Meeting the Universe Halfway

QUANTUM PHYSICS AND THE ENTANGLEMENT OF MATTER AND MEANING

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the philosophical issues in quantum physics, may be tempted to skip chapter 7. I would like to encourage at least a cursory reading of this chapter, if only for its valuable insights into the nature of causality, identity, and nature. Unsuspecting readers may find themselves drawn in more than they would have thought. Poststructuralist scholars, in particular, who are used to making their way through difficult and dense theoretical terrains, will not want to skip over the remarkable and radical reworking of some key concepts in their lexicon. Quantum leaps in any case are unavoidable. Whatever the nature of your entangled engagement, I hope you find it enjoyable and thought provoking.

ONE

Meeting the Universe Halfway

Because truths we don't suspect have a hard time
making themselves felt, as when thirteen species
of whiptail lizards composed entirely of females
stay undiscovered due to bias
against such things existing,
we have to meet the universe halfway.
Nothing will unfold for us unless we move toward what
looks to us like nothing: faith is a cascade.
The sky's high solid is anything
but, the sun going under hasn't
budged, and if death divests the self
it's the sole event in nature
that's exactly what it seems.

—ALICE FULTON, "Cascade Experiment"

On the morning after giving an invited lecture on the constructed nature of scientific knowledge, I had the privilege of watching as an STM (scanning tunneling microscope) operator zoomed in on a sample of graphite, and as we approached a scale of thousands of nanometers . . . hundreds of nanometers . . . tens of nanometers . . . down to fractions of a nanometer, individual carbon atoms were imaged before our very eyes. The experience was so sublime that it sent chills through my body—and I stood there, a theoretical physicist who, like most of my kind, rarely ventures into the basements of physics buildings that experimental colleagues call "home," conscious that this was one of those life moments when the amorphous jumble of history seems to crystallize in a single instant. How many times had I recounted for my students the evidence for the existence of atoms? And there they were—just the right size and grouped in a hexagonal structure with the interatomic spacings as predicted by theory. "If only Einstein, Rutherford, Bohr, and especially Mach could have seen this!" I exclaimed. And as the undergraduate students operating the instrument (which they had just gotten to work the day before by carefully eliminating sources of vibrational interference—

we're talking nanometers here) disassembled the chamber that held the sample so that I could see for myself the delicate positioning of the probe above the graphite surface, expertly cleaved with a piece of Scotch tape, I mused aloud that "seeing" atoms will quickly become routine for students (as examining cells with visual-light microscopes, and in turn the structure of molecules by electron microscopes, became routine for earlier generations) and that I was grateful to have been brought up in a scientific era without this particular expectation.[1]

At this point in my story, I imagine there will be scientific colleagues who will wonder whether this presented a moment of intellectual embarrassment for your narrator, who had on the previous night insisted on the constructed nature of scientific knowledge. In fact, although I was profoundly moved by the event I had just witnessed, standing there before the altar of the efficacy of the scientific enterprise, I was unrepentant. For as constructivists have tried to make clear, empirical adequacy is not an argument that can be used to silence charges of constructivism. The fact that scientific knowledge is constructed does not imply that science doesn't "work," and the fact that science "works" does not mean that we have discovered human-independent facts about nature. (Of course, the fact that empirical adequacy is not proof of realism is not the endpoint, but the starting point, for constructivists, who must explain how it is that such constructions work—an obligation that seems all the more urgent in the face of increasingly compelling evidence that the social practice of science is conceptually, methodologically, and epistemologically allied along particular axes of power.)[2]

On the other hand, I stand in sympathy with my scientific colleagues who want science studies scholars to remember that there are cultural *and* natural causes for knowledge claims. While most constructivists go out of their way to attempt to dispel the fears that they are either denying the existence of a human-independent world or the importance of natural, material, or nonhuman factors in the construction of scientific knowledge, the bulk of the attention has been on social or human factors. To be fair, this is where the burden of proof has been placed: constructivists have been responding to the challenge to demonstrate the falsity of the worldview that takes science as the mirror of nature. Nonetheless, as both the range and sophistication of constructivist arguments have grown, the charge that they embrace an equally extreme position—that science mirrors culture—has been levied against them with increasing vigor. While few constructivists actually take such an extreme position, science studies scholars would be remiss in simply dismissing this charge as a trivial oversimplification and misunderstanding of the varied and complex positions that come under the rubric of constructivism. The anxiety being expressed, though admittedly displaced, touches on the legitimate concern about the privileging of epistemological issues over ontological ones in the constructivist literature. Ontological issues have not been totally ignored, but they have not been given sufficient attention.

The ontology of the world is a matter of discovery for the traditional realist. The assumed one-to-one correspondence between scientific theories and reality is used to bolster the further assumption that scientific entities are unmarked by the discoverers: nature is taken to be revealed by, yet independent of, theoretical and experimental practices, that is, transparently given. Acknowledging the importance of Cartwright's (1983) philosophical analysis decoupling these assumptions and her subsequent separation of scientific realism into two independent positions—realism about theories and realism about entities—Hacking (1982), like Cartwright, advocates realism toward entities. Shifting the focus in studies of science away from the traditional emphasis on theory construction to the examination of experimental practice, Hacking grounds his position on the ability of the experimenter to manipulate entities in the laboratory. That which exists is that which we can use to intervene in the world to affect something else: electrons are counted as real because they are effective experimental tools, not because they have been "found." Galison (1987) also centers experimental practice in his historical analysis comparing three different periods of twentieth-century physics experimentation, wherein he generalizes Hacking's criterion for the reality of entities by underlining the importance of the notions of stability and directness.[3] Other approaches go further in interrogating the immediate thereness of nature. Latour (1993) prioritizes stability as well, posing it as one variable of a two-dimensional geometry whose other axis connects the poles of Nature and Society. Essence thus becomes the trajectory of stabilization within this geometry that is meant to characterize the variable ontologies of quasi-objects. In contrast, Haraway (1988) emphasizes instability: it is the instability of boundaries defining objects that is the focal point of her explicit challenge not only to conceptions of nature that claim to be outside of culture, but also to the separation of epistemology from ontology. The instability of boundaries and Haraway's insistence that the objects of knowledge are agents in the production of knowledge feature her notions of cyborgs (1985) and material-semiotic actors (1988), which strike up dissonant and harmonic resonances with Latour's hybrids and quasi-objects (1993). Moving to what some consider

the opposite pole of the traditional realist position are the semiotic and deconstructionist positions. To many scientists as well as science studies scholars, the theories of semiotics and deconstruction, which call into question the assumed congruity of signifier and signified, insisting on the intrinsic arbitrariness of the sign or representation, seem to be the ultimate in linguistic narcissism. However, while insisting that we are always already in the "theater of representation," Hayles (1993) takes exception to extreme views that hold that language is groundless play, and while she does not provide us with access to the real, she does attempt to place language in touch with reality by reconceptualizing referentiality. Hayles's theory of constrained constructivism relies on consistency (in opposition to the realist notion of congruence) and the semiotic notion of negativity to acknowledge the importance of constraints offered by a reality that cannot be seen in its positivity: as she puts it, "Although there may be no outside that we can know, *there is a boundary*" (40; italics in original).

These attempts to say something about the ontology of our world are exceptions rather than the rule in the science studies literature.[4] What is needed is a deeper understanding of the ontological dimensions of scientific practice. It is crucial that we understand the technologies by which nature and culture interact. Does nature provide some template that gets filled in by culture in ways that are compatible with local discourses? Or do specific discourses provide the lenses through which we view the layering of culture on nature? Does the full "texture" of nature get through, or is it partially obliterated or distorted in the process? Is reality an amorphous blob that is structured by human discourses and interactions? Or does it have some complicated, irregular shape that is differently sampled by varying frameworks that happen to "fit" in local regions like coincident segments of interlocking puzzle pieces? Or is the geometry fractal, so that it is impossible for theories to match reality even locally? At what level of detail can any such question be answered, if at all? And what would it mean? Is it possible to take any of these questions seriously in the academy in the early twenty-first century? Won't this still sound too much like metaphysics to those of us trained during the various states of decay of positivist culture? And if we don't ask these questions, what will be the consequences? As Donna Haraway reminds us, "What counts as an object is precisely what world history turns out to be about" (1988, 588). I seek some way of trying to understand the nature of nature and the interplay of the material and the discursive, the natural and the cultural, in scientific and other social practices. Consequently I will place considerably more emphasis on ontological issues than

is common in science studies, although I will not ignore the epistemological issues either, since there is good reason to question the traditional Western philosophical belief that ontology and epistemology are distinct concerns.

After articulating a new "ontoepistemological" framework, I will own up to its realist tenor.[5] After a resurgence of interest in scientific realism in the 1980s, its popularity seems to have waned once again, if not because of the death knell sounded by Fine's (1984) clever accounting of the metatheoretical failure of arguments for realism, then at least because of the commonplace tendency on the part of constructivists to present scientific realism as naive, unreflexive, and politically invested in its pretense to an apolitical posture. In fact, the pairing of constructivism with some form of antirealism has become nearly axiomatic: if we acknowledge the cultural specificity of scientific knowledge construction, are we not obligated to relinquish the hope of constructing theories that are true representations of independent reality? For example, in offering a concrete case of the underdetermination thesis, Cushing (1994) argues that the fact that distinctive theories can account for the same empirical evidence means that realists are hard-pressed to make an argument for theoretical access to the actual ontology of our world.[6] For the most part, constructivists have expressed either outright disdain for, or at least suspicion toward, realism and have explicitly adopted antirealist positions, or they have refused the realism-antirealism debate altogether either because they feel limited by this very opposition (see, for example, Fine 1984; Pickering 1994) or because they have thought it more fruitful to focus on other issues. I must confess to having sympathy particularly with the latter positions, but I also think that realism has all too quickly been dismissed. Realism has been invoked to support both oppressive and liberatory positions and projects, and my hope is that at this historical juncture, the weight of realism—the serious business and related responsibility involved in truth hunting—can offer a possible ballast against the persistent positivist scientific and postmodernist cultures that too easily confuse theory with play.[7]

Realizing the multiplicity of meanings that realism connotes, at this juncture I want to clarify how I take realism in the first instance. As a starting point, I follow Cushing's lead:

> I assume, perhaps unreasonably, that a scientific realist believes successful scientific theories to be capable of providing reliable and understandable access to the ontology of the world. If one weakens this demand too much, not much remains, except a belief in the existence of an objective reality to

> which we have little access and whose representation by our theories is nebulous beyond meaningful comprehension. In such a situation, is it worth worrying about whether or not one is a realist? (Cushing 1994, 270n26)

Although I will ultimately add substantive qualifications to this definition, I do not intend to weaken what I take to be the spirit of Cushing's demand, and I have therefore selected this starting point to clarify the sense of realism with which I mean to engage, as separate from some other more general uses in the science studies literature, including discussions that oppose realism to relativism, or realism to linguistic monism, or realism to subjectivism. My first concern is not with realism in these senses: I grant that there are forms of antirealism that are not relativist, that do not deny the existence of an extralinguistic reality, and that are compatible with various notions of objectivity. That is, in the spirit of Cushing's query, I want to limit the elasticity of the meaning of realism for my initial purposes. Science studies scholars have labored long and hard to articulate moderate constructivist positions that reject the extremes of objectivist, subjectivist, absolutist, and relativist stances, but it is perhaps inappropriate to label these as realist on just such bases alone. That is, I do not want to turn these accomplishments aside by setting up realism as the foil to the entire family of apparitions, including some that scientists find most haunting. In this regard, it is perhaps important to acknowledge that feminist science studies scholars in particular staunchly oppose epistemological relativism, with an intensity shared by scientists (a fact that may come as a surprise to scientists and others who have not studied the feminist literature), though few have embraced realist positions.[8] Seeing epistemological relativism as the mirror twin of objectivism, and both as attempts to deny the embodiment of knowledge claims, feminist theories of science, including Haraway's theory of situated knowledges (1988), Harding's strong objectivity (1991), Keller's dynamic objectivity (1985), and Longino's contextual empiricism (1990), articulate nonrelativist antirealist positions. Consequently, although my discussion of realism is concerned with the sense in which direct engagement with the ontology of our world is possible, I will also attempt to satisfy the high standards that have already been set by specifying the ways in which the new form of realism that I propose rejects these other extreme oppositions.[9]

I call my proposed ontoepistemological framework "agential realism."[10] (My motivation for using an adjectival form of "agency" as the modifier will be clarified later.) Importantly, agential realism rejects the notion of a correspondence relation between words and things and offers in its stead a causal

explanation of how discursive practices are related to material phenomena. It does so by shifting the focus from the nature of representations (scientific and other) to the nature of discursive practices (including technoscientific ones), leaving in its wake the entire irrelevant debate between traditional forms of realism and social constructivism. Crucial to this theoretical framework is a strong commitment to accounting for the material nature of practices and how they come to matter.

THE NATURE OF NATURE AND THE POSSIBILITIES FOR CHANGE

The sciences and science studies are not the only set of (inter)disciplinary practices that have a stake in understanding the nature of nature. Nature's nature has been a central concern of political theorists for centuries. Not only does Aristotle affirm the belief that women and slaves should be assigned subservient social positions by virtue of their allegedly inherent inferior natures, but he posits the very notion of the state—an intrinsically political body—as a natural entity. Arguing against a host of long-standing and newly conceived biological determinist accounts, the renowned feminist philosopher Simone de Beauvoir disarticulates the notions of sex and gender in an effort to dislodge the misguided belief that women's inferior social status is in accord with nature. According to Beauvoir, women in their becoming, as members of the human species, are to be understood as social beings, as transcendental human subjects, constrained, but not determined, by their natures (in contrast to nonhuman creatures who are slaves to their biology).[11]

Like other existentialist political philosophies, Beauvoir's theory of the subject has been strongly criticized for its humanist shortcomings, particularly its reliance on essentialist conceptions of the human and of men and women. Criticisms from feminists and other critical social theorists include a denunciation of Beauvoir's theory for its failure to take account of important structural aspects of the workings of power and its unexamined presuppositions concerning the nature of the category "women" (despite the acknowledgment of its social situatedness). Challenging the notion of the humanist subject as radically free and constituted through self-determination and transparent access to its own consciousness, structuralists argue that the subject is a product of structures—whether of kinship, language, the unconscious, cognitive structures of the mind, or economic, social, and political structures of society—and hence must be understood as an effect rather than a cause. Structuralist accounts of the determination of the subject have been

further challenged by poststructuralist approaches, which trouble the idea that there are unitary structures that exist outside, and are determining of, the subject.[12] Rejecting both poles, that subjectivity is either internally generated or externally imposed, poststructuralists eschew not only the very terms of the debates over agency versus structure and free will versus determinism but also the geometrical conception of subjectivity, which would validate "internality" and "externality" as meaningful terms in the debate.[13]

For a range of reasons only hinted at in this brief overview, it is not at all surprising that feminist, poststructuralist, and other critical theorists are deeply interested in the nature of nature.[14] Pressing questions of the nature of embodiment, subjectivity, agency, and futurity hang in the balance. What is at stake is nothing less than the possibilities for change.

FROM REPRESENTATIONALISM TO PERFORMATIVITY

> As long as we stick to things and words we can believe that we are speaking of what we see, that we see what we are speaking of, and that the two are linked.
>
> —GILLES DELEUZE, *Foucault*

> "Words and things" is the entirely serious title of a problem.
>
> —MICHEL FOUCAULT, *The Archaeology of Knowledge*

Liberal social and political theories and theories of scientific knowledge alike owe much to the idea that the world is composed of individuals—presumed to exist before the law, or the discovery of the law—awaiting or inviting representation. The idea that beings exist as individuals with inherent attributes, anterior to their representation, is a metaphysical presupposition that underlies the belief in political, linguistic, and epistemological forms of representationalism. Or to put the point the other way around, representationalism is the belief in the ontological distinction between representations and that which they purport to represent; in particular, that which is represented is held to be independent of all practices of representing. That is, there are assumed to be two distinct and independent kinds of entities—representations and entities to be represented. The system of representation is sometimes explicitly theorized in terms of a tripartite arrangement. For example, in addition to knowledge (i.e., representations), on the one hand, and the known (i.e., that which is purportedly represented), on the other, the existence of a knower (i.e., someone who does the representing) is sometimes made explicit. When this happens, it becomes clear that representations are presumed to serve a mediating function between independently existing entities. This taken-for-granted ontological gap generates questions of the accuracy of representations. For example, does scientific knowledge accurately represent an independently existing reality? Does language accurately represent its referent? Does a given political representative, legal counsel, or piece of legislation accurately represent the interests of the people allegedly represented?

Representationalism has received significant challenge from feminists, poststructuralists, and queer theorists. The names of Michel Foucault and Judith Butler are often associated with such questioning. Butler sums up the problematics of political representationalism as follows:

> Foucault points out that juridical systems of power *produce* the subjects they subsequently come to represent. Juridical notions of power appear to regulate political life in purely negative terms. . . . But the subjects regulated by such structures are, by virtue of being subjected to them, formed, defined, and reproduced in accordance with the requirements of those structures. If this analysis is right, then the juridical formation of language and politics that represents women as "the subject" of feminism is itself a discursive formation and effect of a given version of representationalist politics. And the feminist subject turns out to be discursively constituted by the very political system that is supposed to facilitate its emancipation. (Butler 1990, 2)

In an attempt to remedy this difficulty, critical social theorists struggle to formulate understandings of the possibilities for political intervention that go beyond the framework of representationalism.

The fact that representationalism has come under suspicion in the domain of science studies is less well known, but of no less significance. Critical examination of representationalism did not emerge until the study of science shifted its focus from the nature and production of scientific knowledge to the study of the detailed dynamics of the actual practice of science. This significant shift is one way to coarsely characterize the difference in emphasis between separate disciplinary studies of science (e.g., history of science, philosophy of science, sociology of science) and science studies. This is not to say that all science studies approaches are critical of representationalism; many such studies accept representationalism unquestioningly. For example, countless studies on the nature of scientific representations (including how scientists produce them, interpret them, and otherwise make use of them) take for granted the underlying philosophical viewpoint

that gives way to this focus—namely, representationalism.[15] On the other hand, some science studies researchers have made a concerted effort to move beyond representationalism.

Ian Hacking's *Representing and Intervening* (1983) brought the question of the limitations of representationalist thinking about the nature of science to the forefront. The most sustained and thoroughgoing critique of representationalism in the philosophy of science and science studies comes from the philosopher of science Joseph Rouse. Rouse has taken the lead in interrogating the constraints that representationalist thinking places on theorizing the nature of scientific practices.[16] For instance, Rouse (1996) points out that while the hackneyed debate between scientific realism and social constructivism moved frictionlessly from philosophy of science to science studies, these adversarial positions have more in common than their proponents acknowledge. Indeed, they share representationalist assumptions that foster such endless debates: both scientific realists and social constructivists believe that scientific knowledge (in its multiple representational forms such as theoretical concepts, graphs, particle tracks, and photographic images) mediates our access to the material world; where they differ is on the question of referent, whether scientific knowledge represents things in the world as they really are (i.e., nature) or objects that are the product of social activities (i.e., culture), but both groups subscribe to representationalism.

Representationalism is so deeply entrenched within Western culture that it has taken on a common-sense appeal. It seems inescapable, if not downright natural. But representationalism (like "nature itself," not merely our representations of it) has a history. Hacking traces the philosophical problem of representations to Democritus's dream of atoms and the void. According to Hacking's anthropological philosophy, representations were unproblematic before Democritus: "The word 'real' first meant just unqualified likeness" (1983, 142). With Democritus's atomic theory emerges the possibility of a gap between representations and represented—"appearance" makes its first appearance. Is the table a solid mass made of wood or an aggregate of discrete entities moving in the void? Atomism poses the question of which representation is real. The problem of realism in philosophy is a product of the atomistic worldview.

Rouse identifies representationalism as a Cartesian byproduct—a particularly inconspicuous consequence of the Cartesian division between "internal" and "external" that breaks along the line of the knowing subject. Rouse brings to light the asymmetrical faith in word over world that underlines the nature of Cartesian doubt:

> I want to encourage doubt about [the] presumption that representations (that is, their meaning or content) are more accessible to us than the things they supposedly represent. If there is no magic language through which we can unerringly reach out directly to its referents, why should we think there is nevertheless a language that magically enables us to reach out directly to its sense or representational content? The presumption that we can know what we mean, or what our verbal performances say, more readily than we can know the objects those sayings are about is a Cartesian legacy, a linguistic variation on Descartes' insistence that we have a direct and privileged access to the contents of our thoughts which we lack towards the "external" world. (Rouse 1996, 209)

In other words, the asymmetrical faith we place in our access to representations over things is a historically and culturally contingent belief that is part of Western philosophy's legacy and not a logical necessity; that is, it is simply a Cartesian habit of mind. It takes a healthy skepticism toward Cartesian doubt to be able to begin to see an alternative.[17]

It is possible to develop coherent philosophical positions that deny the basic premises of representationalism. A performative understanding of naturalcultural practices is one alternative. *Performative* approaches call into question representationalism's claim that there are representations, on the one hand, and ontologically separate entities awaiting representation, on the other, and focus inquiry on the practices or performances of representing, as well as the productive effects of those practices and the conditions for their efficacy. A performative understanding of scientific practices, for example, takes account of the fact that knowing does not come from standing at a distance and representing but rather from *a direct material engagement with the world*.[18] Importantly, what is at issue is precisely the nature of these enactments. Not any arbitrary conception of doings or performances qualifies as performative. And humans are not the only ones engaged in performative enactments (which are not the same as theatrical performances). A performative account makes an abrupt break from representationalism that requires a rethinking of the nature of a host of fundamental notions such as being, identity, matter, discourse, causality, dynamics, and agency, to name a few. In what follows, I will articulate an understanding of performativity that goes beyond the separate accounts offered by science studies scholars and social and political theorists, incorporating insights from each. Performative accounts in these domains have led parallel lives with surprisingly little exchange between them, thereby reinforcing the perception, which each set

of scholars would be quick to reject, that scientific and social and political concerns are separate. I begin by offering some background on each of these separately circulating discourses and then develop my ideas further in the chapters that follow.

REALISM WITHOUT REPRESENTATIONALISM

> We shall count as real what we can use to intervene in the world to affect something else, or what the world can use to affect us.
>
> My attack on scientific antirealism is analogous to Marx's onslaught on the idealism of his day. Both say that the point is not to understand the world but to change it.
>
> —IAN HACKING, *Representing and Intervening*

As late as the end of the nineteenth century, physicists were predominantly antirealists in their attitudes toward atoms. Atoms were thought to be "representative fictions," not bits of matter.[19] Today the situation is very different. Individual atoms are regularly imaged using scanning tunneling microscopes (STM). Moreover, this technology can be used not merely to view individual atoms but to pick them up and move them—one at a time![20]

The philosopher Ian Hacking uses manipulability—that is, the ability to intervene effectively—as the criterion for determining what is real. Hacking claims that whatever individual experimental physicists might believe about whether scientific theories are true accounts of the world or simply useful models for thinking with, it wouldn't make sense for them to be anything but realists toward the entities that they use as tools: "Experimenting on an entity does not commit you to believing that it exists. Only *manipulating* an entity, in order to experiment on something else, need do that. . . . [For example,] electrons are no longer ways of organizing our thoughts or saving the phenomena that have been observed. They are now ways of creating phenomena in some other domain of nature. Electrons are tools" (Hacking 1983, 263). Thus Hacking spells out his criterion as follows: "We shall count as real what we can use to intervene in the world to affect something else, or what the world can use to affect us" (146).

Reflection is insufficient; intervention is key: "Don't just peer, interfere" (189). According to Hacking, our ability to effectively intervene provides the strongest case for realism. In this regard, he makes a distinction between two kinds of realism: realism toward entities, what might be called "ontological realism," and realism toward theories, or "epistemological realism."[21] Hacking subscribes to the former but not the latter: in his account, intervening (i.e., experimenting) rather than representing (i.e., theorizing) is the basis for realism.

Hacking's intervention is particularly noteworthy for its attempt to disentangle realism from its traditional representationalist formulation. Hacking takes issue with the long-standing philosophical tradition that considers theories and representations to be the stuff of science, while experimentation is either completely ignored or seen as an adjunct of theory (which, in this closed account, provides the very lens through which experiments are designed and interpreted). He argues, by contrast, that experimentation should be understood as a complex practice in its own right.

Take the example of microscopy. In Hacking's account, "seeing" atoms or other entities with the aid of a microscope is not a matter of simply looking—of passively gazing on something as a spectator—but an achievement that requires a complex set of practices to accomplish. To "see," one must actively intervene: "You learn to see through a microscope by doing, not just looking" (189). To begin with, obtaining a reliable image free of all artifacts entails experimental know-how, intuition, ingenuity (all three of which are acquired through practice), a good deal of tinkering, the honing of tactile techniques in tune with the specificities of the instrumentation (including any of its idiosyncrasies), learning how to discriminate between unwanted noise and desired signal, between fact and artifact, and all kinds of other non-theory-based manipulations.[22] And part of seeing is also being convinced about what one sees. Hacking argues that if one uses different practices, based on different physical principles (e.g., uses different kinds of microscopes), and winds up seeing the same thing, then one would be hard pressed to explain this coincidence without invoking some kind of conspiracy of unrelated physical processes. And when what we learn how to see using this instrument and its attached set of skills fits with insights from other fields of science, our confidence deepens. "We are convinced not by a high powered deductive theory about the [entity being imaged]—there is none—but because of a large number of interlocking low level generalizations that enable us to control and create phenomena in the microscope" (209).

The STM is a particularly interesting example in this regard. Since it works on a different set of physical principles than optical microscopes, it undermines any illusion that the image represents the mere magnification of what we see with our eyes. In fact, as Hacking correctly notes, optical microscopes don't work like magnifying glasses, either; while the optics of the eye and magnifying glasses can be explained using the principles of geometrical

optics (e.g., the laws of refraction), Ernst Abbe's meticulous investigations of the workings of the microscope reveal that the phenomenon of diffraction is central to the workings of the optical microscope. Geometrical optics are not sufficient to account for the microscope's operation; the laws of physical optics must be taken into account. But the STM example makes the difference quite stark.

If we zoom in on the practices of forming an image by means of a scanning tunneling microscope, it becomes crystal clear that it would be a distortion of the facts to liken image formation to taking a picture with a point-and-shoot camera.[23] "Representing" isn't simply a matter of standing back at some distance and opening one's eyes or pushing a button. To the contrary, STM experts like Don Eigler have suggested that image formation using a scanning tunneling microscope is more aptly likened to an encounter that engages the sense of touch rather than sight: the STM, he says, "forms an image in a way which is similar to the way a blind person can form a mental image of an object by feeling the object" (Eigler 1999, 427).[24] As a blind person uses a cane to scan the topography of a landscape, so the STM operating system maneuvers a microscope tip across the surface of the specimen being imaged. (The microscope tip, which is a finely sharpened tungsten wire, terminates in a single atom.) But rather than physically touching the cane to a street surface to scan for bumps or indentations in the road, the STM operates by scanning the surface using a "tunneling current" to "feel" the surface.[25]

"Tunneling," a uniquely quantum mechanical phenomenon, enables particles to traverse energy barriers that should be, at least according to the laws of classical Newtonian physics, impossible to cross.[26] In this case, the particles in question are electrons. The electrons' (quantum mechanical) ability to cross the barrier depends on the distance between the microscope tip and the surface atoms of the sample being measured. When the tip is close enough to the sample surface, the electrons flow across the barrier, forming a small electrical current. The current thus formed between the tip and the surface provides a measure of the detailed structure of the surface.

Here's how it works. A small voltage is applied to the microscope tip. If the tip is then positioned sufficiently close to the surface of the specimen (typically within a few nanometers), a small number of electrons bound to the surface of the specimen (by the electromagnetic force) will tunnel across the gap, thereby forming a very small current between the electron "cloud" of the surface atoms of the specimen and the tip. The amount of current that flows is related to the characteristics of the energy barrier, which is directly

related to the specific arrangement of atoms on the surface. Using a piezoelectric crystal to delicately position the microscope tip a few nanometers above the surface of the specimen, it is possible to scan the tip across it at a very close distance. The measured tunneling current data can then be mapped into an image on a computer screen. In other words, the STM provides an image of the atomic arrangement of a surface by sensing corrugations in the electron "cloud" of the surface atoms of the specimen.[27]

So "seeing" using a scanning tunneling microscope operates on very different physical principles than visual sight. And furthermore, as Hacking would be quick to remind us, "seeing" takes a good deal of practice: the STM operator does not simply insert a specimen and push a button, and voilà, an image appears. The specimen has to be prepared and carefully positioned on the scan head; a new tip has to be cut for each specimen; the tip has to be carefully positioned above the surface of the specimen; the specimen's tilt coordinates have to be adjusted properly; the system has to be isolated from direct light, vibrations, air currents, and temperature fluctuations during the scan, or else the image will be compromised; a scan range must be selected; and the operator must decide if the image produced constitutes a "good image." The separation of fact from artifact depends on the proper execution of each of these steps and requires skill and know-how achieved through experience.

Examples like this make it clear that representationalism is a practice of bracketing out the significance of practices; that is, representationalism marks a failure to take account of the practices through which representations are produced. Images or representations are not snapshots or depictions of what awaits us but rather condensations or traces of multiple practices of engagement. An STM image does not, on its own, make or break our belief in the reality of atoms; it's just one more piece of evidence—a spectacular display, to be sure—in a web of evidence and practices that produce what we take to be evidence.

Hacking's intervention in the realism-antirealism debates turns on his insistence that experimentation is not a theory-laden practice (in the Kuhnian sense) but a complex set of practices in their own right. But granting experimentation its due need not entail leaving theory behind, ensnared in the trap of representationalism. This asymmetry in his conceptualization of experimenting versus theorizing is implicated in his asymmetrical realist stance: realism toward entities, but not theories. But how realistic is Hacking's account of theorizing?

The physicist Niels Bohr takes issue with the notion of theorizing as

representing. In Bohr's proto-performative account (which I discuss in detail in chapter 3), theorizing must be understood as an embodied practice, rather than a spectator sport of matching linguistic representations to preexisting things.[28] Concepts, in Bohr's account, are not mere ideations but specific physical arrangements. In the absence of due consideration to this crucial point, Bohr warns that scientists can only speculate about mere abstractions, and in so doing, they fail to provide an objective account of the phenomena they are studying. (Indeed, a failure to correctly identify the objective referent accounts for many of the paradoxical features of quantum theory.)

While Hacking distinguishes between intervening and representing, associating the former with experimental practice and the latter with theory production, I argue that Bohr's proto-performative account suggests that scientific practices may more adequately be understood as a matter of intervening rather than representing, on all counts—that is, with respect to all dimensions of this complex web of practices. Or perhaps "intervening" isn't the appropriate verb for describing the activity at issue, in either case, as we will see.

Ironically, then, Hacking could be accused of making a caricature of theorizing in much the same way that he points out that some philosophers are reductive in their considerations of the complex practice of experimenting. One particularly interesting counterpoint to Hacking's notion of scientific theories is the practice-based account of scientific theorizing offered by Peter Galison, a historian of science, in his study of how Einstein arrived at his special theory of relativity. Galison argues that the theory of special relativity did not hatch full blown from the head of Einstein, the result of a solitary mind occupied with a flurry of *abstract* ideas. Rather, the central idea of clock coordination was an important problem of great *practical* significance in Europe in the early 1900s, and Einstein's seat in the patent office offered him a firsthand view of a multitude of proposed new technological solutions to the problem:

> When Einstein came to the Bern patent office in 1902 he entered into a world in which the triumph of the electrical over the mechanical was already symbolically wired to dreams of modernity. He found a world in which clock coordination was a practical problem (trains, troops, and telegraphs) demanding workable, patentable solutions in exactly his area of greatest concern and professional occupation: precision electromechanical instrumentation. The patent office was anything but a deep-sea lightship. No, the office was a grandstand seat for the great parade of modern technologies. And as coordinated clocks went by, they weren't traveling alone; the network of electrical coordination signified political, cultural, and technical unity all at once. Einstein seized on this new, conventional simultaneity machine and installed it at the principled beginning of his new physics. In a certain sense he had completed the grand time coordination project of the nineteenth century, but by eliminating the master clock and raising the conventionally set time to a physical principle, he had launched a distinctively modern twentieth-century physics of relativity. (Galison 2000, 388–89)

Social, technological, and scientific practices that included the entangled apparatuses of colonial conquest, democracy, world citizenship, antianarchism, trains, telegraphs, clocks, and other electromechanical devices composed of wires and gears all played a role in the production of the special theory of relativity. What was at stake, according to Galison, was "always practical and more than practical, at once material-economic necessity *and* cultural imaginary" (367). Time isn't an abstract idea for Einstein; time is what we measure with a clock. As Bohr argues and Galison's example beautifully illustrates, ideas that make a difference in the world don't fly about free of the weightiness of their material instantiation. To theorize is not to leave the material world behind and enter the domain of pure ideas where the lofty space of the mind makes objective reflection possible. *Theorizing, like experimenting, is a material practice.*

In fact, once theory and experiment are no longer understood in their reified forms but seen as dynamic practices of material engagement with the world, we can see that these sets of practices are complexly entangled in ways that representationalist views of science (which treat theory and experiment as separate domains with one or the other as dominant and primary) elide. Which is not to say that "theorists" and "experimentalists" are trained the same way or engage in the same set of practices, but rather to appreciate the fact that both theorists and experimentalists engage in the intertwined practices of theorizing and experimenting.

Furthermore, despite Hacking's best intentions to leave representationalist beliefs behind, his entity realism takes on board one of representationalism's fundamental metaphysical assumptions: the view that the world is composed of individual entities with separately determinate properties. Indeed, most forms of realism presuppose a metaphysics that takes for granted the existence of individual entities, each with its own roster of nonrelational properties.[29] As such, realism is often saddled with essential-

ism. But realism need not subscribe to an individualist metaphysics or any other representationalist tenet (indeed, I would argue that any realist account worth its salt should not endorse such idealist or magical beliefs). Realness does not necessarily imply "thingness": what's real may not be an essence, an entity, or an independently existing object with inherent attributes. The assumption of thingness remains in place at the base of Hacking's entity realism: words and things are still the order of the day.

Like Hacking I am interested in a nonrepresentationalist realist account of scientific practices that takes the material nature of practices seriously. Not Hacking's realism toward entities, but rather realism toward *phenomena* and the entangled material practices of knowing and becoming. *Phenomena*, according to my agential realist account, are neither individual entities nor mental impressions, but entangled material agencies (to be discussed more fully below).[30] The agential realist understanding that I propose is a nonrepresentationalist form of realism that is based on an ontology that does not take for granted the existence of "words" and "things" and an epistemology that does not subscribe to a notion of truth based on their correct correspondence. Agential realism offers the following elaboration of Hacking's critique of representationalism: *experimenting and theorizing are dynamic practices that play a constitutive role in the production of objects and subjects and matter and meaning.*[31] As I will explain, theorizing and experimenting are not about *intervening* (from outside) but about *intra-acting* from within, and as part of, the phenomena produced.[32] Agential realism is explicated in chapter 4 and subsequent chapters; for now, I want to return to the question of metaphysics.

Importantly, it is precisely on this same point that one encounters in crossing the threshold between representationalism and performativism—namely, the metaphysics of individualism—that many other science studies approaches stumble as well, although the issue that they trip over is often quite different. Like Hacking, most science studies scholars are not apt to take the objects of scientific practices for granted; rather, they too are interested in investigating the details of the laboratory practices that produce them. Unlike Hacking, however, actor network theorists, among others, have disassembled the belief that what scientists make evident through their practices is the existence of discrete objects; on the contrary, they have emphasized that the efficacy of the scientific endeavor depends on specific procedures for making networks or assemblages of humans and nonhumans. That is, "things" (in the traditional sense) are surely not the order of the day.[33] Ironically, however, mainstream science studies approaches, and

even some feminist science studies approaches, take it as a given that social variables like gender, race, nationality, class, and sexuality are properties of individual persons, thereby reinstalling the metaphysics of individualism. The taken-for-granted object-nature of things gets dislodged, but questions related to discursive practices—especially those Foucault would consider to be at the crux of the discourse-power-knowledge nexus, such as the discursive constitution of the subject—are neglected. Lest this important point be misunderstood in a particularly ironic fashion, it is perhaps worth emphasizing that this is *not* to say that subject production is all about language—indeed, that's precisely Foucault's point in moving away from questions of linguistic representation and focusing instead on the constitutive aspects of discursive practices in their materiality.

Building on Foucault's critique of representationalism, Judith Butler's influential theory of gender performativity theorizes the gendered constitution of the subject. As Butler emphasizes, gender is not an attribute of individuals. Rather, gender is a doing, not in the sense that there is a pregendered person who performs its gender, but rather with the understanding that *gendering* "is, among other things, the differentiating relations by which . . . subjects come into being" and "the matrix through which all willing first becomes possible" (1993, 7). Gendering, Butler argues, is a temporal process that operates through the reiteration of norms.[34] In other words, Butler is saying that gender is not an inherent feature of individuals, some core essence that is variously expressed through acts, gestures, and enactments, but an iterated doing through which subjects come into being. But these are precisely the kinds of points that one would think that actor network theorists and other scholars attuned to looking for ways in which "objects" emerge through scientific practices would be especially attentive to. And yet there has been surprisingly little cross-pollination between feminist poststructuralist theory and science studies.[35] Even in the feminist science studies literature, one is hard pressed to find other direct engagements with Butler's work on performativity.

Science studies approaches that fail to take these insights into account are not simply setting aside a variable or two that can easily be added into analyses at a later date; rather, they make the same kind of mistake as the representationalist approaches they reject—they fail to take account of the constitutive nature of practices. Indeed, as Butler and Bohr emphasize, that which is excluded in the enactment of knowledge-discourse-power practices plays a *constitutive* role in the production of phenomena—exclusions matter both to bodies that come to matter and those excluded from mattering.

Crucially, there are epistemological, ontological, and ethical issues at stake. This applies both to the practices that are being observed (e.g., laboratory practices) and to the knowledge-making practices that contribute to the science studies literature. But the mere acknowledgment of the fact that science studies scholars are actors involved in performing their own set of practices doesn't go nearly far enough. Turning the mirror back on oneself is not the issue, and reflexivity cannot serve as a corrective here. Rather, the point is that these *entangled practices* are productive, and who and what are excluded through these entangled practices matter: different intra-actions produce different phenomena.[36] Or so I will argue, but I am jumping ahead of myself here. The point is this: one can't simply bracket (or ignore) certain issues without taking responsibility and being accountable for the constitutive effects of these exclusions. Since science studies needs to take account of gender and other crucial social variables (for the sake of consistency, at the very least), and since it no doubt wants to avoid reinstalling the metaphysics of individualism or other representationalist remnants into its theories, its methods, and its results, turning to performative accounts of gender to find out what they have to offer at least seems like a good place to start.

I want to emphasize in the strongest terms possible that it would be a mistake to think that the main point is simply a question of whether or not gender, race, sexuality, and other social variables are included in one's analysis. The issue is not simply a matter of inclusion. The main point has to do with power. How is power understood? How are the social and the political theorized? Some science studies researchers are endorsing Bruno Latour's proposal for a new parliamentary governmental structure that invites nonhumans as well as humans, but what, if anything, does this proposal do to address the kinds of concerns that feminist, queer, postcolonial, (post-)Marxist, and critical race theorists and activists have brought to the table?[37] Nonhumans are in, but the concerns of this motley crew of theorists and activists seem not to have been heard, let alone taken into account. Indeed, their presence has barely been acknowledged. Not that they/we are standing in line waiting to be granted entrance into the Halls of Power.

In his book *Politics of Nature*, Bruno Latour deftly exposes the modernist constitution for its illicit bicameral assemblies—the House of Sciences, which claims to represent things as they are, and the House of Politics, which claims to represent humans' concerns—and the faulty notions of representation they evoke. I couldn't agree more that the old bicameralism that splits the governmental houses into separate powers, with nature on one side and the social on the other, is broken. But it can't simply be repaired by making a new bicameralism—a new *representationalist* form of government. The political field is not limited to the statehouse. And representationalist governments have a long history of shoring up their "own" borders while raiding and ravaging other lands. What conception of power, what model of citizenship, what immigration policy is being enacted when a new representationalist democracy is being proposed that only acknowledges two kinds of citizens and their offspring—the fully human (those who had already been granted citizenship) and the fully nonhuman and their hybrids? Haraway (1985) long ago emphasized that this would not be sufficient: cyborg politics are not merely about the cross between human and machine but also about the technobiopolitics of the differentially human and their motley kin. As Butler puts it: "It is not enough to claim that human subjects are constructed, for the construction of the human is a differential operation that produces the more and the less 'human,' the inhuman, the humanly unthinkable" (1993, 8). Any proposal for a new political collective must take account of not merely the practices that produce distinctions between the human and the nonhuman but *the practices through which their differential constitution is produced*. All the efforts to unseat epistemological representationalism (of the House of Science) will be undercut if the political and social field is theorized (yet again) in terms of political and linguistic forms of representationalism. Representationalism (with its metaphysics of individualism) will simply be reinstalled as the order of the day. This is one reason why science studies cannot afford to ignore the insights that our best political and social theorists have to offer.[38]

Poststructuralism offers a notable alternative to representationalism. Poststructuralism is not just some high-tech toy that humanities scholars use to entertain themselves. Poststructuralist approaches aim to take seriously the concerns of the "motley crew," while offering alternative understandings of power and subject formation (displacing the modernist obsession with the representationalist problematic), while furthermore including an examination of the *constitutive* effect of exclusions.

PERFORMATIVITY AND SOCIAL AND POLITICAL AGENCY

> Nature has a history, and not merely a social one.
>
> —JUDITH BUTLER, *Bodies That Matter*

The search for alternatives to social constructivism has prompted performative approaches to the study of social, political, economic, and cultural phenomena. Judith Butler's theory of gender performativity has been enormously

influential, opening up a range of different investigations into the practices that produce subjects and identities.[39] Performative approaches to questions of race, the economy, and transnational politics are increasingly prevalent. "Performativity" has become a ubiquitous term in literary studies, theater studies, and the nascent inter-interdisciplinary area of performance studies as well. Theorists who adopt performative approaches are often quick to point out that performativity is not the same as performance, and to merely talk of performance does not necessarily make an approach *performative*.

In her groundbreaking and influential book *Gender Trouble*, Butler problematizes the social constructivist model that figures gender as a cultural inscription on the naturally sexed body. To assume that the body is a mute substance, a passive blank slate on which history or culture makes the mark of gender, is to deprive matter of its own historicity, to limit the possibilities for agency, and to instate the sex-gender distinction not simply in terms of the problematic nature-culture dualism but *as* this very distinction.

Butler draws on Foucault's seminal study of the history of sexuality in troubling the very nature of "sex": "For what is 'sex' anyway? Is it natural, anatomical, chromosomal, or hormonal, and how is a feminist critic to assess the scientific discourses which purport to establish such 'facts' for us?" (Butler 1990, 6–7).[40] Foucault's genealogy of sex exposes the fact that the category of sex is a mechanism for unifying an otherwise discontinuous set of elements and functions in the service of the social regulation and control of sexuality, which is effected through the concealment of this construction and the presentation of sex as a bodily given. As Butler notes:

> Not only is the gathering of attributes under the category of sex suspect, but so is the very discrimination of the "features" themselves. That penis, vagina, breasts, and so forth, are *named* sexual parts is both a restriction of the erogenous body to those parts and a fragmentation of the body as a whole. Indeed, the "unity" imposed upon the body by the category of sex is a "disunity," a fragmentation and compartmentalization, and a reduction of erotogeneity. (Butler 1990, 114)

Given this artificial suturing of otherwise disparate features and functions, it is perhaps not surprising that the attempt to provide a determinate scientific test for "the truth of sex" reveals more about the indeterminate nature of sex, and the nature of the practices that seek to quash the indeterminacies intrinsic to this disparate unity, than the mere disclosure of its failure might otherwise seem to suggest. Butler examines the work of a group of molecular biologists who identify TDF (testis-determining factor)

as "*the* binary switch upon which hinges all sexually dimorphic characteristics."[41] For their study, the researchers chose individuals who "were far from unambiguous in their anatomical and reproductive constitutions," including XX-males and XY-females. But the question arises then as to how these very determinations are made when it is precisely this question that is at issue. Relying on external genitalia for this determination seems to root particular ideas about sexuality into the foundations of a study that seeks to investigate the very nature of sex. The researchers also reduce the notion of sex determination to one of male determination to one of testis determination, revealing a set of gendered assumptions at work that enable this conflation. On the basis of these and other considerations, Butler concludes that

> cultural assumptions regarding the relative status of men and women and the binary relation of gender itself frame and focus the research into sex-determination. The task of distinguishing sex from gender becomes all the more difficult once we understand that gendered meanings frame the hypothesis and the reasoning of those biomedical inquiries that seek to establish "sex" for us as it is prior to the cultural meanings that it acquires. (1990, 109)

But if the very notion of a "sexed nature" or "a natural sex" turns out to be "produced and established *as* 'prediscursive,'" that is, is made to pose as that which is prior to culture, as "a politically neutral surface *on which* culture acts," then gender is not the cultural interpretation of sex but "the very apparatus of production whereby the sexes themselves are established" (1990, 7). But is this to suggest that it's gender all the way down? Does culture replace nature? And if so, what happens to the body? Where does the question of matter figure in? For Butler, these reflections do *not* serve as a basis for denying the body its materiality; on the contrary, they reveal the inadequacies of the inscription model of social constructivism.

Indeed, Butler is not out to deny the materiality of the body whatsoever. On the contrary, she proposes "a return to the notion of matter," as we will see hereafter. This "return" to matter is not a simple going back to the notion that matter is the given, that which is already there. It is, however, crucial to Butler's project, for what is at stake is the very nature of change. Butler's intervention calls into question not only the sex-gender binary, which has been foundational to a good deal of feminist theory and gender analysis, but also the nature of agency that is entailed in the inscription model of construction: "When feminist theorists claim that gender is the cultural interpretation of sex or that gender is culturally constructed, what is

the manner or mechanism of this construction? If gender is constructed, could it be constructed differently, or does its constructedness imply some form of social determinism, foreclosing the possibility of agency and transformation?" (1990, 7). As Butler notes, the "controversy over the meaning of *construction* appears to founder on the conventional philosophical polarity between free will and determinism" (8). She promptly rejects both options, indeed the very binary conception of causality, and insists that what is needed is a radical rethinking of the nature of identity.

Butler proposes that we understand identity not as an essence but as a doing. In particular, she suggests that gender is not an attribute or essential property of subjects but "a kind of becoming or activity . . . an incessant and repeated action of some sort" (Butler 1990, 112). Butler cautions that this claim—that gender is performed—is *not* to be understood as a kind of theatrical performance conducted by a willful subject who would choose its gender. Such a misreading ironically reintroduces the liberal humanist subject onto the scene, thereby undercutting poststructuralism's antihumanism, which refuses the presumed givenness of the subject and seeks to attend to its production. Crucially, the performative "is not a singular act used by an already established subject, but one of the powerful and insidious ways in which subjects are called into social being from diffuse social quarters, inaugurated into sociality by a variety of diffuse and powerful interpellations" (Butler 1997a, 160). As Butler explains, "the 'I' neither precedes nor follows the process of this gendering, but emerges only within and as the matrix of gender relations themselves" (1993, 7). That is, gender performativity constitutes (but does not fully determine) the gendered subject. Butler's refusal to embrace the binary conception of agency versus structure is evident here. In an effort to avoid problematic conceptions of agency and power embedded in a host of different approaches to subject formation, Butler draws on Foucault's poststructuralist rendering of regulatory power and discursive practices to understand the gendered formation of the subject.

Writing against the competing philosophical paradigms of structuralism and phenomenology (and hermeneutics in its phenomenological influences), Foucault rejects both the idea that subjects are the mere effects of external structures of intelligibility located in large-scale social systems and the idea that reality is an internal product of human consciousness. That is, Foucault refuses the humanist assumption that presumes the existence of an autonomous subject that stands before discourse-power-knowledge practices; on the contrary, Foucault is interested in analyzing the historical conditions that call forth certain kinds of subjectivity. At the same time, he also

rejects structuralist accounts of the production of the subject via the imposition of an external system of Power, Language, or Culture. In particular, Foucault eschews Marxist treatments of ideology and false consciousness as well as humanist accounts that make reference to the intentionality of a unified subject, giving power an interior location within the consciousness of a subject whose interests are taken to be self-transparent. Indeed, Foucault cuts through the agency-structure dualism held in place by the clash between phenomenology and structuralism. In Foucault's account, power is not the familiar conception of an external force that acts on a preexisting subject, but rather an immanent set of force relations that constitutes (but does not fully determine) the subject.[42]

Foucault's analytic of power links discursive practices to the materiality of the body. In *Discipline and Punish*, Foucault argues that the body's materiality is regulated through the movements it exercises. In particular, it is through the repetition of specified bodily acts that bodies are reworked and that power takes hold of the body. Foucault claims that the specific material configuration of the prison (e.g., the Panopticon form) supports and enacts particular discursive practices of punishment. It is crucial to understand that in Foucault's account discursive practices are not the same thing as speech acts or linguistic statements. Discursive practices are the material conditions that define what counts as meaningful statements. However, Foucault is not clear about the material nature of discursive practices. In fact, criticism of Foucault's analytics of power and his theory of discourse often centers on his failure to theorize the relationship between discursive and nondiscursive practices. The closest that Foucault comes to explicating this crucial relationship between discursive and nondiscursive practices is through his notion of *dispositif*, usually translated as *apparatus*. Foucault explains that dispositif is "a thoroughly heterogeneous ensemble consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical, moral and philanthropic propositions—in short, the said as much as the unsaid" (Foucault 1980, 194). But this list does not constitute a positive statement about the relationship between the "said and the unsaid."

Butler draws on Foucault's suggestion that the repetition of regulatory practices produces a specific materialization of bodies to link her notion of gender performativity to the materialization of sexed bodies. In particular, Butler reads the "iterative citationality" of performativity in terms of this repetition, thereby linking the question of identity with the materiality of the body, but not as the cultural inscription model would have it. Significantly,

Butler proposes "a return to the notion of matter" in place of the flawed conceptions of construction that circulate in feminist theory and elsewhere, not as site or surface (as in the inscription model) but as "*a process of materialization that stabilizes over time to produce the effect of boundary, fixity, and surface we call matter*" (1993, 9). Not surprisingly, what is at stake in this dynamic conception of matter is an unsettling of nature's presumed fixity and hence an opening up of the possibilities for change. Butler further extends Foucault's analysis of the formation of subjects and bodies by attending to the constitutive exclusions that regulatory practices enact: "Foucault's effort to work the notions of discourse and materiality through one another fail to account for not only what is excluded from the economies of discursive intelligibility that he describes, but *what has to be excluded* for those economies to function as self-sustaining systems" (Butler 1993, 35; italics mine). The constitutive outside marks the limits to discourse. Butler emphasizes that the existence of a constitutive outside thus marks the divergence of her theory from social constructivism: there is indeed an outside to discourse, but not an absolute outside. (She thereby eschews the tired social constructivism versus essentialism debates.) The constitutive outside plays a crucial role in Butler's formulation of the notion of agency.

However, despite these crucial elaborations, it is not at all clear that Butler succeeds in bringing the discursive and the material into closer proximity. The gap that remains in Foucault's theory seems to leave a question mark on Butler's ability to spell out how it is that "the reiterative and citational practice by which discourse produces the effects that it names" can account for the matter of sexed bodies (1993, 2). Questions about the material nature of discursive practices seem to hang in the air like the persistent smile of the Cheshire cat.

If discursive practices constitute a productive social or cultural field, then how much of the very matter of bodies, both human and nonhuman, can be accounted for? Is the matter of things completely social in nature? Are we to understand matter as a purely cultural phenomenon, the end result of human activity? And if so, is this not yet another reenactment of the crossing out of nature by culture? And if not, then how can we explain what nature is in relation to this cultural field? Are there significant ways in which matter matters to the very process of materialization? In other words, while Butler correctly calls for the recognition of matter's historicity, ironically, she seems to assume that it is ultimately derived (yet again) from the agency of language or culture. She fails to recognize matter's dynamism.[43]

This is a crucial point that I want to belabor a bit further. If Foucault, in

queering Marx, positions the body as the locus of productive forces, the site where the large-scale organization of power links up with local practices, then it would seem that any robust theory of the materialization of bodies would necessarily take account of *how the body's materiality* (including, for example, its anatomy and physiology) *and other material forces as well* (including nonhuman ones) *actively matter to the processes of materialization*. As Foucault makes crystal clear in the last chapter of *The History of Sexuality, Volume I*, he is not out to deny the relevance of the physical body; on the contrary, he aims to

> show how the deployments of power are directly connected to the body—to bodies, functions, physiological processes, sensations, and pleasures; far from the body having to be effaced, what is needed is to make it visible through an analysis in which the biological and the historical are not consecutive to one another . . . but are bound together in an increasingly complex fashion in accordance with the development of the modern technologies of power that take life as their objective. Hence, I do not envision a "history of mentalities" that would take account of bodies only through the manner in which they have been perceived and given meaning and value; but a "history of bodies" and the manner in which what is most material and most vital in them has been invested. (Foucault 1978, 151–52)

On the other hand, Foucault does not tell us in what way the biological and the historical are "bound together" such that one is not consecutive to the other. What is it about the materiality of bodies that makes it susceptible to the enactment of the intertwined forces of biology and history? To what degree does the matter of bodies have its own historicity? Are social forces the only ones susceptible to change? If biological forces are in some sense always already historical ones, could it be that there is also some important sense in which historical forces are always already biological? (What would it mean to even ask such a question given the strong social constructivist undercurrent in certain interdisciplinary circles in the early twenty-first century?) For all of Foucault's emphasis on the political anatomy of disciplinary power, he fails to offer an account of the body's historicity in which its very materiality plays an *active* role in the workings of power. This implicit reinscription of matter's passivity is a mark of extant elements of representationalism that haunt his largely postrepresentationalist account.[44] But this is not its only limitation. As Haraway (1997) correctly points out, Foucault's notion of the biopolitical field is seriously outdated and incapable of taking account of the new technoscientific practices that continually rework the boundaries between the "human" and the "nonhuman."

Crucial to understanding the workings of power is an understanding of the nature of power in the fullness of its materiality. To restrict power's productivity to the limited domain of the social, for example, or to figure matter as merely an end product rather than an active factor in further materializations is to cheat matter out of the fullness of its capacity. How might we understand not only how human bodily contours are constituted through psychic processes but also how even the very atoms that make up the biological body come to matter, and more generally how matter makes itself felt? It is difficult to imagine how psychic and sociohistorical forces alone could account for the production of matter. Surely it is the case—even when the focus is restricted to the materiality of "human" bodies (and how can we stop there?)—that there are "natural," not merely "social," forces that matter. Indeed, there is a host of material-discursive forces—including ones that get labeled "social," "cultural," "psychic," "economic," "natural," "physical," "biological," "geopolitical," and "geological"—that may be important to particular (entangled) processes of materialization.[45]

What is needed is a robust account of the materialization of *all* bodies—"human" and "nonhuman"—including the agential contributions of all material forces (both "social" and "natural"). This will require an understanding of the nature of the relationship between discursive practices and material phenomena; an accounting of "nonhuman" as well as "human" forms of agency; and an understanding of the precise causal nature of productive practices that take account of the fullness of matter's implication in its ongoing historicity.[46] (Notice that the notion of a "causal" account need not entail singular causes or linear relationships or even postulate causes separable from their effects.) My proposed contributions toward the development of such a robust understanding include a new account of matter's dynamism, the nature of causality, and the space of agency, as well as a *posthumanist* elaboration of the notion of performativity. My posthumanist account calls into question the givenness of the differential categories of human and nonhuman, examining the practices through which these differential boundaries are stabilized and destabilized.[47] Relatedly, agential realism does not merely offer a unified theory of cultural and natural forces but inquires into the very practices through which they are differentiated.

AGENTIAL REALISM AND QUANTUM PHYSICS

An important inspiration for agential realism comes from my reading of Niels Bohr's philosophy-physics. (I use this hyphenated structure, instead of the usual "philosophy of physics," to emphasize Bohr's unwillingness to

think of these interests as distinctive in any sense, contrary to the sharp disciplinary boundaries that are important to contemporary physics culture [Barad 1995].) Bohr's philosophy-physics is a particularly apt starting point for thinking the natural and social worlds together and gaining some important clues about how to theorize the nature of the relationship between them because Bohr's investigations of quantum physics opened up questions not only about the nature of nature but about the nature of scientific and other social practices. In particular, Bohr's naturalist commitment to understanding both the nature of nature and the nature of science according to what our best scientific theories tell us led him to what he took to be the heart of the lesson of quantum physics: *we are a part of that nature that we seek to understand.*

Bohr starts with a critical examination of measurement processes. Measurement is a meeting of the "natural" and the "social." It is a potent moment in the construction of scientific knowledge—it is an instance where matter and meaning meet in a very literal sense. This is one reason why science studies scholars have been interested in studying the role of detectors (in high energy physics)—they are sites for making meaning (Traweek 1988; Galison 1987; Pickering 1984). Significantly, in contrast to the inconsequential role that measurement plays in Newtonian physics, Bohr argues that quantum physics requires a new logical framework that understands the constitutive role of measurement processes in the construction of knowledge. I argue that much like the poststructuralist theories mentioned earlier, which are also centrally concerned with the relationship between matter and meaning, Bohr's new framework moves beyond representationalism and proposes a rich and complex proto-performative account in its stead.

Now, I am quite aware that the ubiquitous appropriation of quantum theory makes it dangerous material to handle these days, and the addition of feminist theory to my list of concerns seems to be quite enough to detonate the explosive mixture, so a few preliminary words of caution may be in order. In a sense, to accomplish my task, I need to "rescue" quantum theory from the problematic discourses of both its overzealous advocates and its unreflective practitioners. In the popular literature, quantum physics is often positioned as the scientific path leading out of the West to the metaphysical Edenic garden of Eastern mysticism. Paralleling these popular renditions, one can find suggestions in the literature that quantum physics is inherently less androcentric, less Eurocentric, more feminine, more postmodern, and generally less regressive than the masculinist and imperializing tendencies found in Newtonian physics. But those who naively embrace quantum physics as some exotic Other that will save our weary Western souls forget too quickly that quantum physics underlies the workings of the A-bomb,

that particle physics (which relies on quantum theory) is the ultimate manifestation of the tendency toward scientific reductionism, and that quantum theory in all its applications continues to be the purview of a small group of primarily Western-trained males. It is not my intention to contribute to the romanticizing or mysticizing of quantum theory. On the contrary, as a physicist, I am interested in engaging in a rigorous dialogue about particular aspects of specific discourses on quantum physics and their implications. Hence the reader will not find any claims here to the effect that Niels Bohr is an unappreciated or closet feminist, or that his theory is inherently feminist. Nor is my aim to critique physics by holding it up to some fixed notion of gender. On the contrary, the analysis I present here calls into question notions of identity, agency, and causality that are presumed by such critiques.

On the other hand, I part company with my physics colleagues with neopositivist leanings who believe that philosophical concerns are superfluous to the real subject matter of physics. Rather, I am sympathetic to Bohr's view that philosophy is integral to physics. Indeed, Einstein felt much the same way and once quipped: "Of course, every theory is true, provided you suitably associate its symbols with observed quantities." In other words, physics without philosophy can only be a meaningless exercise in the manipulation of symbols and things, much the same as philosophy without any understanding of the physical world can only be an exercise in making meaning about symbols and things that have no basis in the world. This is why Einstein and Bohr engaged with all their passions about the meaning of quantum theory. Their long-standing debate on the topic is legendary. For the most part, however, the physics community turned its gaze toward more "practical" matters.

Niels Bohr's "philosophical" writings span a period of approximately four decades. Bohr is considered to be (one of) the primary author(s) of the so-called Copenhagen interpretation of quantum mechanics.[48] Although alternative interpretations have been advanced since the formulation of the quantum theory in 1925, from the late 1920s onward the physics community has claimed allegiance to the Copenhagen interpretation.[49] In point of fact, the vast majority of physicists treat the interpretative issues as though they were "merely philosophical," preferring to focus instead on the powerful tools that the quantum formalism provides for purposes of calculation. This particular circumscription of what constitutes "physics" versus what constitutes "philosophy" has exacted a substantial cost for the physics community: the foundational issues of this fundamental physical theory remain unresolved, decades after its founding, and the culture of physics is such

that unreflective (read "pragmatic" or "antiphilosophical") attitudes and approaches are rewarded, despite the fact that there are good reasons to believe that persistent difficulties in the fields of cosmology, quantum gravity, and quantum field theory are derivative of these unresolved issues.[50] The simultaneous centrality and marginality of Bohr's views is also particularly interesting: on the one hand, he was a hero, a leader of the physics community; on the other hand, he was too "philosophical" in his approach to physics.[51]

Bohr often makes reference to the epistemological lessons of quantum theory, and he sees the framework that he offers for quantum physics as having general relevance beyond physics (Folse 1985). There has been a substantial amount of interest in the larger philosophical implications of Bohr's philosophy-physics. Many such investigations leave the interpretative issues in the foundations of quantum theory aside. My interest, however, is not only in the larger philosophical implications. My approach will be to draw out the specifics of a consistent Bohrian framework, grounding the analysis in the physics, and further elaborating Bohr's approach, making explicit implicit ontological dimensions of his account. Once this elaboration is in hand, I return to the interpretative questions in the foundations of quantum theory.[52]

The first task is necessary because there is much disagreement in the secondary literature about how to interpret Bohr. For example, Bohr has been called a positivist, an idealist, an instrumentalist, a (macro)phenomenalist, an operationalist, a pragmatist, a (neo-)Kantian, and a realist by various authors. One of the difficulties in assigning a traditional label to Bohr's interpretative framework is the fact that Bohr is not specific about his ontological commitments. To fill this crucial gap, I propose an ontology that I believe to be consistent with Bohr's views, although I make no claim that this is what he necessarily had in mind. That is, my primary goal is to develop a coherent framework. I try to make sense of the ontological issues on the basis of what Bohr tells us, but I am less interested in trying to figure out what Bohr was "actually" thinking than what makes sense for developing a coherent account. My approach, therefore, is to use Bohr's writings for thinking about these issues, but I do not take them as scripture.[53] Using this analysis of Bohr's philosophy-physics as inspiration, I introduce agential realism as a framework that attends to both the epistemological and ontological issues.

I then offer some examples of applications of agential realism. I consider some specific issues of interest to researchers in the fields of critical social

theory, social and political philosophy, feminist theory, queer theory, political economy, physics, philosophy of physics, ethics, epistemology, science studies, and others. I diverge from Bohr in strategy here, but not in spirit. Bohr's methodological approach was to draw out the epistemological lessons of quantum theory for other fields of knowledge by essentially trying to guess what the relevant complementary variables would be in each arena. This analogical strategy often failed, both because he proposed a set of variables that turned out not to be complementary, and because the implications drawn on this basis watered down the complexity and richness of the "epistemological lessons."[54] By contrast, my approach will be to examine specific implications by directly taking on a different set of epistemological and ontological commitments. That is, I will not use the notion of complementarity as a springboard; instead I directly interrogate particular philosophical background assumptions that underlie specific concerns.

Finally, I want to emphasize and make explicit the distinction between my approach and a host of analogical (mis)appropriations of quantum theory that are more common in the literature than physicists (including this one) would wish. I will not put forward any argument to the effect that the quantum theory of the micro world is analogous to situations that interest us in the macro world—be they political, spiritual, psychological, or even those encountered in science studies. My focus is on the development of widely applicable epistemological and ontological issues that can be usefully investigated by a rigorous examination of implicit background assumptions in specific fields. To ask whether it is not suspect to apply arguments made specifically for microscopic entities to the macroscopic world is, in this case, to mistake the approach as analogical. The epistemological and ontological issues are not circumscribed by the size of Planck's constant.[55] That is, I am interested not in mere analogies but in the widely applicable philosophical issues such as the conditions for objectivity, the appropriate referent for empirical attributes, the role of natural as well as cultural factors in technoscientific and other social practices, the nature of bodies and identities, and the efficacy of science.

TWO

Diffractions: Differences, Contingencies, and Entanglements That Matter

> Reflexivity has been recommended as a critical practice, but my suspicion is that reflexivity, like reflection, only displaces the same elsewhere, setting up worries about copy and original and the search for the authentic and really real. . . . What we need is to make a difference in material-semiotic apparatuses, to diffract the rays of technoscience so that we get more promising interference patterns on the recording films of our lives and bodies. Diffraction is an optical metaphor for the effort to make a difference in the world. . . . Diffraction patterns record the history of interaction, interference, reinforcement, difference. Diffraction is about heterogeneous history, not about originals. Unlike reflections, diffractions do not displace the same elsewhere, in more or less distorted form. . . . Rather, diffraction can be a metaphor for another kind of critical consciousness at the end of this rather painful Christian millennium, one committed to making a difference and not to repeating the Sacred Image of Same. . . . Diffraction is a narrative, graphic, psychological, spiritual, and political technology for making consequential meanings.
>
> —DONNA HARAWAY,
> *Modest_Witness@Second_Millennium.FemaleMan©_Meets_OncoMouse™*

The phenomenon of diffraction is an apt overarching trope for this book. Diffraction is a physical phenomenon that lies at the center of some key discussions in physics and the philosophy of physics, with profound implications for many important issues discussed in this book. Diffraction is also an apt metaphor for describing the methodological approach that I use of reading insights through one another in attending to and responding to the details and specificities of relations of difference and how they matter.

As Donna Haraway suggests, diffraction can serve as a useful counterpoint to reflection: both are optical phenomena, but whereas the metaphor of reflection reflects the themes of mirroring and sameness, diffraction is marked by patterns of difference. Haraway focuses our attention on this figurative distinction to highlight important difficulties with the notion of

23 The notion of "intra-action" is a general term that speaks to the nature of being. In particular, it is not a concept that is limited to the microscopic domain. That is, although quantum physics provides unambiguous empirical evidence for the existence of intra-acting (rather than interacting) agencies, this *ontological* notion is completely general, and, in particular, is not limited in its applicability to microscopic objects. (Of course, it's an empirical question whether or not there are different ontologies at different length scales, but at least so far there is no evidence that that is the case, and contemporary physics does not incorporate such a belief. See chapter 7 for a discussion of the question of decoherence.)

24 With terms like "interventions" and "consequences" suitably redefined.

ONE • MEETING THE UNIVERSE HALFWAY

1 In the original text from which this passage is drawn (Barad 1996b), I deployed the term "social constructivism" for rhetorical purposes as part of an overall strategy aimed at destabilizing the realism-versus-constructivism debate (as the tensions in this paragraph self-consciously enact). To be clear, I am *not* a social constructivist, a point that should be understood from the very naming of the alternative I propose: "agential realism." My hoped-for intervention at this historical juncture was to point out that, despite the heated debates of the mid-1990s, there was sufficient play in both of these terms to render the debate meaningless. Indeed, I choose the subtitle "Realism and Social Constructivism without Contradiction" as a direct index of the futility of a debate centered on terms that are indeterminate. An alternative subtitle such as "Beyond Realism and Social Constructivism" might have been more direct in some ways, but "beyond" speaks of transcendence in a way that is misleading and the moment seemed to cry out for a more poignant marker of the senselessness of this tired debate. Actually, I originally had a very different subtitle: "Ambiguities, Discontinuities, Quantum Subjects, and Multiple Positioning in Feminism and Physics," which I changed at the last moment because the debate was growing in ferocity with the consequence that there was less productive interchange across the "divide." The agential realist view that is put forward in the paper, and in this book, cuts across the traditional divide between realism and social constructivism; that is, it challenges the very terms of the debate. (In particular, the "halfway" in the title is *not* a way of marking agential realism as an attempt to find some "middle ground" between social constructivism and scientific realism, as has been suggested. This suggestion is entirely misguided.) The point is that agential realism calls into question representationalism, individualism, and other foundationalist assumptions that prop up *both* traditional forms of realism and social constructivism.

2 A less obvious point perhaps is that the success of scientific theories is not automatic for realists either, as Laudan (1981) and Fine (1984) argue.

3 For Galison, stability refers to the invariance of results under changing experimental conditions (rather than the narrower category of manipulation), and directness is an epistemological, but not necessarily logically noninferential, matter.

4 Ontology has been given increasingly more attention in science studies since I originally offered these observations (Barad 1996). See, for example, Cussins (1998); Haraway (2003); Latour (1999); Law and Singleton (2000); Mol (2003); and Stengers (1997). While this is not intended to be an exhaustive list, and it is encouraging that the literature on ontology has grown significantly, my original point—that the bulk of attention in science studies has been and continues to be devoted to concerns about the nature of knowing rather than the nature of being—still holds.

5 For further discussion of "ontoepistemology" (the study of the intertwined practices of knowing and being), see chapter 4.

6 Cushing asserts that "realism is in double jeopardy." The sense in which he intends this remark is best illustrated in terms of his example, which centers on the competing interpretations of quantum physics offered by Niels Bohr (the so-called Copenhagen interpretation) and David Bohm. First, Cushing argues that realism is called into question by the almost universally accepted "antirealist" Copenhagen interpretation. And furthermore, realism is challenged by the very existence of competing theories that are empirically indistinguishable. Although I will be arguing here for a realist stance on Bohr's part (as opposed to Cushing's antirealist reading of Bohr), this divergence in and of itself does not weaken the underdetermination aspect of Cushing's argument. (Note that there are a few important unresolved issues not made explicit in Cushing's argument. One is that the empirical equivalence of these theories depends on the resolution of the measurement problem for the Copenhagen interpretation [see chapter 7]. And it still remains to be seen whether Bohm's theory and the Copenhagen theory are empirically coincident in all respects.) In any case, while underdetermination may pose a problem for the correspondence theory of truth, it does not preclude realist positions according to my rendering of "realism" (see hereafter).

7 See Barad 1995 for a further discussion of "play" in the culture of science.

8 This fact isn't at all surprising to those who realize that a substantial number of feminist science studies scholars, including many of the most highly regarded scholars in the field, are scientists or at least have significant training in the sciences.

9 Rather blasphemously, agential realism denies the suggestion that our access to the world is mediated, whether by consciousness, experience, language, or any other alleged medium. See the discussion hereafter and in chapter 4. Rather like the special theory of relativity, agential realism calls into question the presumption that a medium—an "ether"—is necessary.

10 The neologism "ontoepistemological" marks the inseparability of ontology and epistemology. I also use "ethico-onto-epistemology" to mark the inseparability of ontology, epistemology, and ethics. The analytic philosophical tradition takes these fields to be entirely separate, but this presupposition depends on specific ways of figuring the nature of being, knowing, and valuing. See chapters 4 and 8 for further discussion.

11 See especially the chapter "The Data of Biology" in *The Second Sex*. Unlike some

recent feminist attempts to rethink the body, Beauvoir displays an unapologetic willingness to engage important biological dimensions of embodiment. Of course, her willingness may seem like so much naiveté at this historical juncture, but it is refreshing to read excerpts from this chapter which may be usefully meditated on by contemporary feminists in order to help recalibrate the possibilities for direct engagement with the body's biology.

12 It is important not to conflate poststructuralism with postmodernism. Both terms refer to complex sets of discourses, but a brief explanation of the differences between them might usefully be understood in the following way. Postmodernisms are concerned with a critique of modernism. Poststructuralism concerns itself with a radical critique of individualist ontologies, especially as found in the notion of the liberal humanist subject. Poststructuralism focuses on the productive nature of social practices and the discursive constitution of the subject. Michel Foucault's and Judith Butler's poststructuralist accounts are taken up later in this book.

13 See Grosz's *Volatile Bodies* (1994) for a detailed discussion of the limitations of both "internal" and "external" accounts.

14 Readers unfamiliar with these issues may want to consult any one of a number of introductory texts on feminist theory and poststructuralist theory.

15 Note that representationalism is not a prohibition against talk about "representations," nor does it take the notion of representations to be meaningless. The issue at hand is what role representations play and how referentiality is conceived.

16 Rouse begins his interrogation of representationalism in *Knowledge and Power* (1987), wherein he examines how a representationalist understanding of knowledge gets in the way of understanding the nature of the relationship between power and knowledge. He continues his critique of representationalism and the development of an alternative understanding of the nature of scientific practices in *Engaging Science* (1996). Rouse proposes that we understand science practice as ongoing patterns of situated activity, an idea that he further elaborates in *How Scientific Practices Matter* (2002).

17 The allure of representationalism may make it difficult to imagine alternatives. I discuss performative alternatives hereafter, but these are not the only ones. For example, Foucault points out that in sixteenth-century Europe, language was not thought of as a medium; rather, it was simply "one of the figurations of the world" (1970, 56), an idea that reverberates in a mutated form in the posthumanist performative account that I offer.

18 While Andrew Pickering has been one of the few science studies scholars to take ownership of this term, there is surely a sense in which science studies theorists such as Donna Haraway, Bruno Latour, and Joseph Rouse also propound performative understandings of the nature of scientific practices. In *The Mangle of Practice*, Pickering explicitly eschews the representationalist idiom in favor of a performative idiom. It is important to note, however, that Pickering's notion of performativity would not be recognizable as such to poststructuralists, despite their shared embrace of *performativity* as a remedy to representationalism, and

despite their shared rejection of humanism. Significantly, Pickering, in his appropriation of the term, does not acknowledge its politically important—arguably inherently queer—genealogy (see Sedgwick 1993), or why it has been and continues to be important to contemporary critical theorists, especially feminist and queer studies scholars and activists. Indeed, he evacuates its important political history along with many of its crucial insights. This is perhaps not surprising given that Pickering ignores important discursive dimensions of scientific practices, including questions of meaning, intelligibility, significance, identity formation, and power, which are central to poststructuralist invocations of performativity and feminist accounts of technoscientific practices. And he takes for granted the humanist notion of agency as a *property* of individual entities (such as humans, but also weather systems, scallops, and stereos), which poststructuralists problematize. On the other hand, poststructuralist approaches fail to take account of "nonhuman agency," which is a central focus of Pickering's and other performative accounts of scientific practices.

19 As the historian of science David Cassidy (1999) describes it, at this historical juncture there was a move away from the mechanistic worldview in favor of the energetic and electromagnetic views and Einstein was a member of a dwindling minority in holding on to the hope for a unified mechanistic account of nature. In fact, although the notion that the atom is indivisible (as its namesake suggests) was already coming apart around the edges with J.J. Thomson's 1897 discovery of the electron, it wasn't until Einstein's 1905 explanation of Brownian motion that physicists were convinced that atoms are material particles and not merely theoretical entities. The die-hard positivist Ernst Mach was a notable holdout.

20 See chapter 8.

21 Nancy Cartwright also makes this distinction. Like Hacking, she is a realist toward entities and not theories. While Hacking focuses on experimental practice, Cartwright pays more attention to the intricacies of theorizing and model building.

22 See, for example, the chapter "Microscopes" in Hacking 1983.

23 Of course, "zooming in" on any practice of image formation—including the use of point-and-shoot cameras—will make it clear that images don't simply capture what is already there.

24 Valerie Hanson (2004) suggests using the notion of "haptic vision" practices to understand STM image formation.

25 The distinction between physical touch and the interaction between the microscope tip and the sample is not as great as one might think. "Touching" as we know it in our everyday lives is an electromagnetic interaction, a repulsion between electron clouds that don't so much "touch" in the sense of encountering each other's boundaries through physical contact as sense one another's electron clouds; and furthermore, the gap between the STM tip and the surface atoms involves a separation of a mere few nanometers, so the question of whether this is "really touching" in the sense of physical prximity is moot.

26 That is, according to the principles of classical Newtonian physics, the particles

shouldn't be able to cross the barriers, but they do because of the quantum mechanical wave nature of matter. The "dual" (wave-particle) nature of matter is discussed in detail in chapter 3.

27 Gerd Binning and Heinrich Rohrer of the IBM Zurich Research Labs created the STM in March 1981. They received the 1986 Nobel Prize in Physics for their contribution.

28 Bohr eschews representationalism and moves toward a performative account, where scientific practices entail direct material engagement with the world rather than reflection from afar. Unlike Hacking, though, Bohr does not take account of the dynamics of practice (e.g., the fact that part of the difficulty of an experiment is getting the equipment to work; an experimental setup doesn't simply appear ready for the task at hand). See chapter 4.

29 Paul Teller (1989) calls this "particularism" (see chapter 7).

30 For some readers, the term "phenomenon" will no doubt carry what for my purposes are unwanted phenomenological connotations. Crucially, the agential realist notion of *phenomenon* is not that of philosophical phenomenologists. In particular, phenomena should *not* be understood as the way things-in-themselves *appear*: that is, what is at issue is not Kant's notion of phenomena as distinguished from noumena. Rather, as will be explained in later chapters, my notion of phenomenon is an elaboration of Bohr's notion of phenomenon. I preserve the term not merely to honor Bohr but to underline the important shift that an agential realist understanding of phenomena plays in reconsidering the foundational or interpretative issues in quantum mechanics (see chapter 7). And last but not least, I preserve the term "phenomenon" because of its common usage, especially in the scientific realm, to refer to that which is observed, what we take to be real. This is useful because when the term is invoked an opportunity presents itself for the possibility of getting the objective referent right—that is, of associating the term with the full complexity that is a "phenomenon" in the agential realist sense (see especially chapter 4).

31 Rouse makes this point about experimenting and theorizing as well; see especially Rouse 2002.

32 "Intra-action" is a core concept in my agential realist account. I discuss it in detail in later chapters (see especially chapters 3 and 4).

33 Unless, of course, you take "things" to be collectives. This is the strategy that Latour advocates in his recent work: redefining the term "thing" (through a reclamation of its etymological roots) to stand for the human-nonhuman collective that is assembled. See especially Latour 2004 and the introduction to the catalog for the exhibit Making Things Public—Atmospheres of Democracy, http://www.ensmp.fr/latour/articles/article/96-DINGPOLITIK2.html. However, not nearly as much effort has been put into dislodging "words" (in the "words and things" staging of representationalism)—that is, questions related to discursive practices (the material conditions for meaningful expression)—especially in relation to issues that Foucault would consider to be at the crux of the discourse-power-knowledge nexus, that is, the discursive constitution of the subject. This is precisely the point that needs attention.

34 Crucially, this statement must be understood with an appreciation of the Foucauldian point that disciplinary power is not an external force that acts on the subject; rather, there is "only a reiterated acting that is power in its persistence and instability" (Butler 1993, 9).

35 Few feminist science studies scholars take poststructuralist insights seriously (that is, take them into account in any systematic fashion). Haraway and Rouse are notable exceptions.

36 See chapter 4. Also see the discussion in chapter 7 on the use of auxiliary apparatuses that take the measuring agencies (of the original system—for example, laboratory practices) to be (in this new configuration) part of the system under investigation. Significantly, as I explain, the addition of an auxiliary apparatus entails the constitution of a new phenomenon.

37 The metaphors of governmental politics in this paragraph are Latour's (2004), but the difficulties I am highlighting are not his alone.

38 See introduction, note 19.

39 Most of these multiple and various engagements trace performativity's lineage to the British philosopher J. L. Austin's interest in speech acts, particularly the relationship between saying and doing and the productive rather than merely descriptive efficacy of certain speech acts. Derrida is usually cited next as offering important poststructuralist amendments. For Derrida, the effectiveness of a speech act is not due to the originating will of a subject, or the situational context in which the citation occurs, as Austin suggests; rather, it is through iterative citationality that discourse gains the power to bring about what it names. Butler elaborates Derrida's notion of performativity through Foucault's understanding of the productive effects of regulatory power in theorizing the nature of identity as performative. Butler introduces her notion of gender performativity in *Gender Trouble*. In *Bodies That Matter*, Butler argues for a linkage between gender performativity and the materialization of sexed bodies. My sketch of the complex genealogy is far too coarsegrained and simplified to do the topic justice here. See Eve Kosofsky Sedgwick (1993) for more details.

40 See especially Foucault 1978. Butler cites a range of sources from the feminist science studies literature on the gendered construction of "sex."

41 Quoted in Butler 1990, 106 (italics mine).

42 Foucault writes: "Power is not something that is acquired, seized, or shared, something that one holds on to or allows to slip away. . . . Power is not an institution, and not a structure; neither is it a certain strength we are endowed with. . . . Power's condition of possibility, or in any case the viewpoint which permits one to understand its exercise, even in its more 'peripheral' effects, and which makes it possible to use its mechanisms as a grid of intelligibility of the social order, must not be sought in the primary existence of a central point, in a unique source of sovereignty from which secondary and descendent forms would emanate; it is the moving substrate of force relations which, by virtue of their inequality, constantly engender states of power, but the latter are always local and unstable. [P]ower . . . is produced from one moment to the next, at every point, or rather in every relation from one point to another" (Foucault 1978, 92–94; reordered).

43 See also Kirby 1997 and Cheah 1996 on this point.

44 See also Butler 1989.

45 The agential realist terms "material-discursive" and "intra-action" are defined later. It is perhaps important to note in relation to the foregoing discussion that the hyphen in "material-discursive" is not simply a convenient way to make a conjunction out of otherwise disparate terms but rather denotes a theorized joining of the two. See chapter 4.

46 Strictly speaking, agency is not a property of entities—whether "human," "nonhuman," or "cyborgian." On the contrary, the differential constitution of the "human" and the "nonhuman" is agentially enacted, as I discuss in chapter 4.

47 Donna Haraway's work is explicitly and tenaciously posthumanist in this sense (even if she doesn't use the label). Indeed, Haraway's scholarly opus—from primates to cyborgs to companion species—develops a complex understanding of the technoscientific practices through which the various differentiations of the "human" and its others are enacted.

Notably, this notion of posthumanism differs from Andrew Pickering's idiosyncratic assignment of a "posthumanist space [as] a space in which the human actors are still there but now inextricably entangled with the nonhuman, no longer at the center of the action calling the shots" (1995, 26). While Pickering thereby decenters the human from his accounts of scientific practice, he nonetheless takes the human, and its distinction from the nonhuman, for granted. (Note that Pickering's notion of "entanglement" is explicitly epistemological, not ontological.) What is at issue for him in dubbing his account "posthumanist" is the fact that it is attentive to the mutual accommodation, or responsiveness, of human and nonhuman agents. While Pickering (1995) identifies his account of the "mangle of practice" as specifically "posthumanist" and "performative," his use of both these key terms is very different from mine. Ironically, the liberal humanist actor that makes choices in the context of scientific practices is everywhere evident in his theory.

I distinguish my specific invocation of "posthumanist" from other uses as well, such as the notion that the posthuman designates an era following the "end of man." My use of posthumanism is also to be contrasted with (anti)humanism and its attendant anthropocentrisms. Furthermore, I am not drawing a contrast between some posthuman entity and its human predecessor. Rather, in an unsettling of (anti)humanist assumptions, I want the focus to be on the boundary-making practices that delineate human from other. For further discussion, see chapter 4.

48 While physicists, philosophers, historians, and others talk of *the* Copenhagen interpretation, in an important sense there are really many Copenhagen interpretations; or to put it another way there is no determinate or well-defined, coherent, and complete Copenhagen interpretation. The physicists who contributed to the Copenhagen interpretation displayed significant philosophical and interpretative differences in their specific contributions, so that what is taken to be *the* Copenhagen interpretation is actually a superposition of the disparate views of a group of physicists who include Bohr (complementarity), Heisenberg (uncertainty), Born (probability), and von Neumann (projection postulate), to name a few of the key players. Beller (1999) also argues that the Copenhagen interpretation is not a coherent framework but rather a compromise that was achieved among the key players.

49 See Cushing 1994 on the hegemony of the Copenhagen interpretation of quantum mechanics.

50 In the mid-1990s, the foundational issues in quantum theory started to become a respectable topic of conversation in physics (once again) in large part due to related developments in quantum information theory, including applications to quantum cryptography, quantum teleportation, and quantum computing (see chapters 7 and 8).

51 Increasingly, quantum textbooks do not mention any of Bohr's contributions to the field (except for reference to his model of the atom, which predates the full theory of quantum physics). In particular, there is often no mention of his principle of correspondence and the role it played in the development of the quantum theory, or complementarity and its importance to an understanding of quantum theory. The implicit justification is that these are "mere historical facts" of no practical or computational consequence, which means "of no real significance." But this turns out not to be the case (see chapter 7).

52 See chapter 7.

53 See "Methodological Interlude" in chapter 3. It would not be unreasonable to think that Bohr would find himself in sympathy with this approach, which attempts to be attentive and accountable to our specific engagements with, and as part of, the world as opposed to merely honoring his authority. In his stance toward the world, it is evident that intellectual integrity trumps authority.

54 For Bohr, "complementary" means simultaneously necessary and mutually exclusive (as explained in detail in the next section). See Bohr 1963b, vol. 2, for examples of this approach. One often-noted example of the failure of Bohr's analogical methodology is his attempt to resolve the vitalism-mechanism debate in biology. His approach seems to have failed because he assumed, from his limited technological perspective, that the conditions for examining the underlying mechanics of life processes and the conditions for maintaining the life of the specimen under investigation were mutually exclusive. On the other hand, the question how "life" ought to be defined is perhaps more complex than some of Bohr's critics acknowledge (see Barad, "Living in a Posthumanist Material World: Lessons from Schrödinger's Cat").

55 It is important to note that the fact that Newtonian physics "works" (i.e., it gives adequately accurate numerical values in its predictions) in the macroscopic domain does not mean that Newtonian physics is a strictly true theory in the macroscopic domain (or any other); in fact most physicists do *not* believe that to be the case or that the assumptions of measurement transparency (i.e., the metaphysical background assumptions that support Newtonian physics) hold in that domain (see chapter 3). Rather, the fact that Newtonian physics makes predictions that are approximately the same as those made by quantum theory in the macroscopic domain is simply due to the fact that in this domain the ratio of Planck's constant to the mass of the particle is generally smaller than the

accuracy required of the macroscopic situation in question—but it is *not* zero. And the fact that this ratio is not strictly zero is the key point. In other words, the fact that Newtonian physics provides good approximations to the exact quantum mechanical solutions for many macroscopic situations is not evidence against the new epistemology or ontology suggested by my elaboration of Bohr's account, which is in fact supported by the new experiments that have far-reaching implications for the foundations of quantum theory. Indeed, there is no evidence to suggest that there are two separate "worlds"—the Newtonian (macro) world in which Newton's equations apply, and the quantum (micro) world in which Schrödinger's equation applies. In fact, as Bohr points out, the reverse seems to be the case: once the epistemological (and ontological) shift suggested by quantum theory is made, we can understand why the old assumptions weren't readily questioned and lay hidden for centuries. This is why Bohr refers to the *general* epistemological lessons of quantum theory. For further discussion, see chapter 3.

TWO • DIFFRACTIONS

1 For a discussion of reflexivity in the science studies literature, see, for example, Woolgar 1988a.

2 In her essay "The Promises of Monsters," Haraway (1992) proposes the notion of diffraction as a metaphor for rethinking the geometry and optics of relationality. In her book *Modest—Witness*, Haraway (1997) promotes the notion of diffraction to a fourth semiotic category. My elaboration does not follow a semiotic course of analysis; rather, in carefully exploring the details of diffraction as a physical phenomenon and a methodology, my elaboration engages with and helps me reformulate the notion of discursive analysis. Attending to quantum aspects of diffraction phenomena I also examine in detail the notion of entanglement and propose a rethinking of space, time, and matter that, among other things, shows the need to take account of topological as well as geometrical reconfigurings in genealogical analysis.

3 It's easy to make a diffraction pattern for yourself. Facing a light source, hold two fingers very close together (but without touching) in front of one of your eyes. Look carefully. You should be able to detect lines of dark and light between your fingers. Try varying the distance between your fingers and observe the change in pattern. Diffraction patterns vary with the size of the slit. The pattern also varies with the wavelength (color) of the light and the distances between slits if there is more than one.

4 The light source used to make this image is monochromatic (one wavelength) and coherent (the waves are in phase—that is, in lock step—with one another).

5 Superposition is discussed in more detail in chapters 3 and 7. As we will see, superpositions in quantum mechanics have far-reaching implications.

6 A wave has two important characteristics: amplitude and wavelength. The wave's amplitude is its height (i.e., the relative size of the disturbance). The wavelength is the distance between the wave's crests. The amplitude of a wave is related to its intensity (or brightness in the case of light waves). The relative *phase* of component waves in a waveform relates similar features to one another (e.g., one may speak of the relative phase of the crests of the component waves). When the component waves in a waveform are lined up with one another, they are said to be "in phase."

7 It is perhaps also worth noting that "interference" can be a misleading term for the novice, since the verb "to interfere" carries the connotations of disruption, hindrance, or obstruction. When waves meet, they don't disrupt or obstruct each other, no impact or collision occurs, as in the case of two particles. On the contrary, the whole point is that the waves can coexist unhindered by each other's presence; they can overlap in a common spatial region—indeed, at a single point. There are wonderful online interactive programs for learning about diffraction and interference. See, for example, the Physics Java Applets page by Chiu-king Ng, a high school physics teacher in Hong Kong, http://www.ngsir.netfirms.com/englishVersion.htm#lightwave. See p. 407, n.20.

8 The actual pattern depends on specific features including the wavelength of the waves, the width of the slits (holes), and the distance between them. In particular, for a given diffraction grating (breakwater), different wavelengths will constructively and destructively interfere at different places on the screen (the shore or another surface). This explains why diffraction gratings separate white light into different component colors (effectively acting like a prism).

9 Physically speaking, diffraction and interference are one and the same. They both have to do with the fact that when waves overlap, their amplitudes combine.

10 A single-slit diffraction pattern also exhibits bands of constructive and destructive interference. You can find an explanation of single-slit diffraction in terms of the interference of "wavelets" (using Huygen's principle) in elementary textbooks on optics.

11 This is called a Poisson spot. This phenomenon played an important historical role in debates about the wave-versus-particle nature of light. In 1818, hoping to disprove the ridiculous conjecture that light is a wave, Siméon Poisson submitted a paper in a scientific competition sponsored by the French Academy of Sciences wherein he deduced the "ludicrous" conclusion that if light were a wave there would be a bright spot in the center of a shadow cast by a round opaque object. Much to his chagrin, in short order one of the judges, Dominique Aargo, performed the experiment and observed the resulting bright spot at the center of the diffraction pattern.

12 When sunlight, which contains the full spectrum of colors in the visible part of the electromagnetic spectrum, passes through a diffraction grating, the overlapping of light waves results in the enhancement of some colors in some regions of the disc and the diminishment (or elimination) of others. Which colors are enhanced and which are diminished in particular regions depend on the wavelength of the light wave, that is, on its color. Thus different regions are differently colored.

13 The various colors that make up white light are separated here as a result of the