, modifications upon the other monads. In so doing, we are getting to Fr. Boscovich's and Kant's [early] system, with their material monads exerting upon one another, *even at a distance*, attractive and repulsive actions, true causes, and sources of a true explanation of physical phenomena. So, by reducing matter to extension, Descartes necessarily rejected action at a distance; by claiming that matter is not extension only, Leibniz had suppressed all the reasons that had authorized the denial of action between non-contiguous parts of matter.

While Leibniz's metaphysics was giving birth to a philosophy that made attractive and repulsive actions at a distance the true cause of all phenomena, some geometricians, using different ways, reached a similar conclusion.

Newton had separated the role of physics, which, according to him, is about reducing the great number of experimental laws to a small number of theoretical principles, from metaphysics, which looks for the causes from which these principles come. He had shown that the first of these orders of research should be pushed very far before one should begin working on the second, and that without metaphysics, physics had a legitimate right to exist, even if it provided us with an incomplete knowledge of the world.

Following these teachings, the great geometricians gave up the tradition of Descartes and Huygens and others who did not separate the study of the theoretical laws of nature and the research of causes those laws come from. They were looking to deepen the laws of nature without using a metaphysical explanation, and, by giving those laws the form which was so fertile in Newton's hand, they tried to reduce all the phenomena of the material world to attractive and repulsive actions being exerted at vast or minute distance between material molecules.

Their researches were astonishingly fecund. While D'Alembert, Mac Laurin, Clairaut, Euler, Lagrange, and Laplace were perfecting celestial mechanics, Coulomb, Poisson, and Ampère were creating the theory of electricity, Clairaut, Laplace, and Gauss the theory of capillarity, Navier, Fresnel, Poisson, and Cauchy the theory of elasticity, Laplace the theory of heat.

These prodigious successes made physicists forget Newton's wise reservations. The power of the tool they were using made them mistake it for the key to the universe. They believed such a tool provided them not only with a theoretical image, but also with a metaphysical explanation of the world. They switched the theory of actions at a distance from the level of symbolic representation to the level of explanation.

This presumptuous tendency can be detected in the writings of the greatest among them. Laplace, speaking of molecular attraction, says:

> All earthly phenomena depend on these kinds of forces, as celestial phenomena depend from universal gravitation. Their consideration seems to me the main object of mathematical philosophy. It seems to me even useful to introduce it into the demonstrations of mechanics, giving up considerations about lines without mass, flexible or inflexible, or of perfectly hard bodies. Some attempts I have made have showed me that by *thus getting closer to nature*, one could give these demonstrations much more simplicity and clarity than used to be the case with methods used up to now.

Similarly, Poisson says:

> That it would be desirable for geometricians to take over the main questions of mechanics from a physical point of view and *adjusted to nature*. They had to analyze in a highly abstract manner in order to discover the general laws of balance and motion; and, with this kind of abstraction, Lagrange went as far as one can conceive it [. . .] This is what constitutes *analytical mechanics*; but, next to this admirable conception, one could now develop *physical mechanics* whose unique principle would be to reduce everything to molecular actions.

Ampère writes, at the beginning of his great paper on electrodynamics:

> The Newtonian era in the history of science is not only the one wherein the most important discoveries were made upon the causes of nature; it is also the era wherein the human spirit opened for itself a new road for the sciences whose object is the study of these phenomena.
>
> Up to that time, causes were almost exclusively looked for in the impulse of an unknown fluid which drained material particles in the same direction as its own particles; and where a rotative motion was seen, a vortex was assumed to take place in the same direction.

> Newton taught us that this sort of motion must, as for all nature offers us, be reduced by calculation to forces always working between two material particles according a straight line that links them, so that the action exerted by one upon the other be equal and opposite to the one the latter exerts upon the former, so that, when one assumes these two particles invariably linked, no motion can come out of their mutual action. This law, confirmed today by all observations and by all calculations, he expressed in the last three axioms he placed at the beginning of his *Philosophiae naturalis principia mathematica*. But it was not enough to raise to that high view; a law had to be found explaining how these forces vary according to the relative situation of particles in between which they are exerted, or, which is the same thing, its value had to be expressed in a formula.
>
> Newton was far from thinking that such laws could be invented starting with more or less plausible abstract considerations. He established that they should be reduced to observable data, or that these empirical laws are like Kepler's laws, the result of generalization made after a great number of facts. The main advantage of formulae drawn immediately from some general facts and a satisfactory number of observations is that their certainty cannot be disputed, they remain independent of the hypotheses their authors have used when they were looking for these formula, hypotheses which can be then changed thereafter. The expression of universal gravity deduced from Kepler's laws does hinge upon the hypothesis some authors have to formulate upon a mechanical cause they were attributing to it.

We could go on with these kinds of quotations, or borrow some from Fresnel or Cauchy. We would get the same impression from all those quotations: not only do these great geometricians think that, when the laws of a class of phenomena have been reduced to the actions of attraction and repulsion exerted at a distance, they have accomplished their task as physicists—and that is their right to think so—but also, one feels they are full of contempt for the attempts made by those who intend to assign a cause to those actions; sometimes they even proclaim highly they have found a theory fitting the nature of things and that nothing has to be looked for beyond it.

So the metaphysicians who followed Leibniz and the physicists who followed Newton arrive, at the end of the last century and at the beginning of this one, with the same cosmology: the world is made up of material points, distant from one another, in between which the attractive and repulsive forces are exerted, causes of all physical phenomena. These actions are the primary proprieties of matter. They explain everything and cannot be further explained.

It is around that time (1782–1818) that Lesage, from Geneva, attempted to react against the general tendency of trying to explain universal gravity as a primary property of matter. Lesage[22] represents material particles not as fully solid, but as hollow thin frameworks. Space is supposed to be full of projectiles, "beyond-the-world-corpuscles," extraordinary small in relation to material atoms, moving in

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22 We borrow this exposition of Lesage's theory, whose works are not available to us, from the exceedingly interesting work of Mr. Marcel Brillouin, *Recherches récentes sur diverses questions d'hydrodynamique* (Paris: Gauthier-Villars, 1891).

every direction at an amazing speed, some going through the atomic domain, and a very small number of them, when they come across it, moving the atoms out of the way, and losing a small quantity of motion. The set of corpuscles moving toward the atom is endowed with a greater quantity of motion than those emanating from it. Another atom exposed to their impacts will be pushed toward the first one by a force in reverse proportion to the square of the distance. Regarding the laws of their mass, it will be derived from the hypothesis made after the law on the loss of motion through impact. If the relative decrease of the quantity of motion of the corpuscles produced by an atom is small enough, the attraction will be in proportion to the mass, even for bodies as big as planets.

This theory, very close to Fr. Laray's, remained an isolated attempt; it did not disturb the triumph of the "attractionists."

This triumph lasted, without serious challenge, up to the middle of the 19th century. Its last echo can be heard today; Weber and his disciples in Germany, Athanase Dupré and Hirn in France—to name only the dead ones—have built their cosmology upon the existence of attractive and repulsive actions between separated material particles, actions which stem from the essence of matter itself, and which, consequently can be reduced to an explanatory mechanism.

But any triumph has its limits, with philosophical theories, as with human affairs. The Tarpeian Rock is located near the Capitol. We are witnessing, for some years now, a reaction against the explanation by the actions at a distance and a return to the general tendencies of the Cartesian School.

There are different causes of this reaction.

First, the excess of the method recommended by Laplace and Poisson; it is a general law that any reaction against a tendency has its main cause in the excess of that very tendency. In order to replace Lagrange's linking forces with molecular actions, Poisson wrote numerous unreadable papers, full of cumbersome and complicated calculations; the consequences of these calculations put him in contradiction sometimes with the experiments, as is the case of his study of elasticity, sometimes even with the most beautiful conquests of the theory of corpuscular attraction, and the theory of capillary action which led him to challenge Laplace and Gauss's doctrines about this topic. Cauchy, pushing all the way the attractionist tendency with an incredible audacity in his analysis, wanted, in order to provide an account of the laws of optics, to go into details about the relations of matter and ether; he did not only say that molecular attraction explained everything; he wanted to explain "how the whole machinery is built." The highly complicated nature of his calculations, the lack of certainty of his hypotheses, made his theory unattractive to the physicists.

Second, the fashion of the theory of corpuscular attraction had been greatly diminished by the progress of other sciences, independent from it and in contradiction with it.

Thermodynamics, by getting rid of the caloric and the attractive or repulsive forces that were its foundation, has strongly diminished the domain of the theory of molecular attraction. The kinetic theory of gases has taken up the explanations that were once connected by Bernoulli to Cartesian philosophy. The study of the vortex motions of the fluids has brought Descartes's vortices back to the fore and has manifested apparent attractions very similar to the electrodynamic actions Ampère deemed real.

This double challenge has led the physicist to do without the actions at a distance whenever it was possible, and when it could not be avoided, they have tried at least to explain them. From thence came Faraday and Maxwell's views on the explanations of electrical actions by the properties of an ethereal medium; from thence came Sir W. Thompson's cosmological theory based upon a notion of vortical atoms; from thence, in one word, come the development of a mechanical physics which could be rightly regarded as a rebirth of Cartesianism. Fr. Laray's work is part of that trend and is not an insignificant contribution to it.

We have examined the main views of philosophers regarding the nature of action at a distance. The reader might be entitled to ask for a conclusion, but with so many diverse opinions formulated by so many geniuses, we stop, a little scared, and dare not claim to be competent in such a trial. We will simply remind those who could accuse us of leaving the principles of physics suspended upon a doubt, that the outcome of such a trial, highly interesting from a metaphysical point of view, has no bearing upon physical theories. Whether action at a distance be or not be a primary proprieties of bodies or elements, the physicist has always the right to use them in his endeavor. But he has to be reminded that very often he will be compressing into few principles a multitude of experimental laws and that he will not be assigning a cause to the phenomena. We will end by quoting Newton: "Drawing from phenomena two or three general principles; explaining thereafter all the properties and actions of the bodies by the means of those very clear principles; it is actually a very significant progress made by philosophy even though the causes of such principles would not be discovered."

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