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CHAPTER ONE

A Word from Physics

A Lately Coined Word

At first glance, the word “reaction” does not seem more difficult to understand than the word “action.” One does not usually stop to question its origins. The word does not present an enigma. As for “action,” its career and the variety of its semantic functions do catch the historian’s eye if he takes the trouble to look into them. How did the value of the word change? How did it penetrate various domains? What intellectual roles did it take on and leave behind? What memory does it awaken? Today it is a rather banal term, but this was not always the case.

Tracing a more remote etymology will help to stimulate reflection. Knowledge of a word’s antecedents invites the reader to conceive of it as a *derivative*. Certainly, the deepest “roots” of the words belonging to intellectual language do not necessarily lead to their secret truth, which might just as easily lie in their emergence in concrete gestures at the beginning of a metaphoric transfer. According to etymologists, “act” and “action” (and their homologues in several modern languages) go back to the Latin verb *agere*, meaning “to push forward,” “to move a herd forward” — a movement that occupies space on the terrestrial soil and a moment of the day at a time when man was considered in relationship to livestock.¹

One can therefore wonder about this ancient substantive, *actio*, which has been used a great deal to designate the delivery of a speech and may have carried the memory of a more ancient pastoral activity. In its abstract sense, the only one retained today, it appears to be a metaphor that has forgotten its origin. The poet can reflect on it. But this memory does not make us more efficient in our acts and actions. The jurist who “initiates an action” or the “holder of shares [*actions* in seventeenth-century English and in French]” on the stock exchange are not concerned with this echo.

What about *reactio*? History does not allow us to see it as the exact counterpart of “action.” It is a much later composite, of scholarly origin, one half of a pair in conceptual abstraction rather than in life. In fact, *reactio* and *reagere* are not part of the ancient Latin lexicon. They are not found in any text from Antiquity. Their components — the prefix *re-*, the verb *agere*, and the substantive *actio* — certainly existed, but they were never combined to form *reagere* or *reactio* in classical language. The antonym of *agere* in classical Latin is *patior* (to suffer, to undergo); the antonym of *actio* is *passio*. Action and passion are much more solidly established conceptual opposites. This couple was present in philosophical Greek (*poieō/paskhō*). Passed on to Latin, it was later transmitted to the European languages. *Reagere* came much later, among the Scholastics, and provided a double for *patior*, while also giving it an active sense. It was formed by being cut from the same cloth as *agere*, of which it became a sort of shadow or a reverse rejoinder. *Reagere* is therefore a derivative (or correlative) term, to which the prefix *re-* added an antagonistic, spatial, and temporal determination: antagonistic because there is no reaction except in opposition to an action; spatial because one thinks spontaneously of a reaction as repelling an action; and temporal because there is no reaction — apparently — that does

not follow an action which precedes and provokes it, even if action and reaction can be imagined as infinitely close. Immanuel Kant, as we shall see, denies this consecutive aspect and argues for the simultaneity of action and reaction.

Based on the documents I have consulted, I believe I am able to conjecture that *reactio* was introduced gradually into narrative Latin in the early Middle Ages. Was this indeed the case? I could not find any proof of it.² On the other hand, between the twelfth and the thirteenth century, *reagere* and *reactio* appeared in scholarly Latin and never left it. They were specialized words. They enriched the terminology of the natural sciences, that is, of “physics” in its broadest sense — ranging from cosmology to what for the last two hundred years has been called biology — which was the sense this word and this branch of knowledge had in the Aristotelian tradition. My first example is Albertus Magnus, who decisively contributed to the medieval philosophical canon’s adoption of Aristotle.

When a Child Does Not Resemble Its Father

In Aristotle’s thought, there is much discussion of reciprocal action, in which the “patient” acts upon the “agent.” The treatise *On Generation and Corruption* offers a perfect example. Aristotle expounds at length on the opposition between “to act” (*poiein*) and “to suffer” (*paskhein*).³ This opposition corresponds to the one in the category of motion between “to move” (*kinein*) and “to be moved” (*kineisthai*). But to be moved is to be incited to move in return (*antikinein*). Only one mover is impassive and cannot be moved or move in return: the *prōton kinoun*, the *primum movens*. The “first mover” is unmovable. “And since that which is moved and moves is intermediate, there is a mover which moves without being moved, being eternal, substance, and actuality. And the object of desire and the object of thought move in this way; they

move without being moved.”⁴ In this sense, the first unmovable mover (*prōton kinoun*) is also the final cause, which “produces motion by being loved.” Motion in the world proceeds from a sphere lower than God, who is the upper sphere of the heavens and the first mover (*prōton kinēton*, *primum mobile*). “For motion in space is the first of the kinds of change, and motion in a circle the first kind of spatial motion; and this the first mover *produces*.”⁵ Motion, beginning with the eternal motion in space of the sky’s upper sphere, propagates itself from sphere to sphere toward the sublunary world. But in this lower world inhabited by living creatures, the perennial nature of the local circular motion ends, and death is present: “On such a principle, then, depend the heavens and the world of nature. And it is a life such as the best which we enjoy, and enjoy for but a short time.”⁶ What is eternal is the succession of generations and corruption, which “imitate circular motion.” Indeed, “being . . . is better than not-being: but not all things can possess being, since they are too far removed from the principle. God therefore adopted the remaining alternative, and fulfilled the perfection of the universe by making coming-to-be uninterrupted: for the greatest possible coherence would thus be secured to existence, because that coming-to-be should itself come-to-be perpetually is the closest approximation to eternal being.”⁷ The hylomorphic theory of nature makes it “acted upon” (*to paschōn*).⁸

Local motion, or translation (*phora*), is the first motion produced by the cosmos, but it is only one of the four kinds of motion (*kinēseis*) imagined by Aristotelian physics. The other three are increase and diminution (*auxēsis* and *phthisis*); alteration (*alloiōsis*); and generation and destruction (*gēnesis* and *phthora*).⁹

Kinein, “to move”: this term comes into play in definitions of the efficient cause, or the very particular motion that through fertilization ensures the generation of living beings. Fertilization is

understood as transmitting motion. The same is true for growth and various observable qualitative changes. In fertilization, semen, the addition (or residue, *perissōma*) of nourishment from the paternal body, moves the menstrual matter, which on its part is the residue of the maternal blood. The maternal blood is also considered an addition. The embryo, and later the actual living being, are formed by the consequences of this encounter between the formative agent and the material substratum. That which takes on a form will bear the characteristics of the species and the singular qualities of the individual.

Individual particularities owe a great deal to this “being moved in turn,” which prevents the agent from exercising all its formative power. The future *reactio* of medieval Latin terminology will designate that which makes the patient not entirely passive (*patiens*, *paskhōn*) but obliges the agent to be moved and acted upon in turn (*repati*, *antikineisthai*). In *Generation of Animals*, Aristotle expounds on the reasons why children sometimes do not look like their parents. This results from a slackening of the semen’s movements; semen, endowed with heat and formative power, acts upon the maternal matter, which is colder and, even while taking on a form, puts up resistance to it, sometimes successfully:

The reason why the movements relapse is this. The agent is itself acted upon by that on which it acts; thus that which cuts is blunted by that which is cut by it, that which heats is cooled by that which is heated by it, and in general the moving cause (except in the case of the first cause of all) does itself receive some motion in return; e.g. what pushes is itself in a way pushed again and what crushes is itself crushed again. Sometimes it is altogether more acted upon than acting, so that what is heating or cooling something else is itself cooled or heated, sometimes having produced no effect, sometimes less than it has itself received.¹⁰

Consequently, when the semen's movement is the most energetic, the resemblance to the father (male sex, the father's features) will be greatest. More distant resemblances (with the mother or a grandparent), the formation of a daughter, and the formation of a monster are all results of an increased resistance in the feminine substratum.¹¹ This theory gives form an active power over matter, just as it privileges the agent over the patient, heat over cold, the male sex over the female. If one subscribes to Aristotle's propositions, then reaction, cold, and femininity are in secondary positions. This aspect of the doctrine lends itself, of course, to the accusation of phallocentrism. Note, however, that there can be action and reaction between the semen and the menstrual residue because their "substratum" is "a single something."¹² What they have in common is what allows one to act upon the other. Heat and cold, along with wetness and dryness, are the primary qualities that form the four elements and are contained within these elements in pairs: fire (hot and dry), air (hot and wet), water (cold and wet), and earth (cold and dry). According to Aristotle, heat and wetness have active powers, cold and dryness have passive powers. These oppositions between qualities enable the elements to act upon each other. Reciprocal action takes place between "tangible" qualities capable of coming together and being mixed. On the other hand, opposites such as lightness and gravity do not exercise a reciprocal action.

Aristotelian thought, as we see, easily accepts the inequality between action and reaction, even while assigning them both to the same genus, within which they differ through contrariety. It also brings the couple *kinein/antikinein* into the realm of perceptions, behaviors, and passions. As proof, one can read this passage from *On Memory*, the interpretation of which is not without its problems: "For a similar reason bursts of anger or fits of terror, when once they have excited such motions, are not at once

allayed, even though the angry or terrified persons set up counter motions, but the passions continue to move them on, in the same direction as at first.”¹³

Centuries went by before the Latin *reagere* was used as an equivalent to *antikinein*. This occurred in a passage on the reproduction of animals in which Albertus Magnus, directly inspired by Aristotle, introduced *reactio* into scholarly language. In *Quaestiones super De animalibus*, we first read the following lines, which appear like a commentary on the passage from Aristotle I have just cited on the “slackening” (or “remission”) of semen:¹⁴ “The more distant any natural agent is from its beginnings, the more continuous its operation, the more it weakens and tends to fail, since the agent, in the realm of nature, must in turn be acted upon when it acts, and in being acted upon, it reacts, as the Philosopher says.” This principle is invoked in the same work to explain the shorter length of the upper limbs compared with the lower limbs; their growth encounters a greater resistance: “The closer growth comes to its completion, the more it weakens due to the reaction of the contrary.”¹⁵

In his *Physica*, Albertus Magnus writes, in terms that already appeared in the Latinized Averroës: “It is necessary for the agent to submit in turn to the patient [*Necesse est quod agens repatiatur a passio*].”¹⁶ This time Albertus does not use the word *reactio*, but he gives it the definition that would appear in philosophical dictionaries until the eighteenth century. Purists, attached to classical Latin, accepted this definition, but they concluded, along with Gerardus Johannes Vossius, that *reagere* and *reactio* are incorrect terms that are better avoided or at least restricted to Scholastic debates. Vossius admitted that *reagere* and *reactio* had technical pertinence (*vox idonea rei quam signant*), but he preferred locutions such as *vicissim ager* (to act reciprocally) and *resistere agenti in se* (to resist that which acts upon oneself).¹⁷

In medieval universities, the teaching of natural philosophy and the arguments between philosophers included propositions on motion, action and passion, and reaction. This teaching and these arguments accompany medieval and Renaissance interpretations of the works of Aristotle and those of his commentators Avicenna and Averroës. In the beginning, there is almost total agreement on the principles of physics set forth by Thomas Aquinas and based on Aristotle: “The fulfillment of what is potentially, as such, is motion”; or, “A thing that is in motion derives its motion from something . . . other than the thing itself.”¹⁸ To speak of motion is to speak of nature, for, according to Thomas Aquinas, who appeals to Aristotle on the matter, “nature is the principle of motion and of rest.”¹⁹ The Scholastics generally refer to Aristotle to affirm that when a reciprocal action occurs, there is a similarity of genus between agent and patient but a dissimilarity of species.²⁰ Aristotle postulated both community and difference at the moment of a reciprocal action.²¹ One can see here a source or a first formulation of what will become the Kantian notion of community (*Gemeinschaft*).

Intensions and Remissions

The great English universities played an important role in the history of medieval science. The writings and reputations of English philosophers who were active at Oxford, especially at Merton College, are still with us: Thomas Bradwardine, Richard Swineshead, and William Heytesbury.²² At the beginning of the fourteenth century, they revived and discussed the problems of Aristotelian physics, kinematics, weight, the impact of bodies, and especially heat.²³ Those called the Calculators attempted, speculatively, to quantify reaction. They asked themselves what part of an agent undergoes a reaction (*pars repassa*) and what other part remains unaffected or affected to a lesser degree by the action

undergone. They wanted to account for the equal (“uniform”) or unequal (“deformed”) distribution of qualities in bodies. Depending on the case at hand, some denied a reaction had taken place. These problems were taken up again by the theorists of *impetus* from the Paris school, where Jean Buridan’s nominalism had its followers (Albert of Saxony, Marsilius of Inghen, and the brilliant Nicole Oresme).²⁴ The discussion spread to Italy (Paolo Veneto, Giovanni Marliani). In the course of these debates, a problematic was elaborated that some recent historians have seen as the first glimmer of the rules later imposed by Galileo. Based on the fundamental concepts inherited from Antiquity, the idea of a possible mathematization came to light in an innovative way. It involved a geometry of proportions, a calculation of the “intensions” and “remissions” of moving “forms.”

According to the assessment of post-Galilean scientific thought, however, the Calculators’ efforts at quantification were applied to inadequate objects. These calculations and “measurements” remained bound to a physics that, despite its principled option in favor of an analytic method, had not yet reduced its object to local motion and had not come to see all of nature as the *experimental* field of application for arithmetic and geometry — that is, a field open to a *possible* experience. It is true that this physics distinguished in principle between “*extensive* magnitudes” (spatial) and “*intensive* qualities.” But it did not elaborate on the consequences of this distinction. It granted preeminence to local motion but did not clearly separate it from other types of motion: generation, growth, alteration. And among the intensive qualities of motion it included speed, heat, and cold, as well as tastes and colors insofar as they are perceived by the senses. These qualities were so many “forms,” whose increase was known as *intension* and whose diminution was referred to as *remission*. As for “intensive qualities,” their calculations remained arbitrary and uncontrollable.

Quantitative evaluation remained entirely dependent on sensory intuitions, unaided by disciplined instrumental measurements. As Alain de Libera has said, the Oxford Calculators' project led to "a physics of imaginary reasoning and thought experiments with no empirical aim."²⁵ Except in the cases of speed and accelerated motion, gradations were attributed to poorly defined phenomena. Numerical transcriptions were imposed on things that cannot be numbered. This physics was therefore incapable of reducing its object to "extensive magnitudes" alone and of squaring its calculations with experimental results. The results obtained were endlessly controvertible. Over three centuries, however, Swineshead's *Liber calculationum* enjoyed surprising success in Europe and was still cited in the seventeenth century.²⁶

What phenomena were cited most often up to the eighteenth century? The privileged example of reaction is the red-hot iron immersed in water, such that the iron is cooled and the water is heated. And Aristotle's authority is constantly invoked: "In some of the bodies which are called hot the heat is derived from without, while in others it belongs to the bodies themselves."²⁷ The type of motion in question is therefore qualitative alteration (*aloiōsis*). While a distinction was made between them, alteration and mixing, which preoccupied chemistry in its first stages, were often compared. The propagation and dissipation of heat were not understood scientifically and formulated in equations until much later, when they were interpreted in terms of local molecular motion.²⁸ Medieval thinkers, as seen above, believed they could treat this subject on the basis of the physics of the four elements and according to a scale of substantial qualities — each endowed to varying degrees with activity or resistance. It was supposed in particular that the series of qualities — hot, cold, wet, and dry — were organized along a scale that decreased in *active* properties and increased in *resistant* properties. Degrees of heat (generally eight in number) were not

measured but simply attributed, as was the case in the Galenic tradition for the heating or cooling virtues of medicines.²⁹

Agreement on the circumstances of its application was far from universal, and almost all of the treatises titled *De reactione* and the dense chapters devoted to this subject in the most general works had a polemical element. And they multiplied; to mention only a few: a work by Giovanni Marliani (around 1482); then those of the Aristotelians of the Padua school, Pietro Pomponazzi (1515) and Jacopo Zabarella (1533–1589).³⁰ In one of his first writings, Pomponazzi ironically took issue with the English Calculators and with Nicole Oresme and his calculations of forms, that is, of intensive qualities.³¹ The *intentio* of these intensive qualities was the result not of an addition of discrete units or supplementary parts but of a qualitative improvement: the form itself can be more intense (*intenditur*) or more attenuated (*remittitur*). One must distinguish, in addition, between the reactions of the inanimate world and those of life. Zabarella, an opponent of Platonic dualism, recognized the omnipresence of natural motion; but he distinguished between an absolute principle, made up of the motion of the heavens, and a motion of terrestrial bodies, which is transmissible (“transient”) and is either active or passive.³² His treatise *On Reaction* defends Pomponazzi and develops a theory of nature that claims to remain faithful to the theories of Aristotelian physics; for example, following Aristotle, he asserts that extreme distance — such as that between the stars and Earth — makes a reciprocal action between elements and lower bodies impossible. In action and reaction, there is a battle (*pugna*) and an effort of self-conservation on the part of each opposite. “When fire acts on water, it acts insofar as it is hot; when fire is acted upon by water, this is not insofar as the fire is hot but insofar as it is potentially cold; for it is through form that it acts and through matter that it is acted upon.”³³ Zabarella makes the heavens a

corporeal first mover not radically separate from the world in which our life unfolds. Nature is universal, it rules all things, and its goal, through the action and reaction of its elements, is to ensure their conservation and the production of mixed bodies.³⁴

A decisive change did not take place until the moment — at the beginning of the seventeenth century — when physics abandoned the metaphoric couple form/matter and when speed and acceleration ceased to be “intensive qualities” and joined the category of “extensive magnitudes.” From that moment, geometrized physics, as it established its formulas and turned more and more (though not without difficulty) to measuring instruments in order to verify them, slowly acquired the means to quantify other “intensive qualities” of the medieval doctrine: colors (colorimetry) and heat and cold (thermometry and calorimetry).³⁵ From the red-hot iron cooled by water (the technique of water tempering) to steam-powered and thermodynamic machines, we find the passage from one era of physics to another.

New Worlds

In seventeenth-century Europe, while Galileo and his first disciples were laying the foundations for what appears today as the great “paradigm shift,” scholars remained attached to the Peripatetic definitions of motion, of the different types of motion, of contact (that is, impact), and of mixture. The doctrine was often explained with classic examples and problems: the heated iron and water, the sun acting upon terrestrial bodies without being acted upon in turn. In scholarly works, these examples often use the word *reactio* or the verb *repati*. Such is the case in Johannes Magirus’s manual.³⁶ There is a shared opinion, a common denominator, that simply repeats the formula of Averroës and Albertus Magnus. In his philosophical dictionary, Rudolphus Goclenius the Elder included an entry on *reactio* and defined it as follows:

A WORD FROM PHYSICS

“Action, in return or reciprocated, of a body that has undergone an action, whereby this body resists the initial agent and changes it, at the same time as it is changed by it.”³⁷ Note that the definition uses the prefix *re-* in three terms.³⁸ It thus does not avoid the tautology that threatens so many definitions. Here it establishes a quasi synonym, likening “react” to “resist.”

In view of the dates when the new ideas appeared in the great books that marked the first scientific revolution (those of Kepler, Galileo, and Descartes), one might be tempted to believe that important changes took place in the commonly shared worldview. In fact, these ideas at first reached only the small number of minds capable of understanding, discussing, and extending them. The number of “latecomers” was considerable. As late as 1690, Father Jean-Gabriel Boivin, a Minorite, carefully summed up the thought of Duns Scotus for the students at his seminary and repeated the cosmological formulas of Aristotelian provenance: on this earth, there are active and passive powers; but the motion of the earth has its origin in powers that are active and impassive, for universal motion is caused by the perfection of the immobile first mover. This physics abounds in anthropomorphic images: action and reaction imply the “victory” of an “agent” over a “patient.” Relationships of power, later analyzed quantitatively by classical mechanics as successive states of equilibrium, are expressed in terms of a dramatized conflict.³⁹ Boivin raises the usual objection: stars act upon the objects of the lower world without suffering any action in return. The explanation appears simple to him, and it has been formulated countless times: the stars are so distant from sublunary things that they cannot be reached by the latter’s reaction, and, furthermore, stars cannot receive “sublunary qualities” (*non sunt capacia qualitatum sublunarium*). Other authors are more influenced by themes from the Stoics’ physics, through Hermetism or Paracelsism. They agree that the world is fraught with

“influences” or sympathies, through which occult qualities are manifested, causes that the intellect can recognize but are not accessible to the human senses.⁴⁰ The sympathies (and antipathies) bring stars, rocks, plants, animals, and the organs of living bodies into contact with each other. Indeed, it was through the interplay of sympathies — which lent the force of reality to metaphoric bonds — that the world could be interpreted as an organism, and the organism as a microcosm. “Sympathetic effects,” wrote the Jesuit father Gaspar Schott, “arise from a friendly affection, or coordination and innate relation, of one thing to another . . . so that if one is acting, or reacting, or only just present, the other acts or is acted upon.”⁴¹

If this solidarity is not confined to the lower spheres, and if a human being can contain not only all of the heavens but God himself (which Schott takes care not to say, but which the heretics will assert), then there is no imperfection or fall from grace in the lower world. The hierarchies of the organized cosmos disappear, and all condemnation of the disorder of “base” sublunary nature ceases. The consequences of radicalizing the doctrine of sympathies, with its share of poetic magic, paradoxically cleared the path for the new Galilean discipline: the world is one, the powers that govern it are everywhere the same. In the first case, the metaphoric discourse was based on the generality of comparison; in the second, mathematics and successful experiments confirmed the generality of calculation. Good fortune was indeed granted to those who recognized perceptible analogies between different regions of the world, but phenomena can be subjected to calculation. The result of this subjection, for the good Calculators, was technical mastery, which quickly spread. The couple action/reaction found a use in both languages, that is, in an imaginary vitalism that delighted in the divination of sympathies and in a mechanism that applied the rules of geometry to nature.

On the Vernacular

Until this point, I have commented on scholarly texts written in Latin. Many more such texts will be discussed below. Yet one must also ask how the Latin *reactio* gained a foothold in the so-called vernacular languages.

Its entry into French was quite slow. I know of only one use of the word “react” in the sixteenth century, in *La Complainte de nature à l’alchimiste errant* (1516) by the painter Jean Perréal (c. 1455–1530). With Perréal, the term continues to express a process of the most general and most traditional physics. It does not belong to the specialized vocabulary of alchemy, where I have never encountered it, even in much later texts:

But must I say
That there is no active element
That can act with the passive one.
Just as fire in air acts,
Air in water reacts,
And water acts in the air
When fire wants to wage war.⁴²

Perréal paints a picture of a storm, a battle of three elements. One does not, however, find *réagir* (react) or *réaction* (reaction) in the works of the most important sixteenth-century authors, at least if one trusts Edmond Huguet’s dictionary or the many indexes that have recently been drawn up. The most likely possibility – until we have more information – is that the term came into circulation in French sporadically and only in works that, popularizing the notions of physics, bore the imprint of Aristotelian and Scholastic thought.⁴³

In the Italian of Giordano Bruno, *reazione* is but one of many examples of *contrarietà* that reign in natural phenomena:

ACTION AND REACTION

Dove è la contrarietà, è la azione e reazione, è il moto, è la diversità, è la multitude, è l'ordine, son gli gradi, è la successione, è la vicissitudine.

And where there is contrariety, there is action and reaction, there is motion, there is diversity, there is number, there is order, there are degrees, there is succession, there is vicissitude.⁴⁴

Is this idea new? Not at all. Bruno borrowed the notion of contrariety from Aristotle (*enantiotès*: *Metaphysics* 1.3.4; *Categories* 14), and he follows the Stagirite's text almost word for word; the short juxtaposed propositions are hurried and breathless, giving a baroque impression.

What about English? The expressions "to react" and "reaction" appear in the language as early as the end of the sixteenth century. In *The Nature of Bodies* (1644), the English Paracelsist Kenelm Digby remains faithful to the binary Aristotelian formula that had become canonical: "If fire doth heate water, the water reacteth againe . . . upon the fire and cooleth it."⁴⁵ Digby is a magician who likes to call upon astral sympathies. On the other hand, Thomas Hobbes also used these terms, as we shall see, but within the context of a materialist philosophy that privileged corporeal reality and attempted to formulate mechanically all natural phenomena, including mental operations.

In all the languages in which it appears, the word "reaction" belongs to "physiology" — that is, to natural philosophy. For solid bodies, it serves as a stand-in for the more recent *contrecoup* (rebound, repercussion) (which appeared in French in 1560). At first, it was used solely for natural phenomena, without application to the human world.

Speech and Numbers

It was a good while before the ancient meanings and examples of the word “reaction” were left behind: the hot iron plunged into cold water seemed never to wear out. In Ephraim Chambers’s *Cyclopaedia* (1743; “Reaction” entry), then in Diderot and d’Alembert’s *Encyclopédie* (1765; “Reaction” entry, translated from Chambers), one reads: “The Peripatetics define re-action to be that which a passive body returns upon the agent by means of some quality contrary to that received from it, in the same part with which the agent acted, and at the same time; as water, while it is heated by fire, does at the same time cool the fire.” Nonetheless, Chambers and the *Encyclopédie*, after paying tribute to the Peripatetic school tradition, add a reference to Sir Isaac Newton’s third law: “But the equality of the actions was not known. Sir Isaac Newton established it as one of the laws of nature, that action and re-action are equal and contrary.” An unusual juxtaposition of Scholastic physics and the new science, in the middle of the eighteenth century, no less. Only now is a line beginning to separate the prevalent philosophical authority of the Peripatetics from modern knowledge, inaugurated by Galileo, in which mathematical precision set forth laws that cleared the way for calculation. The *Cyclopaedia*’s definition does not dismiss the canonical one: it *adds* the notion of equality to it, as if the ancient notion simply needed to be completed. In fact, the ancient definition was not false; but it included too many phenomena, to which it proposed no measurable approach. It is as if the qualified and the quantified definitions could support each other, at least for a while. Thus it was that the Renaissance doctrine of reciprocal action and sympathies could stay in circulation long enough to be reactivated by the Romantics. The word “reaction” did not undergo a radical semantic change in the immediate wake of Newton; rather, it became two-sided, taking on a double connotation.

It could be marshaled under two different banners, as I will often have occasion to note. On the one hand, as soon as the principle of calculable equality was accepted, Newton's third law was interpreted as a valid argument in a mechanistic interpretation of the universe. On the other hand, the word recalled a more ancient idea, less "precise" in the modern sense, which Galileo and Descartes did not use, no doubt in order to distance themselves from Aristotelianism.⁴⁶ To be sure, the *Cyclopaedia's* juxtaposing the ancient conception of reaction with its new quantified status could only be provisional. Before long, the Peripatetic definition became obsolete. Indeed, the favorite examples of ancient physics — notably heat and water — were taken up and treated altogether differently in the new physics.

During its first phase, the new physics set in place a complete theory of mechanics, based on the work of Newton and his immediate successors: more or less explicitly, action and reaction constantly occupied the stage. Then, in the nineteenth century, there was a second phase when modern physics began to reflect on "heat engines" able to produce motion, and this required new laws. Thermodynamics took into consideration heat and its effects on cold bodies "regardless of the substance involved or the way in which one acts upon this substance." Sadi Carnot, who was audacious enough to posit this generalization in the study that opened the thermodynamics era, spoke of "the action of heat" but did not use the word "reaction." He mentioned the "re-establishment of equilibrium," and his successors (Emile Clapeyron, William Thomson, Rudolf Clausius) did a great deal more than refine his thought: they mathematically formulated it, without resorting to Carnot's discursive argumentation. Before returning to the remarks that the Newtonian language calls for here, I want to cite the passage in which Carnot notes the success of classical mechanics, even as he marks the limits of its field of application:

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The machines that do not receive their movement from heat; those that are moved by the force of men or animals, by a waterfall, by a current of air, etc., can be studied down to their smallest details by the mechanical theory. Every case can be foreseen, every imaginable movement is subject to firmly established general principles applicable in all circumstances. Such is the nature of a complete theory. A similar theory is obviously lacking for heat engines. We will not possess it until the laws of physics are sufficiently extended and generalized, such that we can know in advance all the effects of heat as it acts in a determinate manner on any body whatever. . . . The production of motion in steam engines is always accompanied by a circumstance that we should carefully note. This circumstance is the re-establishment of the equilibrium of caloric, that is, its passage from a body whose temperature is relatively high to another body whose temperature is lower.⁴⁷

In Newton's *Principia* (1687), the third law of motion is formulated as follows:

To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

Whatever draws or presses another is as much drawn or pressed by the other. If you press a stone with your finger, the finger is also pressed by the stone. If a horse draws a stone tied to a rope, the horse (if I may say so) will be equally drawn back toward the stone; for the distended stone, by the same endeavor to relax or unbend itself, will draw the horse as much toward the stone as it does the stone toward the horse, and will obstruct the progress of the one as much as it advances that of the other. . . . This law takes place also in attractions.⁴⁸

The law's corollaries, which are just as important, establish the rules of the composition of forces. D'Alembert, without directly citing Newton's third law, declares that all the problems of dynamics can be solved by calculating the composition of forces.

Historians of science have often noted that the inventors of the new physics gave preference to the Platonic notion of a geometer God, as opposed to Aristotle's "naturalism," while at the same time reviving Epicurean atomism and especially the idea that motion becomes no less perfect as it moves away from the first cause. God, or nature, imposes the same law at all levels of the universe.⁴⁹ This was therefore the end of the Peripatetic distinction between natural motion and violent motion, as well as the end of the perfection attributed to the circular motion governing the celestial spheres. "Classical" mechanics thus defined itself by postulating relative motion in a homogeneous and isotropic space.

The impact of bodies before Newton formulated his laws of mechanics (particularly the third law) has been the focus of assiduous study. One can trace the idea's successive stages from the fifteenth-century theories of *impetus* to the formulas elaborated by the new physics, from Galileo to Edme Mariotte, by way of Johannes Kepler, Christiaan Huygens, Christopher Wren, and John Wallis. Without using the word "reaction," Descartes saw it as a special case of the transmission of motion.⁵⁰ On this point, Newton gave credit to his predecessors in the scholium to the laws of motion. As this debate progressed, it became more and more clear that the idea of motion could not be considered "in different senses," as Aristotle had maintained. Only local motion deserved to be examined and analyzed. The other types of motion proposed by Aristotle (generation and corruption, growth and diminution, alteration) must either be reduced to local motion or cease to be considered. The third law and the notion of reaction

allowed Newton decisively to advance ideas he had developed in an earlier manuscript on motion (*De motu*):

The concept of the internal force of a body transformed itself from a force that carries a body in uniform motion into a force of reaction, a force that a body “exerts only in changes of its state produced by another force impressed upon it,” and with this change Newton clarified once and for all his understanding of the concept of inertia as we find [it] in Law 1. Newton was now in a position to perceive the full implication of the notion implicitly present in his concept of centripetal force from the beginning, that uniform circular motion is dynamically equivalent to uniformly accelerated motion in a straight line. This may well be the central insight on which the whole of Newtonian dynamics stands.⁵¹

The third law makes it possible to dispense with the parallelogram of forces.

The semantic mutation of the word “reaction” is therefore one effect of the scientific revolution. The new scientific mind aspired to translate the laws of nature into a mathematical language, and thus to find the equations through which the physical phenomena could be submitted to precise measurements. It meant abandoning progressively all unverifiable speculation on the four elements, on the substantial qualities (heat, cold, wetness, dryness). It was recognized that one could not speak of changes in inert things the way one speaks of changes in living bodies or appetites. Mathematization succeeded because the variables under consideration were restricted to those that could be measured. Reflection dominated by the model of the living being gave way to a purely mechanical science. Only local motion was retained: henceforth it became necessary to consider only masses in space, distances, speeds, quantities of motion, forces, and

kinetic energies.⁵² One concept that was profoundly modified was that of the natural agent, which, ceasing to be a power in the process of actualization, became a measurable force. The efficient cause, now calculable, made final causes undesirable and superfluous. Correlatively, the word “passion,” which, as we have seen, was the classical antonym of “action,” took on an outmoded meaning with respect to natural phenomena and was henceforth used only in matters of the soul. “Reaction” designated the rules and principles that make it possible accurately to predict the speed and direction taken by a body of determinate mass affected by a set of forces. Gravity itself represented a special case in which action and reaction are produced at a distance.

In Newtonian thought, there is no incompatibility, between these exact laws and a recognition of the existence of God. The laws of gravity govern the planetary orbits, but the *regularity* of the position of these orbits is not derived from these same laws. Newton called upon God to guarantee the stability of the universe: the cosmic system is placed in his care. And the famous final “Scholium generale” of the *Principia* carefully defines the attributes that must necessarily belong to the Creator God. This God, without being eternity and space himself, occupies the infinity of space and time, while remaining identical with himself. Although omnipresent, he does not suffer from the action of bodies in motion, nor do these bodies suffer any resistance from the fact of God’s existence. One cannot assert any action or reaction between the spirit of God and the matter of the world. “As a blind man has no idea of colors, so we have no idea of the manner by which the all-wise God perceives and understands all things.”⁵³

In the *Principia*, as in his letters to Richard Bentley, Newton asserts that the force of attraction is not essential to matter.⁵⁴ The only force essential to matter, in his opinion, is inertia. He was anxious to counter the reproach of the Cartesians (and of Chris-

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tian Wolff in Germany) that he appealed to occult qualities. He did not believe that the laws of mechanics (by which, it has long been agreed, he wanted strictly to abide) were capable of explaining everything that can be observed. In the *Queries* of his *Opticks*, and in his papers on chemistry (only recently discovered), Newton speculates on various types of ether, on the periodic renewal of the world, and on cosmic cycles and vital fermentations, without reducing them purely and simply to the laws of motion. This was one of the points upon which he asserted his disagreement with Cartesian mechanism. Newton's uneasiness stemmed from his religious convictions. Some of his first commentators — those who popularized his works — readily pointed to the equality of action and reaction as proof of the manner in which God operates in nature. Thus in his *Account of Sir Isaac Newton's Philosophical Discoveries*, Colin Maclaurin adopts the idea of absolute space but also reintroduces the notion of a first mover and appeals to the pseudo-Aristotelian *De mundo*. Newton himself declared the need to go back to a Cause superior to pure mechanism, for mechanism itself attests to a divine intention, a beneficent Providence:

It is because *action* and *reaction* are always equal, that the mutual actions of bodies upon one another have no effect upon the motion of the common center of gravity of the system to which they appertain. . . . If it was not for this law, the state of the center of gravity of the earth would be affected by every action or impulse of every power or agent upon it. But by virtue of this law, the state of the center of gravity of the earth, and the general course of things, is preferred, independent of any motions that can be produced at or near its bowels. By the same law, the state of the lesser systems of the planets, and the repose of the general system, is preferred, without any disturbances from the actions of whatever agents there may be in them. . . . And the necessity of this law, for preserving the

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regularity and uniformity of nature, well deserved the attention of those who have wrote so fully and usefully of *final causes*, if they had attended to it. . . .

Tho' [God] is the force of all efficacy, yet we find that place is left for causes to act in subordination to him; and mechanism has its share in carrying on the great scheme of nature.

Thus the equality of action and reaction limits and mechanically restricts the forces that are the “instruments” God made “to perform the purposes for which he intended them.”⁵⁵

Newton is not the only one to transmit this conceptual tool to the Enlightenment. His great adversary Gottfried Wilhelm Leibniz integrated the same idea into his system, though he developed it in an entirely different way. In “Principles of Nature and of Grace,” Leibniz asserts:

Everything is a plenum in nature. . . . And since everything is connected because of the plenitude of the world, and each body acts on every other one more or less, depending on the distance, and is affected by it *in reaction*, it follows that each monad is a living mirror, or a mirror endowed with an internal action, and that it represents the universe according to its point of view and is regulated as completely as is the universe itself.⁵⁶

Leibniz does not accept Newton's concept of absolute space and time. He could only sanction a cosmology in which God intervenes like a watchmaker who might, from time to time, need to repair his timepiece. An attraction exerted across the void seemed absurd to him. Even when discussing the material realm, Leibniz was preoccupied with not leaving the field wide open for mechanism: “The origin of action cannot be a modification of matter.”⁵⁷ Speaking of himself in the third person in a text in which Philare-

tus is in dialogue with Aristes, he introduces the Platonic idea of antitypy:

Bodies are composed of two natures, that is, the active primitive force . . . and matter, or the passive primitive force, which seems to be *antitypy*. For this reason, he maintains that everything in material things can be explained mechanically, with the exception of the principles of mechanism themselves, which would never be derived from the consideration of matter alone.⁵⁸

According to Leibniz, the active primitive force could also be called the vital force. Here one finds a hypothesis that Newton did not propose so openly but that enjoyed great success among eighteenth-century physicians and nineteenth-century vitalists.

In making each monad a mirror of the universe, Leibniz gives a logical-mathematical and dynamic expression to the vitalism of sympathies that before him had been expressed in an intuitive and disordered way in “magical” cosmologies. He offers a system — that of a preestablished harmony — that can make room for mechanism, without letting it take up the entire space.

Kant

In his pre-critical writings, Kant addressed the question of the order of the world, but without claiming to find in this order cosmological proof of God’s existence. Unlike Maclaurin and even Newton, Kant did not call on God to establish or preserve universal order. The creation of the world could be explained entirely by the laws of mechanics. Kant was satisfied with ontological proof: the world and matter belonged in the category of the *possible*, God alone was *necessary*.⁵⁹ For the creation of the solar system, Pierre-Simon Laplace hypothesized an initial nebula (also imagined by Buffon), but without postulating the existence of

God: this was the hypothesis that Laplace, according to the famous anecdote, did not need.

In his *Metaphysical Foundations of Natural Science*, Kant, extending the *Critique of Pure Reason*, no longer examined proofs of the divinity: he elaborated a “philosophy without theology.”⁶⁰ Having learned from Newton, he then renounced the idea of absolute motion, limiting himself to relative motion instead. In his examination of mechanics, which follows those of phoronomy (our kinematics) and dynamics, the third law of motion is interpreted as establishing the principles of both relation and simultaneity: “This is, then, the *mechanical law* of the equality of action and reaction. This law is based on the fact that no communication of motion takes place except insofar as a community of these motions is presupposed.”⁶¹ Jules Vuillemin rightly observes: “We note the reason why simultaneity is for Kant the *sui generis* synthesis of permanence and succession. These two terms are abstractions in relation to which simultaneity reestablishes the concrete character of the real.” It follows that “the idea of necessity has no application outside the community of substances, which is to say outside the limits of space and time, the subjective forms of possible experience. While in Leibniz’s system this community would require preestablished harmony for its principle, the simple law of the equality of action and reaction suffices as soon as one gives up trying to construct a theory of knowledge of things in themselves.”⁶² According to Kant’s deduction, the judgment of *relation* is at work in the third law of motion, in its *disjunctive* form, and in accordance with the category of *reciprocity*.⁶³

It is a matter of mechanics, then, and one must avoid attributing a phantom life to matter. In the third theorem of chapter 3 (“Mechanics”) and in an important appended remark, Kant interprets the second law of mechanics (inertia) as the principle

according to which “all changes in matter have an external cause.” He goes on to say:

The inertia of matter is and signifies nothing but its lifelessness, as matter in itself. Life means the capacity of a substance to determine itself to act from an internal principle. . . . Now, we know of no other internal principle of a substance to change its state but desire and no other internal activity whatever but thought, along with what depends upon such desire, namely, feeling of pleasure or displeasure, and appetite as well. But these determining grounds and actions do not at all belong to the representations of the external senses and hence also not to the determinations of matter as matter. Therefore all matter as such is lifeless.⁶⁴

Jules Vuillemin writes in turn:

Kant does not stop at life; and herein lies the principal difference that sets him apart from the Romantics. Or if, in the *Critique of Judgment*, he makes it the object of meditation, it is by insisting on the purely regulative (reflective) character of judgments that come into play. . . . Romantic philosophy would contradict this affirmation: in the hylozoism of *Naturphilosophie* — a hylozoism which for Kant was “the death of all philosophy of nature” — it would find again the essential themes that inspired Leibniz’s metaphysics insofar as the latter endowed each monad with a representative faculty; it would create a poetic universe of value, but only by substituting reveries and imaginings for exact science — and the only exact science at that time was Newton’s.⁶⁵

Kant’s philosophy attempted to highlight the discipline of scientific reasoning, to reveal its conditions of possibility and of validity. But the discipline that applied to matter and material bodies

had its limits. Without passing directly into a Romanticism of desire, certain eighteenth-century mathematicians attempted at times to go beyond the realm of matter. They proposed their arguments as correctives or supplements to Newton's thought and presented them as propositions submitted to the scholarly community's judgment. Whatever one might reproach them with, it is not with abusing words or wanting to impress the public.

Among those who wished to perfect Newton's theory and find the "causes of gravity" was the very curious Genevan scholar George-Louis Le Sage, author of *Lucrèce newtonien*, which proposed a "system of otherworldly minute particles."⁶⁶ More important still was the theory of force and elementary particles proposed by the Jesuit Ruggero Giuseppe Boscovich (1711–1787), with whom Le Sage was in communication. This theory postulates an action-at-a-distance diffused among these particles of matter, which are indivisible, unextended, lacking in mass, and noncontiguous. In announcing his theory of mutual forces (*vires mutuae*), Boscovich invokes both Leibniz and Newton. Why Leibniz? Because he upheld the principle of continuity. Why Newton? Because in the last of the famous Queries of the *Opticks*, he addresses the phenomena of gravity, cohesion, and fermentation conjointly. Boscovich hastens to add that his thought differs as much from one as from the other and that he is answering the questions they left hanging.⁶⁷ His system, which is both original and coherent, did not receive full consideration until the end of the nineteenth century. Friedrich Nietzsche, the philosopher of force, praised Boscovich for having definitively substituted force for matter, thereby destroying an apparent truth that had been wrongly accepted, as Copernicus had done before him: "While Copernicus has persuaded us to believe, contrary to all senses, that the earth does *not* stand fast, Boscovich has taught us to abjure the belief in the last part of the earth that 'stood fast' — the

belief in ‘substance,’ in ‘matter,’ in the earth-residuum and particle-atom.” Nietzsche was not alone in recognizing Boscovich’s merits. Boscovitch was also given his due by James Clerk Maxwell, who decisively advanced knowledge of electromagnetism.⁶⁸ The advent of electromagnetism, which gave rise to the theory of relativity, opened a region of the physical world in which phenomena are not determined according to the gravitational laws of classical mechanics. Add to this the problems concerning the large-scale structure of the universe and the domains in which atomic and subatomic interactions occur, and physicists soon felt the need to formulate a “unified theory” that would gather these various regions together under a single law.

We still lack such a theory. It is nevertheless generally accepted today that classical mechanics is no longer sovereign or fundamental and that Newtonian action and reaction are but a special case in which a symmetrical formula can be favorably applied.⁶⁹

Derivative Fictions

The history of scientific words is not limited to the writings of reputable scholars who use them in good conscience. This history also encompasses those who use scientific terminology without its method and who look to it for easy inspiration or for a way to impress a public unlikely to know the difference. The spread of a vocabulary also takes place through distorted appropriations and illegitimate venues. It is difficult to sort out the naive meanderings from the deliberate impostures. A number of adventurers, passing themselves off as inventors, assumed the oracular tone of assertion to appropriate the third law of Newtonian mechanics without considering whether or not there was the least simultaneity or the least measurable “community” (to use Kant’s term) between the bodies or forces they presented as acting and reacting upon each

other.⁷⁰ A properly established law, such as Newton's third law of mechanics, can be used to legitimate unverifiable propositions. The more a science succeeds through innovative formulas, the more the predators of its vocabulary multiply. It is made to answer for things it never said. It is amalgamated with its opposite. Scientific language, which (since Galileo) was constituted by separating itself from ordinary language, was formed from calculations and equations; but it could not avoid resorting to simple words to designate its operations, and these words, sometimes borrowed from the common language, naturally return to this language or slip back into it. They are available to everyone, and, in the absence of technical competence, they become banal and unremarkable. The word, with its scientific aura, circulates in ordinary conversation, newspapers, and poetry. Since my research is lexical, I will not ignore these displaced uses that, according to rigorous scientific criteria, are considered degraded.

Some catchwords of the newly created mechanical science could thus be adopted independently of the requirement of quantification. Someone was always ready to buy into the most foolhardy speculations, which were presented on the same footing as the most methodical experiments. All kinds of reciprocities and alternations, both verifiable and unverifiable, took on the aspect of universal laws once they were associated with Newton's third law. Inexact or supernatural assumptions took shelter under the auxiliary words used by the exact and natural sciences or by rigorous mathematics. From the inception in the eighteenth century of a scientific language that was both rigorous and prestigious, its vocabulary was abused to enhance confused intuitions. The search for the scientific effect, in order to intimidate adversaries and seduce the public, hardly began in our day. The contemporary cultural phenomenon discussed in Alan Sokal and Jean Bricmont's *Fashionable Nonsense* was already quite evident in the

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