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Pasteur on Lactic Acid Yeast: A Partial Semiotic Analysis

Bruno Latour
UC-San Diego and Ecole des Mines, Paris
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One of the interests of studying scientific practice from the vantage point of literature is that it adds another series of mediations to the many that historians, sociologists, and philosophers are unfolding when they analyze laboratories, instruments, controversies, disciplines or institutions.¹ Scientific texts, to be sure, have no privilege, but neither are they inferior to the many sources we have for understanding science. Indeed, when properly studied, they offer a convenient model to show how many mediations can be retrieved from the scientist's own practice. A scientific text is not only a more or less transparent medium to convey information to the author's scientific colleagues, nor is it only a document to help historians, psychologists, or sociologists retrieve the state of mind of its author or the context in which it has been written. As many decades of literary theory have helped us to see, texts are a little bit less and a good deal more than information and document. They build a world of their own that can be studied as such in relative and provisional isolation from the other aspects. They are localized events, with their own matter and their own practice.

¹ See Andrew Pickering, ed., *Science as Practice and Culture* (Chicago: Chicago University Press, 1992).

Although this point is taken for granted in many studies of fictional literature,² it has not been rendered as acceptable in the [End Page 129] study of scientific literature--in spite of Françoise Bastide's work³ and the many studies of scientific texts coming either from the humanities⁴ or from the social sciences.⁵ The same people who would not hesitate to say that laboratory practices, or citations, or instruments, or institutions, or controversies, or conversations, or rhetoric can be studied in relative and provisional isolation from the rest, would balk at allowing a full-blown study of a single text. They would insist that a text is not an island, and that it cannot be understood without its context of use, the reader's response, and the wider social picture.

I understand these worries. They stem largely from the fact that, as Thomas Pavel has so clearly shown, many literary theories are ontologically weak, which makes them of little use for texts that insist on being referential and not fictional.⁶ But as I have shown elsewhere in the case of Einstein, even this question of the referent may be tackled by semiotic theory.⁷ The main advantage of practicing some sort of semiotics on scientific texts lies in the very limitation of the theory. By bracketing out the question of the referent (there exist only internal referents generated by the text itself) and by bracketing out the question of the locutor (authors and readers are built into the texts and may not relate to any authors and readers in the flesh), we let the texts deploy their own categories. Their world-making activity is no longer squeezed in between a referent that it has to grasp and a locutor or a social context from which it emerges. It becomes an event, which has the same activity, the same materiality, the same complexity, the same historicity as any other event.

This provisional independence, both from the referent and from the context, gives a valuable bonus to literary theory in the treatment of nonhumans. In the study of texts there is no a priori distinction to be made between an anthropomorphic actor and a [End Page 130] "physimorphic" or "zoomorphic" one: the same amount of work is required to attribute a role to a human or to a nonhuman character. In a

² See Algirdas Julien Greimas, *On Meaning: Selected Writings in Semiotic Theory* (Minneapolis: University of Minnesota Press, 1976).

³ Françoise Bastide, *Oeuvres de sémiotique des textes scientifiques* (in preparation).

⁴ Greg Myers, "Persuasion, Power, and the Conversational Model," *Economy and Society* 18:2 (1989): 221-244.

⁵ Michel Callon, John Law, and Aric Rip, eds., *Mapping the Dynamics of Science and Technology* (London: Macmillan, 1986).

⁶ Thomas Pavel, *Fictional Worlds* (Cambridge, Mass.: Harvard University Press, 1986); idem, *Le mirage linguistique: Essai sur la modernisation intellectuelle* (Paris: Le Seuil, 1988).

⁷ Bruno Latour, "A Relativist Account of Einstein's Relativity," *Social Studies of Science* 18 (1988): 3-44.2. See Algirdas Julien Greimas, *On Meaning Selected Writings in Semiotic Theory* (Minneapolis: University of Minnesota Press, 1976).

fairy tale identical functions may be fulfilled by a prince, a dwarf, a magic rod, or a fox. This freedom in selecting actors and redistributing properties among them is crucial to understanding scientific practice, and, to my knowledge, no other discipline possesses that freedom. All the others have to start from a "natural" division between human and nonhuman properties. So, even though the ontology embedded in literary theory may be flawed, its ability to deal with nonhumans is without a par, and it allows us to go much further in the study of scientific work than do discourse analysis, rhetoric, or conversation analysis.

Semiotics is the ethnomethodology of texts. Like ethnomethodology, it helps replace the analyst's prejudiced and limited vocabulary by the actor's activity at world making. To be sure, one cannot stop at the study of one text in isolation--but when adding other documents, other sources, other methods, the lessons learned from semiotics must be retained. There are mediators all the way down, and adding sources will only add more mediations, none of them being reducible to mere "document" or "information." That a method is limited does not rule out its usefulness--quite the contrary. After all, any scientist's bench is cluttered with dozens of different instruments that work according to many different principles, and we would consider a lab to be very ill equipped if it employed only one instrument applied over and over again to the same phenomena. Indeed, we would hardly call it a laboratory. I would claim that the same is true for the instruments of literary theory: there should be several on the bench of any well-equipped "science studies" lab.

I want to illustrate the possible usefulness of literary theory for the study of scientific practices by showing how a text written by Louis Pasteur in 1857 makes use of several philosophies of science that are a good deal more sophisticated than many of those we bring to the field of science studies. I have chosen the "Mémoire sur la fermentation appelée lactique"⁸ because it is a short piece [End Page 131] that is considered by historians of science to be one of Pasteur's most important papers.⁹

⁸ Partially translated by James B. Conant in *Pasteur's Study of Fermentation*, in the well-known and widely available *Harvard Case Studies in the History of Experimental Sciences* (Cambridge, Mass.: Harvard University Press, 1957), pp. 453-460. I have completed and modified the translation in many instances to respect Pasteur's wording more literally, and I have added emphasis as appropriate to point up my discussion. Space prevents me from including the complete paper and the complete semiotic inventory.

⁹ For instance, Gerald Geison comments: "With two striking exceptions this memoir contains the central theoretical and methodological features of all of Pasteur's work on fermentation--the biological conception of fermentation as the result of the activity of living microorganisms; the view that the substances in the fermenting medium serve as food for the causative microorganism and must therefore be appropriate to its nutritional requirements; the notion of specificity, according to which each fermentation can be traced to a specific microorganism; the recognition

The First Drama: How the Last Will Become the First

The text is structured around two dramas. The first one modifies the status of a nonhuman and of a human. It converts a nonentity, the Cinderella of chemical theory, into a glorious and heroic character; in parallel, Pasteur's opinion, the Prince Charming of this story, triumphs against all odds and reverses Liebig's theory. "The stone which the builders rejected has become the chief cornerstone." And then there is a second drama, a reflexive one, that appears only at the end: Who is constructing the facts, who is directing the story, who is pulling the strings—the scientist's prejudice, or the nonhumans? To the ontological drama is added an epistemological one.

I will start with the first heroic story of Cinderella-the-yeast. At the beginning of the paper, lactic acid fermentation has no clearcut cause. If there is a yeast, it is nothing but an almost invisible by-product of a purely chemical fermentation mechanism, or even worse, something that may hinder and spoil the fermentation. At the end of the paper, however, it is a fullblown new entity, integrated into a class of similar phenomena, which is the sole cause of fermentation. The whole transformation is indicated in one paragraph:

(§7) When examined under the microscope, when one is not forewarned [prévenu], it is hardly possible to distinguish it from casein, disaggregated [End Page 132] gluten, etc.; in such a way that nothing indicates that it is a special [spécial] material, or that it was produced during the fermentation. Its apparent weight always remains very little as compared to that of the nitrogenous material originally necessary for the carrying out of the process. Finally, very often it is so mixed with the mass of casein and chalk that there would be no reason to suspect its existence. It is it nevertheless that plays the principal role.

The transformation is not only that of the yeast extracted from nothingness to become everything, it is also that of Prince Charming, of Pasteur. At the beginning of the paper, his opinion counts for nothing

that particular chemical features of the medium can promote or impede the development of any one microorganism in it; the notion of competition among different microorganisms for the aliment contained in the media; the assumption that air might be the source of the microorganisms that appear in fermentation; and the technique of directly and actively sowing the microorganism presumed responsible for a given fermentation in order to isolate and purify it. The two missing features, which soon completed Pasteur's basic conception, were the techniques of cultivating microorganisms (and thereby producing fermentation) in a medium free of organic nitrogen and his notion of fermentation as "life without air" (Gerald Geison, "Louis Pasteur," in *The Dictionary of Scientific Biography*, vol.10 [New York: Charles Scribner's Sons, 1974], p. 362).

against Liebig's and Berzelius's powerful theories. At the end of the paper, Pasteur triumphs over his enemies and his view wins against all odds, the chemical account of fermentation being soon defeated:

(§6) The facts [that make the cause of lactic acid fermentation so obscure then seem very favorable to the ideas of Liebig or to those of Berzelius These opinions gain more credit daily.... These works all agree in rejecting the idea of some sort of influence from organization and life as a cause of the phenomena that we are considering. I have been led to an entirely different point of view.

But to accompany this elevation of Cinderella and this triumph of Prince Charming, another, wider-ranging transformation is necessary. The capacity of the natural world is modified between the beginning and the end of the story. At the start of the paper, the ideal reader¹⁰ lives in a world where the relation between organic matter and ferments is one of contact and decay:

(§6) In the eyes of [Liebig] a ferment is an excessively alterable substance that decomposes itself and thereby excites fermentation in consequence of its alteration, by disrupting through communication and by disassembling the molecular group of the fermentable matter. According to Liebig, such is the primary cause of all fermentations and the origin of most contagious diseases. Berzelius believes that the chemical act of fermentation is to be referred to the action of contact.

At the end, the reader lives in a world where a ferment is as lively as a specific life form, so much so that it now feeds on the organic material, which has become food for it instead of being its cause: [End Page 133]

(§22) . . . whoever judges impartially the results of this work and that which I shall shortly publish will recognize with me that fermentation appears to be correlative to life and to the organization of globules, and not to their death and putrefaction; no more than fermentation is a phenomenon due to contact, in which the transformation of sugar would take place in the presence of the ferment without giving up anything to it or taking anything from it.

In addition to the heroic transformation of the yeast and of Pasteur's opinion, in addition to the modification of the world's capacities, a fourth transformation is going on. At the beginning of the paper, fermentation is a haphazard phenomenon that is unknown, uncertain, and understandable. At the end, it can be produced almost at will, and new gestures are invented: sowing or sprinkling yeasts, cultivating yeast in a

¹⁰ The ideal reader is not the reader-in-the-flesh but the built-in reader or user of the text--that is, the reader anticipated and inscribed by the author in the writing of the paper.

medium as one would do with plants in a garden, and varying its conditions of existence, its environment:

(§9) In this experiment the yeast extract can be replaced by an extract of any nitrogenous plastic substance, fresh or decomposed, as the case may be. This limpid liquid, containing a nitrogenous substance in solution, is nothing but food, and in this respect its origin is of little importance provided it is of such a nature as to facilitate the development of the organized body [corps organise] that produces itself and is gradually deposited.

(§16) Whenever an albuminous liquid of a suitable nature contains a substance such as sugar, capable of undergoing diverse chemical transformations dependent upon the nature of such and such a ferment, the germs of these ferments all tend to propagate at the same time, and usually they develop simultaneously, unless one of the ferments invades the medium more rapidly than the others. It is precisely this last circumstance that one determines when using this method of sowing an organism that is already formed and ready to reproduce.

It is now possible to understand retrospectively what we have done all along without knowing it. Prince Charming is a practitioner who masters the culture of organisms instead of being manipulated unwittingly by invisible phenomena. The art of lactic acid fermentation becomes a laboratory science. In the laboratory, conditions may be modified at will.

There are many other transformations in this text. The nonhumans mobilized in the text do not resemble the matter-of-fact objects alluded to in realists' accounts of science. To be sure, a few are imported into the text as so many uncontroversial black boxes composing the background--the microscope, the definition of sugar and of alkalinity, etc.--but many others are foregrounded and used [End Page 134] as grey boxes with many qualifications: "the law of hemihedral correlation," Liebig's theory, the link between optical activity and life, etc. Still others, at the center of attention, are completely transformed in the course of the story: brewer's yeast is now made one instance of a whole class of phenomena; air is now separated into different functions, its chemical composition on the one hand and its action as a carrier of ferments on the other; the organic broth, which before was the cause of the ferment through degradation and contact, is now made the food of organisms and becomes a medium of culture. Nonhumans change in the course of the text and are, at least some of them, reshaped from top to bottom between one paragraph and the next.

Pasteur's Ontology: The Main Circulating Object and Its Transformations

Let us follow the main nonhuman character of the story, to see through how many different ontological stages this entity is forced to pass before becoming something. How does a scientist explain in his own words this emergence of a new actor out of other entities that he has to destroy, redistribute, and reassemble? What happens to this actant *x* that will soon be named lactic acid fermentation yeast? It is a circulating object inside the text, undergoing trials and being submitted to an extraordinary series of transformations. At first its very existence is denied:

(§4) Until now minute researches have been unable to discover the development of organized beings. Observers who have recognized some of those beings have at the same time established that they were accidental and spoiled the process.

Then, the main experiment that Pasteur has staged--in the text as well as in his laboratory--allows "a forewarned observer" to detect it. But this object *x* is stripped of all its essential qualities and redistributed among elementary sense data:

(§7) If one examines carefully an ordinary lactic fermentation, there are cases where one can find, on top of the deposit of the chalk and of nitrogenous material, spots of a gray substance which sometimes form a layer [formant quelquefois zone] on the surface of the deposit. At other times, this substance is found adhering to the upper sides of the vessel, where it has been carried by the movement of the gases.

(§10) When it solidifies [prise en masse] it looks exactly like ordinary pressed or drained yeast. It is slightly viscous, and gray in color. Under the microscope, it appears to be formed of little globules or very short segmented filaments, [End Page 135] isolated or in clusters, which form irregular flakes resembling those of certain amorphous precipitates.

It is not an object yet, but a cloud of floating perceptions not yet the predicates of a coherent substance. In Pasteur's textual philosophy of science the phenomena precede what they are the phenomena of. Existence precedes essence. To grant it an essence, to turn it into an actor, something else is necessary--the laboratory series of trials through which the object *x* proves its mettle. In the next paragraph Pasteur turns it into what I have called elsewhere "a name of action": we do not know what it

is, but we know what it does through the trials staged in the lab.¹¹ This is a form of pragmatism, but extended to nonhuman actors. A series of performances precedes the definition of the competence that will then later be made the sole cause of those very performances:

(§8) About fifty to one hundred grams of sugar are then dissolved in each liter, some chalk is added, and a trace of the gray material I have just mentioned from a good, ordinary lactic fermentation is sprinkled in.... On the very next day a lively and regular fermentation is manifest. The liquid, originally very limpid, becomes turbid; little by little the chalk disappears, while at the same time a deposit is formed that grows continuously and progressively with the solution of the chalk. The gas that is evolved is pure carbonic acid, or a mixture in variable proportions of carbonic acid and hydrogen. After the chalk has disappeared, if the liquid is evaporated, an abundant crystallization of lactate of lime forms overnight, and the mother liquor contains variable quantities of the butyrate of this base. If the proportions of chalk and sugar are correct, the lactate crystallizes in a voluminous mass right in the liquid during the course of the operation. Sometimes the liquid becomes very viscous. In a word, we have under our eyes a clearly characterized lactic fermentation, with all the accidents and the usual complications of this phenomenon whose external manifestations are well known to chemists.

We do not know yet what it is, but we know that it can be sprinkled, that it triggers fermentation, that it renders a liquid turbid, that it makes the chalk disappear, that it forms a deposit, that it generates gas, that it forms crystals, that it becomes viscous.¹² As of now it is a list of records in the laboratory notebook, *membra disiecta* that do not pertain to one entity yet, properties looking for [End Page 136] what they are the property of. At this point in the text, the entity is so fragile, its envelope so undetermined, that Pasteur notes with surprise its ability to travel:

(§10) It can be collected and transported for great distances without losing its activity, which is weakened only when the material is dried or when it is boiled in water. Very little of this yeast is necessary to transform a considerable weight of sugar. These fermentations should preferably be carried on so that the material is protected from the air, so that they will not be hindered by vegetation of foreign infusoria.

Maybe shaking the flask will make the phenomenon disappear, maybe carrying it about will destroy it. Before the entity is safely underlined by an ontological property, Pasteur has to add precautions that he will soon

¹¹ Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, Mass.: Harvard University Press, 1987).

¹² The entity has reached what could be called Hacking's ontological stage: "If it can be sprinkled it has some reality"; see Ian Hacking, *Representing and Intervening* (Cambridge: Cambridge University Press, 1983).

find useless. Not knowing yet what it is, he has to fumble, exploring beyond the dotted boundaries of the entity so as to determine its shape.

But how can he push his entity higher in ontological status, how can he transform this fragile uncertain boundary into an envelope, how can he move from this "name of action" to a "name of thing"? If it acts so much, the entity must be an actor? Not necessarily. Something more is needed to turn this actantial role into a full-blown actor to which will be attributed the origin of those actions; another act is necessary to conjure up the substrate of those predicates, to define a competence that will then be simply "expressed" through so many performances in laboratory trials. In the main part of the paper, Pasteur does not hesitate. He uses everything at hand to stabilize the substrate of this entity and grants it an activity similar to that of brewer's yeast, and similar to a plant in a plot of earth. Borrowing these powerful metaphors allows him to use the well-known ontological status of the domestication and culture of plants in order to give shape to his aspiring actor:

(§11) Here we find all the general characteristics of brewer's yeast, and these substances probably have organic structures that, in a natural classification, place them in neighboring species or in two connected families.

(§13) There is another characteristic that permits one to compare this new ferment with brewer's yeast: if brewer's yeast instead of the lactic ferment is sown in limpid, sugared, albuminous liquid, brewer's yeast will develop, and with it, alcoholic fermentation, even though the other conditions of the operation remain unchanged. One should not conclude from this that the chemical composition of the two yeasts is identical, any more than that the chemical composition of two plants is the same because they grew in the same soil.

[End Page 137]

What was a nonentity in §7, becomes so well established in §11 that it has a name and a place in the most precise and most venerable of all branches of natural history, taxonomy. No sooner has Pasteur thus shifted the origin of all the actions to the yeast that becomes a full-blown independent entity, than he uses it as a stabilized element to redefine all the former practices. We did not know what we were doing before, but now we do:

(§12) All the chemists will be surprised at the rapidity and regularity of lactic fermentation under the conditions that I have specified, that is, when the lactic ferment develops alone; it is often more rapid than the alcoholic fermentation of the same amount of material. Lactic fermentation as it is ordinarily carried out takes much longer. This can easily be understood. The gluten, the casein, the

fibrin, the membranes, the tissues that are used contain an enormous amount of useless matter. More often than not these become a nutrient for the lactic ferment only after putrefaction--alteration by contact with plant or animalcules--that has rendered the elements soluble and assimilable.

A slow and uncertain practice, the explanation of which was obscure, becomes a quick and comprehensible, mastered set of new methods: the cultivation of microorganisms in a medium that provides food for the ferment, food that itself may be varied so as to vary the adaptation to an environment of various ferments in competition. The cause of a useless by-product is transformed into the food of its consequence!

Going further and further, Pasteur turns this newly shaped entity into one "singular case" inside a class of phenomena, the fermentations, the general "circumstances" of which may be now defined:

(§17) One of the essential conditions for good fermentations is the purity of the ferment, its homogeneity, its free development without any hindrance and with the help of a nutrient well adapted to its individual nature. In this respect, it is important to realize that the circumstances of neutrality, of alkalinity, of acidity, or of the chemical composition of the liquids play an important part in the predominant growth of such and such a ferment, because the life of each does not adapt itself to the same degree to different states of the environment.

What is still very much a subject of controversy in the philosophy of science--namely, how a new entity can emerge out of an old one--is given by Pasteur a fresh solution by crossing several seemingly incompatible philosophies of science. It is possible [End Page 138] to progress from a nonexistent entity to a class by being, successively, made of floating sense data, taken as a name of action, and then turned into a plantlike and organized being inside a taxonomy.

Pasteur's Solution to the Conflict between Constructivism and Realism:
The Second Drama

Still, there is a gap in this genealogy. How to go from the barely visible gray matter that sometimes appears on the top of the vessel, to the plant endowed with feeding requirements and rather particular tastes? How to make this crucial step? Who is doing the attribution of action and the endowment of properties? Is Pasteur not giving his entity a little nudge forward? He "confesses" this very explicitly in the very last paragraph of the paper. He is doing the action, he has prejudices, he is filling the gap between underdetermined facts and what should be visible:

(§22) All through this memoir, I have reasoned on the basis of the hypothesis that the new yeast is organized, that it is a living organism, and that its chemical action on sugar corresponds to its development and organization. If someone

were to tell me that in these conclusions I am going beyond that which the facts prove, I would answer that it is quite true, in the sense that the stand I am taking is in a framework of ideas [un ordre d'idées] that in rigorous terms cannot be irrefutably demonstrated. Here is the way I see it. Whenever a chemist makes a study of these mysterious phenomena and has the good fortune to bring about an important development, he will instinctively be inclined to assign their primary cause to a type of reaction consistent with the general results of his own research. It is the logical course of the human mind in all controversial questions.

Not only does Pasteur develop a whole ontology in order to follow the transformation of a nonentity into an entity, but he also has a philosophy of science, and a pretty sophisticated one at that. Like most French scientists, he is a constructivist of the rationalist kind. For him facts always need to be framed and built up by a theory. The origin of this inevitable "ordre d'idées" is to be found in disciplinary loyalties ("a chemist"), themselves tied to past investment ("consistent with the general results of his own research"). This very inertia is rooted by Pasteur in culture and history ("his own research") as well as in nature ("instinct," "the logical course of the human mind"). This is a fascinating account of the origin of a prejudice, all the more so because social historians often criticize Pasteur because he is imbued with prejudice and jumps beyond [End Page 139] the facts.¹³ But this is what Pasteur himself recognizes over and over again. So the metalinguistic resources that historians apply are in large part handed to them by their subject matter!

Does this confessed prejudice weaken Pasteur's claim in his own eyes? Not a bit, and this is the paradox we have to understand. The very next sentence introduces another epistemology, a much more classical one, in which facts may be unambiguously evaluated by impartial observers:

(§22) And it is, in my opinion, at this point in the development of my knowledge of the subject, that whoever judges impartially the results of this

¹³ Such is the constant historiographic line of attack of John Farley, Gerald Geison, and James Secord, which is refuted, ironically enough, by others (Nils Roll-Hansen and Dennis Temple) who claim that there is no circle in Pasteur's reasoning, although Pasteur freely recognizes it. See Geison, "Louis Pasteur" (above, n. 9); John Farley, *The Spontaneous Generation Controversy from Descartes to Oparin* (Baltimore: Johns Hopkins University Press, 1974); Gerald Geison and James A. Secord, "Pasteur and the Process of Discovery: The Case of Optical Isomerism," *Isis* 79 (1988): 6-36; Gerald Geison, "Pasteur on Vital versus Chemical Ferments: A Previously Unpublished Paper on the Inversion of Sugar," *Isis* 72 (1981): 425-445; Nils Roll-Hansen, "Experimental Method and Spontaneous Generation: The Controversy between Pasteur and Pouchet," *Journal of the History of Medicine and Allied Sciences* 34 (1979): 273-292; and Dennis Temple, "Pasteur's Theory of Fermentation: A 'Virtual Tautology'?" *Studies in the History and Philosophy of Science* 17:4 (1968), 487-503.

work and that which I shall shortly publish will recognize with me that fermentation appears to be correlative to life and to the organization of globules, and not to their death and putrefaction.

Whereas in the previous sentence the logical course of the human mind precluded "impartial judgment," especially in "controversial questions" that cannot be "irrefutably demonstrated," it is suddenly possible for the same Pasteur to convince anyone who is impartial. Two entirely unrelated epistemologies are juxtaposed. Why? Is there a contradiction? Or are we unable to reconcile constructivism with empiricism? Facts need a theory to be made visible, and this theory is rooted in the former history of the research program--it is "path dependent," as economists would say--but facts may be judged without the influence of earlier history. Whose contradiction is this--Pasteur's, or ours?

As long as we find contradictions in a text or in a setting it simply means that we are not relativist enough, that we are trying to gloss over an actor's meaning and impose our categories instead of deploying the actor's own. In order to grasp how Pasteur without any sign of being paradoxical may go from one epistemology to its polar opposite, we have to understand how he distributes activity [End Page 140] in the text between himself, the experimenter, and the would-be tentative ferment.

Pasteur's Own Version of Laboratory Studies: The Trouble with Experiments

The beauty of this Memoir lies in its offering a mediation between those two questions, a mediation which is often forgotten or obscured in the philosophy of science but not in science studies --that of experiment and instrument and the question of the interpretive flexibility of facts and artifacts.¹⁴ In Pasteur's account, we can find the solution to the paradox above only through the experimental details.

What is an experiment? It is an action performed by the scientist so that the nonhuman will be made to appear on its own. It is a very special form of constructivism, as Steven Shapin and Simon Schaffer have so beautifully shown, since it overcomes its own construction.¹⁵ The artificiality of the laboratory does not negate its validity and truth; its

¹⁴ See Harry Collins, *Changing Order: Replication and Induction in Scientific Practice* (London/Los Angeles: Sage, 1985); Karin D. Knorr, *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon Press, 1981); Karin D. Knorr, Roger Krohn, and Richard Whitley, eds., *The Social Process of Scientific Investigation* (Dordrecht/Boston: Reidel, 1981); and Pickering, *Science as Practice and Culture* (above, n. 1).

¹⁵ Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985).

obvious immanence is actually the source of its downright transcendence. How does this apparent miracle come about? Through a very simple setup that has baffled observers for a long time, and that Pasteur beautifully illustrates. The experiment creates two narrative planes: one in which the narrator is active, and one in which the action is delegated to another character, a nonhuman one.

An experiment shifts out action from one frame of reference to another.¹⁶ Who is acting in this experiment? Pasteur and his yeast. More exactly, Pasteur acts so that the yeast acts alone. We understand why it is difficult for Pasteur to choose between a constructivist [End Page 141] epistemology and a realist one: he creates a scene in which he does not have to create anything. He develops gestures, glassware, protocols, so that the entity, once shifted out, becomes automatic and autonomous. According to the ways in which these two contradictory features are stressed, the same text becomes constructivist or realist. Am I, Pasteur, making this entity up because I am projecting onto it my prejudices, or am I being made up and forced to behave that way because of its properties? Am I, the analyst of Pasteur, explaining the closure of the controversy by appealing to his human interests, or do I have to add to the balance the active role of those entities he did so much to shape? These questions are not philosophical problems confined to the pages of journals of sociology or the history of science--they are the very questions tackled over and over by scientific papers.

The experimental scenography in this Memoir is extremely varied, to follow all the subtleties of the variable ontology deployed in the text. In the same Memoir, some experiments are backgrounded and blackboxed, while others are the center of the attention and are made to vary. At first, the practice of doing science is alluded to only through very stylized experiments, which are backgrounded.¹⁷ Then, human agency is reintroduced in a recipe-like procedure to describe lactic acid fermentation. But at this stage there is no "trouble with experiments"; the fermentation of lactic acid is a well-known procedure, which Pasteur imports as such:

¹⁶ "Shifting out" is a semiotic expression that describes the possibility of displacing action into another time, another space, or another actant. On its use in scientific text, see Latour, "Relativist Account" (above, n. 7). "Shifting in" means closing the first shift by reverting to the original frame. I have introduced "shifting down" to express the delegation to technical objects: see Bruno Latour, "Where Are the Missing Masses? Sociology of a Few Mundane Artifacts," in *Shaping Technology--Building Society: Studies in Sociotechnical Change*, ed. Wiebe Bijker and John Law (Cambridge, Mass.: MIT Press, 1992), pp. 225-259.

¹⁷ For instance, in a sentence like this one from §2--"for every time that one tries to find the optical activity of a substance in its derivatives, it promptly disappears"--there is nothing more than the vaguest allusion to an experimental setting and to an effort being made in order to recover an activity; the instrument is not specified.

(§4) Lactic acid was discovered by Scheele in 1780 in soured whey.¹⁸ His procedure for removing it from the whey is still today the best one can follow. [text of the note:] First he reduced the whey to an eighth of its volume by evaporation. He filtered it and saturated it with lime to precipitate the phosphate of lime. The liquid was then filtered and diluted with three times its weight of water; into this he poured oxalic acid drop by drop to precipitate all the lime. He evaporated the liquid to the consistency of honey. The thickened acid was redissolved in rectified alcohol, which eliminated the milk sugar and many other materials. The alcohol was removed by distillation.

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Firmly grounded in practice but completely blackboxed, the experimental procedure defines the baseline--lactic fermentation--out of which the foregrounded yeast will be made to appear. Without a stabilized recipe for lactic fermentation, no yeast could start to show its mettle.

Insisting forever on the interpretive flexibility of the matterof-fact is a useless game if one does not specify which part of the document one is studying--the background, the foreground, the baseline, or the main experiment. In one single paper, we may go through several philosophies of experiment, with relativist or constructivist moments preceded by brutal denial of the role of instrument and followed by positivist accounts. For instance, the scenography changes completely when we reach the two central paragraphs, 7 and 8, in which is displayed the main experiment. Activity is back in, and so are the troubles:

(§8) I extract the soluble part from brewer's yeast, by treating the yeast for some time with fifteen times its weight of water at the temperature of boiling water. The liquid, a complex solution of albuminous and mineral material, is carefully filtered. About fifty to one hundred grams of sugar are then dissolved in each liter, some chalk is added, and a trace of the gray material I have just mentioned from a good, ordinary lactic fermentation is sprinkled in; then one raises the temperature to 30 or 35 degrees centigrade. It is also good to introduce a current of carbonic acid in order to expel the air from the flask, which is fitted with a bent exit tube immersed under water. On the very next day a lively and regular fermentation is manifest.... In a word, we have under our eyes a clearly characterized lactic fermentation, with all the accidents and the usual complications of this phenomenon whose external manifestations are well known to chemists.

¹⁸ Note that on the imported procedure Pasteur is not a constructivist and uses the notion of "discovery" without any qualification, but Liebig's theories are on the contrary negatively modalized. So a text deploys in the same space the whole gamut of philosophies of science. It is the same with the philosophy of experiments.

At the very time when the entity is at its weakest ontological status, reshuffled among disconnected sense data, the experimental chemist is in full activity extracting, treating, filtering, dissolving, adding, sprinkling, raising the temperature, introducing carbonic acid, fitting the tube. But then, shifting out the attention of the reader, he says that "we have under our eyes a clearly characterized lactic fermentation." The director withdraws from the scene, and the reader's eyes, merging with those of the stage manager, see a fermentation that takes up independently of any work and construction. All the many mediations have become transparent intermediaries.

Who is doing the action in the new medium of culture? Pasteur, since he sprinkles, and boils, and filters, and sees. The lactic acid yeast, since it grows fast, uses up its food, gains in power ("very little [End Page 143] of this yeast is necessary to transform a considerable weight of sugar"), and enters into competition with other similar beings growing like plants in the same plot of land. If I ignore Pasteur's work, I fall into the pitfalls of realism from which fifteen years of laboratory studies have extracted us. But what happens if we ignore the lactic acid and its delegated automated autonomous activity? We fall into the other pit, as bottomless as the first, of social constructivism, forced to ignore the role of nonhumans, which are the center of attention of all the people we study, and on the staging of which Pasteur spent months of labor.

We cannot even claim that in both cases it is only the author, the human author, who is doing the work, since what is at stake in the text is precisely the reversal of authorship and authority: Pasteur authorizes the yeast to authorize him to speak in its name. Just who is authoring the whole literary process is itself an open question where characters and authors are exchanging credibilities--it is only if his Academy colleagues disbelieve Pasteur that he will be made the sole and only author of a work of fiction. If the whole setup resists the Academy's scrutiny, then the text itself will be in the end authorized by the yeast, the real behavior of which will be said to underwrite the whole text.¹⁹

How can we understand the experimental staging that aimed at letting the lactic acid develop by itself in a pure medium of culture? Why is it so difficult to recognize that an experiment is precisely the place where this contradiction is staged and resolved? We do not have to choose between two accounts of scientific work, since this very scientific work aims at building a scene in which scientists do not do any work. Pasteur is not

¹⁹ This is why it is so difficult to see scientific texts as "simply" text. They appear so only in very rare circumstances--when they have been transformed into fiction, or when they have aged enough for their documentary style to become a style. In the other cases they appear as so many documents and reports acting upon the agonistic fields of science.

plagued here by false consciousness, erasing the traces of his own work as he goes along, since he explicitly stages these two contradictory requirements in the last paragraph. "Yes," says he, "I went well beyond the facts, I had to, but whoever judges impartially will recognize that lactic acid is correlative of life, not of death." To acknowledge his activity is not, in his view, to weaken the claim for the independence of his yeast, no more than seeing the threads in a puppeteer's hands weakens the credibility of the story happening to the puppets "freely" acting in the other plane of reference. As long as we have [End Page 144] not understood why what appears to us as a contradiction is not one for Pasteur, we do not learn from those we study--we simply impose our philosophical categories upon their work. I hope to have shown that literary theory can help us to learn from the scientists.