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Bacterial Lives

Sex, Gender, and the Lust for Writing

> Bacterial sex differs from ours relative to time. Bacterial sex, the first kind of sex on this planet, is speedy sex.
>
> —LYNN MARGULIS AND DORIAN SAGAN

> Language (word choice, metaphors, analogies, and naming practices chosen to explain scientific concepts) and visual representations (images, tables, and graphs chosen to illustrate scientific concepts) have the power to shape scientific practice, the questions asked, the results obtained, and the interpretations made. Rethinking language and visual representation in textbooks can help remove unconscious gender assumptions that restrict discovery and innovation, and thereby reduce gender inequalities. . . . In bacteriology, this includes removing scientifically unsound metaphors that present bacteria as sexed organisms.
>
> —*GENDERED INNOVATIONS*

Putting microphysiologies of desire into practice, this chapter discusses the kinds of molecular projects that become possible when we begin feeling around for an organism such as bacteria. It considers what new lines of flight can emerge at the intersections of molecular biology and feminism when we think with members of the domain bacteria and carefully reflect on the capabilities of these primordial, non-nucleated, unicellular organisms. Regardless of how we frame our scientific theories of evolution—whether through Charles Darwin's ideas on mutation and adaptation, or

Lynn Margulis's ideas on symbiosis—the qualities of changefulness and nonhuman becoming in bacteria are absolutely integral to how we think and what we come to know about genetics, DNA, and molecular biology today.[1] Recent interest in the human microbiome, for example, coupled with the growth of metagenomics, has fostered a great deal of scientific interest in the contributions made by microorganisms such as bacteria to our human lives. The Human Microbiome Project sponsored by the National Institutes of Health recognizes that microbes such as bacteria are essential to our health, providing essential vitamins, breaking down food to extract nutrients, bolstering the immune systems, and producing anti-inflammatory compounds that are needed to fight disease.[2]

We have several modern scientific methods at hand to measure the extent of our biological and genetic kinship with bacteria. However, putting this recent interest aside, our connection with bacteria should come as no surprise. Since the first human observation of microorganisms over three hundred years ago, those of us who have worked with them have long known the important lessons we can learn from organisms such as bacteria. In addition to playing a crucial role in the genesis of this planet and all of its inhabitants including humans, bacteria have a great deal to teach us not only about changefulness and nonhuman becomings but also about desire, response, experimentation, and communication through language, writing, and text. Through an analysis of bacteria, this chapter asks what new ontological, epistemological, and ethical lessons can bacteria teach us? In particular, I turn to a bacterium's ability to alter its genome; importantly, bacterial sex plays a crucial role.

The ability to conduct genetic engineering through recombinant DNA techniques is not even a human invention, but rather a skill set that we as human scientists have simply borrowed from our bacterial kin. By taking advantage of their capacity for changefulness, we have learned a great deal from bacteria, including the physical and chemical features of DNA, the complex processes that are involved in the transcription of genes into messenger RNA (mRNA), and the translation of RNA into proteins. Whether we realize it or not, almost all of the molecular biotechnologies that we use today are based on the bacterial ability to have sex through several mechanisms of gene transfer. As humans, we certainly need to develop a broader understanding of sex, and indeed much of this chapter is dedicated to that very project. By learning more from bacteria, we can begin to expand our

understanding of sex to include the molecular politics and microprocesses of desire, response, experimentation, and communication.

The sex I refer to in this chapter, as well as the sex that Lynn Margulis refers to in the epigraph, is the intricate array of molecular mechanisms involved in the processes of gene transfer. Bacterial abilities to replicate and edit genomes, synthesize new proteins, and adapt their immune systems are at the heart of many recent molecular biology–based research and technologies today, including the industrial and environmental applications of synthetic biology as well as the biomedical and directed engineering applications of the Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-Cas9 gene editing system. No genetic engineering technology, and perhaps not even the field of molecular biology itself, would exist without the spectacular capabilities of bacteria—particularly, the bacterial capability of having sex.

Margulis (1938–2011) dedicated her career as a biologist to thinking differently about evolution and to challenging dominant paradigms in microbiology. She fearlessly promoted a theory of evolution commonly referred to as endosymbiosis theory, symbiogenesis, or symbiosis, at a time when many of her scientific peers were simply not ready to listen. In a 1967 paper titled "On the Origin of Mitosing Cells," Margulis argued that eukaryotic cells originated from three fundamental organelles that were once separate and free-living prokaryotic cells—namely, mitochondria, photosynthetic plasmids, and the basal bodies of flagella.[3] Later, drawing from and promoting the work of the Russian botanists Konstantin Mereschkowski and Boris Kozo-Polyansky, Margulis provided microbiological evidence that similar symbiotic relationships between different organisms actually provided the driving force behind evolution and genetic variation.[4]

In her book *Symbiotic Planet*, Margulis explained that the bacterial capacity to change or transform through metabolic means is at the heart of the origins of life on earth. "The smartest cells," she wrote, "those of the tiniest bacteria, about one ten-millionth of a meter in diameter, continuously metabolize. This simply means they continuously undergo hundreds of chemical transformations. They are fully alive. Recent work has revealed that the tiniest, most simple bacteria are very much like us. They continuously metabolize, using the same components as we do: proteins, fats, vitamins, nucleic acids, sugars, and other carbohydrates. It is true that even

the simplest bacterium is extremely complex. Yet its inner workings are still like those of larger life."[5] Just as Margulis turned to bacteria to provide an alternative paradigm to thinking about the origins of life on earth, she also turned to bacteria to reframe our conceptions about the origins of sex.

Collaborating with her son Dorion Sagan, Margulis's scientific theories on the origins of sex are beautifully complex and yet have been made entirely accessible to nonspecialists.[6] Although open to the possibility that sex may have evolved in "unstable molecules before the origins of life" before the ozone layer even formed around the earth, Margulis believed that sex began as a way for bacteria to repair their DNA that had been damaged by solar radiation.[7] Bacteria did this by using DNA that was introduced from outside of their own bodies.[8] A key argument throughout Margulis's work on the origins of sex is that as humans we need to develop a broader understanding of sex. For instance, Margulis emphasized the distinction that needs to be made between sex and reproduction, claiming that if we think with bacteria, and consider a more historical evolutionary perspective that actually decentralizes the human, we can see that sex is simply a "genetic mixing process that has nothing necessarily to do with reproduction as we know it in mammals."[9]

Margulis stressed that reproduction occurs when a cell or organism copies itself, which, depending on the species, can take place with or without the need for engaging in sex. "Everyone is interested in sex," she wrote. "But, from a scientific perspective, the word is all too often associated with reproduction, with sexual intercourse leading to childbirth. As we look over the evolutionary history of life, however, we see that sex is the formation of a genetically new individual. Sex is a genetic mixing process that has nothing necessarily to do with reproduction as we know it in mammals. Throughout evolutionary history a great many organisms offered and exchanged genes sexually without the sex ever leading to the cell or organism copying known as reproduction."[10] Making this distinction between sex and reproduction, Margulis simultaneously underscored the notion that sex should not be thought of as a unified and singular type of act but rather as a "multifaceted and widespread phenomenon"—an idea that we return to later in this chapter.[11] For now, I would like to highlight the rich intellectual curiosity that Margulis brought to the sciences of evolution, microbiology, and molecular biology. Framing sex as

multifaceted phenomenon, she perceived gene transfer mechanisms including conjugation, lysogeny, phage transduction, transformation, and plasmid transfer as different types of bacterial sex acts.[12] Despite providing this elegant ontological shift in our understanding and grasp of sex, a tension emerges in her work.

Discussing bacterial sex, Margulis was at times surprisingly hesitant in her language describing some of the properties of sex that have come to be associated with gender. Her use of the terms "sex," "gender," "male," and "female" with respect to bacteria foreshadows the message in the chapter epigraph and explains the tone of the cautionary notice posted on the *Gendered Innovations* website regarding the use of "unsound scientific metaphors that present bacteria as sexed organisms."[13] Interestingly, while discussing the origins of sex and the mechanisms of bacterial sex, in many instances Margulis constructs the familiar scenario:

> A sexual being, by biologists' definition, has at least two parents; and "gender" refers to the differences between these two parents. If bacteria have "genders" they are very subtle. Conjugating bacteria, before conjugation, look and behave just like each other. During conjugation, though, the rounded form, the "male" bacterium with a "fertility factor" among "his" genes, injects DNA into a "female" recipient whose DNA lacks fertility factor genes. In this travesty of transvestism, the "female" owing to its possession of the fertility factor, now becomes "male." This genetic gift can be passed on, indefinitely, changing genders as it goes.[14]

With or without the scare quotes, and despite the use of the term "transvestism," Margulis and Sagan's explanation of bacterial sex moves our understanding of sex from not only being richly complex but also being rather complicated. In the time I have spent over the years feeling around for bacteria, I have learned that something that is complicated can be quite generative. In fact, the scholarly and disciplinary complications of learning about the fertility factor in bacteria have provided me with the motivation for getting lost and for learning how to work among the runes/ruins of molecular biology.

For instance, in the entire four years of my undergraduate education and training in microbiology, I learned about male bacterial cells that carried the fertility factor required for conjugation several times over.

However, the curriculum at my well-reputed institution never once mentioned Margulis's work. Not even in my course and lab work in bacteriology and parasitology, where we learned about the possible interrelationships that can form between organisms—including symbiosis, mutualism, commensalism, and parasitism—did I learn about Margulis's ideas on the evolutionary concept of symbiogenesis. Despite this knowledge gap or "ruin," I am forever grateful to my professors for sharing their passion for all things microbial. This passion and the accompanying sets of problematics led me to my encounter with viruses, and thereby to one of my first experiences as a budding feminist scientist. Microbiology taught me the value of thinking with scientific knowledges, languages, and practices that were not just complex but complicated. I didn't have a name for it then, but I stumbled across my first object of "joint perplexity" between feminists and scientists when I asked my virology professor if there was a difference in the etiology of HIV/AIDS in women compared to men.[15] Although the answer given was profoundly insufficient, this was my first attempt to bridge disparate fields of scholarship, to mix disciplinary vocabularies, and to learn not to steer away from either the complexities or the complications of asking and knowing otherwise. I'll admit that after years of conducting interdisciplinary work, I am drawn to those productive tensions that emerge when we as feminist scientists, scientist feminists, feminist theorists, feminist STS scholars, or those of us who wear a combination of these hats, turn toward and not away from such difficult questions.

Thinking alongside bacteria, this chapter deals with a series of complicated binaries. These binaries are often used to encounter and interpret the world around us, starting with the binary of sex/gender. I then move to the binaries of biology/culture and matter/language. These binaries have troubled, and have been troubled by, feminist scholars working in a number of different fields of expertise and, as it turns out, bacteria have played an important role in this work. Bacteria have served as key actors not only in molecular biology research and genetic engineering but also in the growth and development of feminist theory.

First the chapter looks at some specific outcomes of feminist projects that have utilized the sex/gender binary to advance molar projects such as the participation of women and marginalized groups in science. Although diversity in science, technology, engineering, and math (STEM)

fields remains a key issue for feminism, the deployment of the sex/gender binary through molar projects that have been based on liberal/equal rights feminist frameworks in science have, for better or for worse, bolstered binarized sex differences research and produced new areas of scientific research including the field of "gender biology." After demonstrating how the sex/gender binary has been incorporated into scientific analysis, I discuss why some feminist scholars have attempted to move beyond a molar and binary view of sex and gender. Importantly, they have also attempted to completely reframe how it is that we think about the terms "sex" and "gender" in the first place and, as a result, how we think about other related binary oppositions.

Next, the chapter extends these reflections on sex and gender to the relationship between biology and culture as well as matter and language. It takes a generational feminist approach by reviewing key contributions made by feminist poststructuralist accounts of matter and the body, then turning to more recent feminist materialist critiques of these poststructuralist contributions. Recent feminist and materialist scholarship attempts to recover from the purported split between sex and gender that was promoted by second-wave feminism. This has produced important insights for some feminists, particularly those trained and housed in cultural theory, to make their way back to thinking about biology, matter, and language. After several decades of theorizing a firm distinction between sex (read as biology) and gender (read as culture), particularly in English-speaking feminisms, many feminists are now finding the analytical tools of scientific research and feminist STS particularly useful in navigating a path back to sex, biology, and matter. Many are making this return by paying close attention to the complexities of biological processes.

The chapter ends by charting this "material turn" as it has played out specifically in the context of bacteria. I attempt to think more closely with bacterial lives. How can *biophilosophies of becoming* and *microphysiologies of desire* help us to know bacteria and therefore the world within us and around us otherwise? How should new connections and kinships with bacteria be understood in an era where recent advances in molecular biology have led us to the creations of synthetic biology and to genome editing technologies such as CRISPR-Cas9? If we return to a crucial feature of molecular feminisms, we are reminded that all ontological and ethical

gestures, including biophilosophies of becoming and microphysiologies of desire, must be held to some kind of contextual accountability, which is different from enacting a transcendent mode of responsibility. Therefore, within this new era of molecular technologies, I suggest that we see bacteria and bacterial skills as events that can be reframed and understood through postcolonial and decolonial haecceities. It is clear, for instance, that these molecular technologies rely on bacteria as raw sources of labor in the production of new forms of biocapital. Similar to feminist STS, postcolonial and decolonial STS frameworks are rooted in social justice epistemologies. These approaches insist that our relationships with the matter and materiality of organisms such as bacteria are not just peripheral to science but are in fact constitutive of the histories, presents, and futures of scientific knowledge production. They remind us how important it is to think through both the molar and the molecular.

More Than "Add Women and Stir"

During the 1970s and 1980s in the United States, women's rights activists mobilized to raise national awareness of gender discrimination in all aspects of life, public and private. Some of these activists documented and sought to redress the systematic underrepresentation of women in academic, business, political, religious, scientific, and technological careers. Motivated by calls for inclusion from the women's movement and from members of Congress, government agencies such as the National Science Foundation (NSF) began collecting data documenting the underrepresentation of women and minorities in STEM fields.[16] Within a decade the NSF moved from tracking the number of women and minorities working in STEM fields in 1991 to implementing a grants program in 2001. This program—named Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers (or ADVANCE)—was primarily aimed to "develop a more diverse science and engineering workforce."[17] According to the goals of ADVANCE, science itself did not need to change; it simply required a more diverse workforce.

Proponents of more inclusive science noted not only the absence of women as practicing scientists but also their exclusion from clinical trials. Again, in response to activist agitation and a congressional mandate, in 1994 the National Institutes of Health (NIH) issued a policy and created

specific guidelines for the inclusion of women and minorities as subjects in clinical research involving humans.[18] Although the premise was that science itself did not have to change, the "add women and stir" approach in clinical settings pressed scientists to rethink their assumption that the adult male body was the norm on the basis of which all other bodies should be measured. Consider, for example, the announcement made in 2013 by the Food and Drug Administration (FDA) that zolpidem, the active agent in many sleep aids including Ambien, is metabolized differently in women than in men and that in women there is an increased risk of "next-morning impairment for activities that require complete mental alertness, including driving."[19]

To offset that risk, the FDA recommended that the "dose of zolpidem for women should be lowered from 10 mg to 5 mg for immediate release products (Ambien, Edluar, and Zolpimist) and from 12.5 mg to 6.25 mg for extended-release products (Ambien CR)."[20] Although the biological and molecular mechanisms for this difference in zolpidem drug processing are still not known, it turns out that the FDA did know back in 1992 that there was, as they say, an "effect of gender" when they conducted the clinical trials of zolpidem.[21] However, since the NIH policy regarding the inclusion of women was not implemented until 1994, scientists working on zolpidem apparently did not know what to do with this information regarding the effect of gender. Had scientists included women in clinical trials from the get-go and decided to learn about the causes behind the effects of gender that they observed in pharmaceutical research, years of overdosage in women could have been prevented. As this makes clear, the absence or disregard of women from most clinical trials has been problematic, not only for the health of women but also for the adequacy of scientific assumptions and the validity of scientific findings. Despite growing evidence of the importance of including diverse populations in scientific research, the most basic lab science involving animal research continues to use only the cells, tissues, organs, and bodies derived from males.

To address this deficiency, in May 2014 the NIH unveiled a new policy to ensure that preclinical research was sex-balanced by including female animals and cell lines obtained from females.[22] For some feminist scholars, however, simply including more women or female animals in biomedical research is equally problematic.[23] For it is often not known whether different results, which appear to be related to sex or gender, might be caused

by an intervening variable. In the zolpidem case, the difference may have more to do with variations in height or body weight rather than with sex alone. Many feminists have even questioned how it is that scientists think they can go about isolating sex as such within a body, when it is not at all clear whether sex is even a factor that has a discrete biological location.[24] For example, is sex a genetic property that is easily identified through one's chromosomes? Or is it a factor that is located in the cells, hormones, genitalia, tertiary physical characteristics, or some combination of these locations?[25] Thus, for many of these scholars, a presumption of sex difference may be as troubling for scientific investigation as the absence of diverse populations from scientific research.

In light of such vexing questions, in 2009 a research team led by Londa Schiebinger created the web-based resource, *Gendered Innovations in Science, Health and Medicine, Engineering and Environment*. Jointly sponsored by Stanford University, the NSF, and the European Commission, this resource seeks to transform the inclusion question from an additive model to a more sophisticated deployment of sex and gender as analytical categories in research design to produce new discoveries. According to *Gendered Innovations*, project goals are to develop "practical methods of sex and gender analysis for scientists and engineers" and to provide "case studies as concrete illustrations of how sex and gender analysis leads to innovation."[26] The project explicitly seeks to move researchers beyond thinking about the category "women" as a "subgroup" of scientists who can diversify the workforce or as an additional variable to be inserted into an existing experimental protocol. The site pays particular attention to presenting feminist epistemologies and methodologies in science in an accessible manner for the scientific expert who is not trained as, or inclined to identify as, a feminist researcher.

In addition to providing examples of practical methods and case studies, the project defines key terms, including sex and gender, introducing feminist concepts to scientists who are unfamiliar with feminist scholarship. In keeping with the sex/gender binary, sex is defined as "a biological quality" and gender as "a socio-cultural process." Although these terms are treated as analytically distinct, a section titled "Interactions between Sex and Gender" emphasizes that the terms are not independent of one another: "Sex and gender also interact in important and complex ways. Rarely does an observed difference between men and women involve only

sex and not gender, and rarely does gender operate outside the context of sex. The precise nature of their interaction will vary depending on the research question and on other factors, such as socioeconomic status, or geographic location, interacting with sex and gender."[27]

Perhaps it is this binary distinction, yet an emphasis on interaction that causes scientists, including Margulis, to easily conflate the terms "sex" and "gender." To add to this confusion, there is also the complicated nature of their interaction. As the section "Analyzing How Sex and Gender Interact" on the *Gendered Innovations* website explains:

> "Sex" and "gender" are distinguished for analytical purposes. "Sex" refers to biological qualities, and "gender" refers to socio-cultural processes. In reality, sex and gender interact (mutually shape one another) to form individual bodies, cognitive abilities, and disease patterns, for example. Sex and gender also interact to shape the ways we engineer and design objects, buildings, cities, and infrastructures. Recognizing how gender shapes sex and how sex influences culture is critical to designing quality research. Sex and gender also intersect in important ways with a variety of other social factors, including age, socioeconomic status, ethnicity, geographical location, etc.[28]

The *Gendered Innovations* project represents a committed attempt to work with basic research and industry scientists and to have them seriously consider the epistemological moorings of their scientific research by rethinking research priorities, reformulating research questions, considering participatory research and design methods, rethinking language and visual representations, and more. The suggested revision of bacteriology textbooks to remove "scientifically unsound metaphors that present bacteria as sexed organisms" can be found in a subsection titled "Textbooks: Rethinking Language and Visual Representations."[29] The revision of textbooks is presented as a prime example of a gendered innovation. That this project exists and the website serves as a guide and reference for scientists is an important indication that feminism has indeed worked hard to change the sciences or, at the very least, has much to offer to change how we continue to do science into the future.[30]

This project represents progress. It goes a long way to move scientists beyond the "add women and stir" mind-set and introduces scientists to

the idea of co-production through the categories of sex and gender. Yet we should draw attention to the possible consequences of a gendered innovation that draws such clear binary distinctions between sex and gender and that relies on an interactionist framework. The *Gendered Innovations* chapter epigraph states that bacteria should not be thought of as being sexed organisms. In light of recent work in feminist theory, material feminisms, and feminist STS scholarship, I wish to explore what else it might mean to say that bacteria are sexed organisms and what else bacteria might have to teach us so that we can think more robustly about sex.

Conjugating Sex and Gender

Not without good reason, the *Gendered Innovations* project relies on a clean ontological distinction between sex and gender. However, encouraging scientists to consider sex and gender as distinct categories, even if an interactionist framework is added to their analysis, creates a new set of quandaries. For instance, feminist, queer, and postcolonial critiques of "inclusion-politics" have stressed that although no one would want women or other minority groups to be excluded from biomedical and technological research, the use of binary and interactionist models of sex and gender in science and medicine could work to further essentialize these identities. Simultaneously, these models do little more than pay lip service to other crucial interacting factors such as race, ethnicity, class, ability, and sexuality.[31] Not to mention, it is also possible that the inclusion of a specific identity-based group such as an ethnic minority through "race-based medicine" may in fact make individuals who identify with this group into new potential targets for profit-motivated pharmaceutical companies.[32]

Turning to biology and physics for alternatives to such binary frameworks, feminist STS scholars have advanced an important critique of "interactionist" approaches. The problem is that rather than troubling the boundaries between sex and gender, interaction presupposes the existence of two separate realms, which then come into contact. The limits of an interactionist frame can be illustrated by emerging research in gender-based medicine or what has also been referred to as "gender biology."[33] In their attempts to investigate how gender interacts with biology, typically understood in terms of a gene or a group of genes that code for or regulate what have been deemed as masculine and feminine traits, scientists often

envision a Venn diagram. In this Venn diagram, biology occupies one sector, gender occupies another sector, and the space of overlap signifies the prospect of potential interactions. Although this limited interactionist framework could be used to help illuminate how gender inequalities (or race or class for that matter) produce biological *effects* such as health disparities in disease distribution and mortality rates, scientists often tend to interpret the model in a far more essentialist mode. The study of gender biology has come to represent an examination of the interaction of biology and culture in a manner that is reminiscent of sociobiology. Relying upon an ontological framework that produces a fixed biology (whether in the form of gene expression or hormones secretion), biological matters once again become the starting point of explaining the *causes* of perceived gender differences.

Philosophers of biology and feminist biologists have theorized alternative models in order to avoid the trap of biological determinism that is so frequently associated with the sex/gender binary system and its accompanying interactionist paradigm. They have turned to developmental systems theory (DST), for example, which offers a framework for understanding biology and development in relation to several major factors, including (1) joint determination by multiple causes, (2) context sensitivity and contingency, (3) extended inheritance, (4) development as construction, (5) distributed control, and (6) evolution as construction.[34] DST conceptualizes organisms beyond familiar binaries such as nature/nurture, genes/environment, and biology/culture. Anne Fausto-Sterling has perhaps been the most vocal champion of this theoretical frame through her work on intersex issues, bones, and more recently gender development in infants.[35] Yet DST also tells a cautionary tale for those who seek to move beyond dualisms by turning to interactionist conclusions. As philosophers of biology Susan Oyama, Paul Griffiths, and Russell Gray have noted:

> The standard response to nature/nurture oppositions is the homily that nowadays everyone is an interactionist: All phenotypes are the joint product of genes and environment. According to one version of this conventional "interactionist" position, the real debate should not be about whether a particular trait is due to nature or nurture, but

> rather how much each "influences" the trait. The nature/nurture debate is thus allegedly resolved in a quantitative fashion. . . . DST rejects the attempt to partition causal responsibility for the formation of organisms into additive components. Such maneuvers do not resolve the nature/nurture debate; they continue it.[36]

In order to avoid this outcome, Karen Barad uses the concept of "intra-action" as a means to move beyond the binary concepts of sex/gender, biology/culture, and matter/language. Advancing what she refers to as an agential realist ontology, Barad suggests that "the primary ontological unit is not independent objects with independently determinate boundaries and properties but rather what Niels Bohr terms 'phenomena.'" As discussed in the previous chapter, Barad advocates this ontological view of phenomena in response to questions of social constructivism, materiality, and more specifically, to feminist and queer reworkings of sex and gender. Intra-action is key to this ontological framework. "The neologism 'intra-action' signifies the mutual constitution of entangled agencies," she explains. "That is, in contrast to the usual 'interaction,' which assumes that there are separate individual agencies that precede their interaction, the notion of intra-action recognizes that distinct agencies do not precede, but rather emerge through, their intra-action."[37] Barad's theorization of intra-action reworks traditional ontological notions of causality and challenges binary relationships. This calls into question the preexistence and fixedness of any entity. Whether the phenomenon under investigation is an atom, a body, an experimental apparatus, a language, a scientific knower, or a collectivity, through their intra-action, each emerges in relation to other entities. Intra-action illuminates a relational ontology that is populated by mutually constituted phenomena.

Working with the categories of sex and gender in science, health, medicine, and engineering, feminist STS scholars do not ignore questions concerning the underrepresentation of women and other minorities in science. However, what has also become clear is that they have moved well beyond the "woman question in science." In 1985, Donna Haraway published "A Manifesto for Cyborgs: Science, Technology and Socialist Feminism in the 1980s," where she problematized essentialisms, including the idea of what it means to be a woman.[38] In 1986, Sandra Harding started

moving us beyond the women in science question by challenging us to consider the science question in feminism.[39] As discussed in chapter 2, Sue Rosser followed up Harding's challenge by calling for more feminists to enter into the sciences and to discover what else we could know about the relationship between science and feminism.[40] As a feminist physicist, Barad responded to this call and used her knowledge and experience of thinking simultaneously with feminism and quantum physics to open up a fresh ontological terrain that troubles the ontological distinctions between sex and gender.

Conjugating Biology and Culture

Feminist STS scholars have identified a host of theoretical and empirical problems that emerge when sex and gender are placed in a binary. For some time now this scholarship has called attention to such unsavory consequences of the uncritical deployment of the sex/gender binary, while also questioning the viability of the biology/culture distinction.[41] Drawing on ontological lessons brought forward by poststructuralist debates, as well as developments in biology and physics, these scholars have argued that biology and culture cannot be easily separated. Laying out a rich genealogy of the role and contribution of intersexuality in our understandings of gender as a concept, David Rubin has summarized trajectories of intersecting work on intersex, biomedicine, and feminism. "Biological processes are not exterior to culture," he states. Rather than suggesting that the two simply interact, Rubin's survey on decades of feminist, queer, and intersex scholarship indicates that the category of "sex cannot be definitively disentangled from gender" (i.e., a Venn diagram might not work).[42]

This ambiguity between the categories of sex and gender, as well as biology and culture, has been quite troublesome but also productive for feminist scholarship. In *Gender Trouble*, Judith Butler posed a series of far-reaching questions:

> Can we refer to a "given" sex or a "given" gender without first inquiring into how sex and/or gender is given, through what means? And 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? . . . Are the ostensibly natural facts of sex discursively produced by various scientific discourses in the service of other political social interests? If the immutable character of sex is contested, perhaps this construct called "sex" is as culturally constructed as gender; indeed, perhaps it was always already gender, with the consequence that the distinction between sex and gender turns out to be no distinction at all.[43]

Putting aside for a moment the crucial ontological disruptions of sex and gender that Butler proposes here, she also raises the important question of how a feminist critic is to "assess the scientific discourses which purport to establish such 'facts' for us."[44]

Since Butler posed this question in 1990, the field of feminist STS has flourished. To be a feminist critic today does not automatically disqualify one from also being an informed scientist and/or feminist STS scholar who is able to knowledgably "assess the scientific discourses" and the facts that they "purport to establish." Much of this increased participation with the sciences is of course directly due to the efforts made by those molar projects in early feminist science studies that were dedicated to increasing the number of women and feminists in the sciences. Those efforts may have directly fed into the work produced by several feminists who went on to train in the sciences such as Barad. Interestingly, their grasp of scientific knowledge and intimate exposures to scientific practices have given rise to a subsequent generation of feminist scholars who can now attempt to answer Butler's questions regarding our treatment of sex. The next section highlights the work of two feminist scholars, Luciana Parisi and Myra Hird, who have done just this. Working closely with Lynn Margulis's work, both of these feminist scholars have used their exposure to bacteriology and the details of scientific research and practices to produce new insights for feminism. It is clear that feminists now have the tools to consider the question of whether sex is natural, anatomical, chromosomal, or hormonal, or whether the natural facts of sex are discursively produced. The answer of course is that it is all of these.

After more than three decades of critical engagement, feminist scientists and feminist STS scholars have learned a great deal about the scientific and biological treatments of the categories of sex and gender.[45] Many would agree that the use and understanding of the category "sex" in the

discourses of the sciences remains complicated and highly nuanced, but that more often than not, sex (1) is treated as a given or as an ontologically fixed category; (2) is still either conflated with gender; and/or (3) is placed into a binary and interactionist relationship with gender (as seen in the *Gendered Innovations* project). This does not mean that feminist critics, who are qualified and able to rigorously assess the scientific discourses, wish to entirely dismiss the work of the biological sciences or sex differences research for that matter. For instance, Angie Willey has introduced the term "biopossibility" as "a species- and context-specific capacity to embody socially meaningful traits or desires," as well as "a tool for naturecultural thinking."[46] What scholars such as Willey, Rubin, and other feminist and queer STS scholars are interested in doing is challenging the supposed "immutable character of sex."[47] They do so not only by showing how cultural ideals and language play a role in shaping our understanding of biology and matter, but also by recognizing the contributions that biological matters make in shaping our cultural expressions and grasp of what we come to know as sex.

Thinking with biophilosophies of becoming, we can begin to see that biology and biological processes need not be essentializing for feminists. Importantly, however, such ontological and ethical gestures should not distract us from also examining the "political and social interests" that shape the sciences and our scientific discourses of sex.[48] As Rubin has stated, we understand that sex and gender are both associated with a biological materiality and cannot be definitively disentangled from each other or from culture. The question now is, How do we begin to reframe sex?

A Thousand Tiny Bacterial Sexes

In *A Thousand Plateaus*, Deleuze and Guattari discuss the idea of segmentarity, proposing that it exists principally in two modes—namely, a rigid mode and a supple mode. The rigid mode reflects an arborized state and molar view of segmentarity, whereas the supple mode is rhizomatic, representing openness to the multiplicities of molecular processes. They argue that the "binarities" that form from within supple modes of segmentarity are the result of "multiplicities of *n* dimensions."[49] While describing rigid and supple segmentarities, Deleuze and Guattari state that it is incorrect to simply oppose these modes of segmentarity and that

they too are entangled. I am most interested in how they develop their concept of segmentarity in relation to sex. They state:

> Every society, and every individual, are thus plied by both segmentarities simultaneously: one molar, the other *molecular*. If they are distinct, it is because they do not have the same terms or the same relations or the same nature or even the same type of multiplicity. If they are inseparable, it is because they coexist and cross over into each other. . . . In short, everything is political, but every politics is simultaneously a macropolitics and a micropolitics. . . . If we consider the great binary aggregates, such as the sexes or classes, it is evident that they also cross over into molecular assemblages of a different nature, and that there is a double reciprocal dependency between them. For the two sexes imply a multiplicity of molecular combinations bringing into play not only the man in the woman and the woman in the man, but the relation of each to the animal, the plant, etc.: a thousand tiny sexes.[50]

Elizabeth Grosz quotes these same lines from Deleuze and Guattari in her own theories on the body and in an effort to envision the deterritorialized body without organs (BwO). She is interested in using Deleuze and Guattari's approaches to becoming in order to develop a feminist project of rhizomatics. This project views subjectivity through the lens of molecular becomings and treats the body, above all else, as a corporeal event that is capable of transformation.[51] My intention is similar. By working with bacteria, I wish to better understand how the quality of changefulness is made possible by sex. More specifically, I am interested in what happens to our understandings of sex and gender when we allow them to cross over from molar treatments into the molecular. I am also interested in thinking with bacteria to better understand sex as an event that plays on and emerges from the "multiplicity of molecular combinations."[52]

Extending feminist theories of sex and gender in her book *Volatile Bodies*, Grosz notes that "feminists have exhibited a wide range of attitudes and reactions to conceptions of the body and attempts to position it at the center of political action and theoretical production." Differentiating "sexual difference" approaches from "egalitarian feminism" and "social constructionism," Grosz suggests that such thinkers as Luce Irigaray, Helene Cixous, Gayatri Spivak, and Judith Butler are particularly wary of

the sex/gender distinction. Grosz argues that for these feminists the body is not accepted as a blank biological slate upon which culture or gender is projected. Rather, Grosz explains that feminisms of difference understand the body to be *active*. In contrast to universal notions of essences or categories, she suggests that the body is seen as a "cultural interweaving and production of nature." As such, there are irreducible differences not only between the sexes but also among members of the same sex. Turning to Deleuze to support her reconceptualization of the body, and to reframe the ontological distinctions that have been drawn between biology and culture, Grosz notes that a "Deleuzian framework de-massifies the entities that binary thought counterposes against each other: the subject, the social order, even the natural world are theorized in terms of the microprocesses, a myriad of intensities and flows, with unaligned or unalignable components, which refuse to conform to the requirements of order and organization. . . . Identities and stabilities are not fixed."[53]

The work of Luciana Parisi and Myra Hird offers examples of what we can come to know if we do learn to de-massify the binary that counterposes sex and gender. For some time now feminist STS scholars have questioned the stable ontological moorings associated with binary and categorical notions of sex and gender as well as biology and culture. They have started to elaborate on the idea of processual bodies and, as a result, are looking more closely at the materiality and material contributions made by biological matter. Using bacteria as their guide, both Parisi and Hird have emphasized the importance of understanding bodies and biologies as microprocesses, and sex in particular, as an event comprised of a multiplicity of differences.

In *Abstract Sex: Philosophy, Bio-Technology and the Mutations of Desire*, Parisi argues that in this age of information, cybernetics, and human reproductive technologies such as genetic engineering and cloning, we must reformulate our understandings of sex. In this new era of cybernetic capitalism, she claims, human sex has been separated from so-called "natural" reproduction, further blurring the distinctions we make between natural sex and artificial sex. This blurring further impacts the distinction between the biological and technological as well as between embodiment and disembodiment. Parisi proposes her idea of "abstract sex" as a micropolitical framework that can address this blurring effect and that can work

to integrate three main nonlinear layers within which sex is stratified—namely, the biodigital, the biocultural, and the biophysical. "Instead of re-articulating sex within a post-feminist critical framework where difference is no longer material," Parisi states, "abstract sex extends the feminist politics of desire by mapping the transversal mixing of information between bodies of all sorts (bacteria, vegetables, animals, humans and technical machines). Abstract sex proposes to tap into the kinetic ethology of tiny sexes that lay out a micropolitics of symbiotic relations between different levels of mutation of matter and desire."[54]

Parisi also turns to the work of Margulis, and explicitly to bacteria, emphasizing that sex is ancient and that it emerged as a way for "bacterial cells to repair their DNA damaged by intense solar radiations." As she points out, sex, as a mode of transmission and reproduction of information, is almost as old as the Earth itself. In what can also be interpreted as an unapologetically posthumanist move, Parisi makes it clear that as humans we are embarrassingly new to this Earth compared to bacteria and have very little appreciation of the multiplicities of sex. We live in the "Age of Bacteria," as Parisi emphasizes, and have much to learn from the sex lives and practices of bacteria.[55]

Drawing our attention to the multiplicities of molecular combinations that are present in bacteria, Parisi reminds us that "transgenic sex, the recombination of genetic material from two or more cellular bodies, constitutes the most ancient mode of genetic transfer on the biophysical stratum: bacterial sex."[56] So that we do not mistake this propensity for transfer, change, and multiplicity with life and proliferation alone and forget to associate genetic transfer with death and destruction also, Parisi reminds us of the full range of consequences of the microprocesses of sex by turning our attention to the relationship between viruses and bacteria. She states:

> Viruses attack bacteria and inject their genetic material into the cell. They hijack the bacterial genetic system and start viral replication. The bacterial cell eventually reaches a critical point, a threshold of change by breaking apart, and new viruses, produced by the combination of bacterial and viral genes, will spread into a new bacterium host. Such a virulent sex corresponds to bacterial abilities to trade genes by developing a

> variety of metabolisms—including the use of metals—of which plants and animals have learned to use only few. Bacterial sex not only breeds new genes, but also manipulates the genetic composition of the bacterial body itself. . . . Transgenic sex puts up no resistance to mutations and affords no protection from contagion.[57]

The virology professor from my undergraduate days would be very pleased to see this no-nonsense treatment of virus-bacterial encounters, even though he would probably not be interested or impressed in the slightest by the link made above between viruses, bacteria, transgenic sex, molecular politics, and feminism. I, on the other hand, am absolutely thrilled by Parisi's success at bridging these fields of scholarship, by her smooth mixing of disciplinary vocabularies, and by her ability to steer us directly into the rich complexities and complications that come with thinking about sex otherwise. As should be clearly evident, in response to the query made by Butler in 1990, feminists can indeed trouble the ontological categories of sex and gender and also be informed feminist critics—not only of the humanities and social sciences but also of the biological, physical, and natural sciences.

In a similar show of interdisciplinary expertise, Hird has called for a "bacterial ontology" and "microontologies" to reinvent our understanding of sex and sexual difference.[58] In *Sex, Gender and Science*, Hird turns to bacteria to create a "nonhumanocentric position" and shows that by "paying attention to nonlinear biology it is possible to acknowledge that human bodies, like all living matter, physically actualize sex diversity."[59] As Hird states:

> Our remote ancestors continue to promiscuously exchange genes without getting hung up on sexual reproduction. Bacteria are not picky, and will avidly exchange genes with just about any living organism anywhere in the world, including the human body. Thus bacteria are beyond the false male/female dichotomy of human discourse. Since bacteria recognize and avidly embrace diversity, they do not discriminate on the bases of "sex" differences at all. The bacteria that move freely into and within our bodies are already infinitely "sex" diverse. . . . So in the tired game of identity, I would choose neither goddess nor cyborg. I would rather be a bacterium.[60]

By suggesting that bacteria are infinitely sex diverse, Hird may be in favor of the statement made by *Gendered Innovations* that microbiology textbooks should not represent bacteria as being "sexed" organisms in a binary understanding of the term. After all, the naming of bacteria as male is based on the criteria that males are the "donor" cells that possess a fertility factor (F+) that allows for the extension of a sex pili, which in turn is required for conjugation. Alternatively, female bacterial cells are those recipient cells that lack the fertility factor (F-).

For some, the language and model used to describe bacterial conjugation in this way may resemble the development of male and female sexuality as articulated by psychoanalytic theory and Freud's explanation of the development of normal female sexuality through her lack of a penis and subsequent penis envy. However, Hird's work helps us to see that bacteria do in fact engage in sex, and that we could instead be using a bacterial ontology to reframe how it is that we think about sex. For instance, drawing from the work of Margulis, Deleuze and Guattari, Grosz, Parisi, Hird, and many others, we could be thinking about sex as a process or as an event through the framework of symbiogenesis, rather than as a stable factor that exists within a closed binary. Given the distance that feminist theory and interdisciplinary feminist STS work has come in reframing the sex and gender binary, it would be a shame not to incorporate this thinking into our textbooks. If we can learn to treat sex as a haecceity, as a multiplicity, or as an event, we may even be able to reconcile this fact with the idea that bacteria actually are "sexed" organisms—multiple times, perhaps even a thousand tiny times over.

In addition to drawing our attention to sex diversity in bacteria, Hird highlights the capacity that bacteria have to communicate with each other. In *The Origins of Sociable Life: Evolution after Science Studies*, Hird points to the growth patterns of bacterial colonies and to their collective ability to sense, process information, and regulate gene expression in each individual bacteria through various signaling mechanisms.[61] Describing the processes that bacteria use to communicate changes required for antibiotic resistance, she states, "In other words, bacteria make use of a collective epigenetic memory that can, for instance, track previous encounters with antibiotics: they collectively glean information from the environment, 'talk' with each other, distribute tasks, and convert their colonies into a massive "brain" that processes information, learns from past

experiences, and, we suspect, creates new genes to better cope with novel challenges."[62] This ability to communicate indicates the complexity that is involved in bacterial signaling and it goes without saying that microbiologists and genetic engineers have developed a great interest and appreciation for this capability.

However, Hird also touches upon the difficulty that biologists often experience while trying to avoid anthropomorphizing these bacterial communicative processes.[63] She motions us toward Charles Sanders Peirce's original theory of semiotics and suggests that microbiologists would do well by trying to understand bacterial communication through biosemiotics. "Constituting a theoretical approach or frame," Hird explains, "biosemiotics 'is concerned with the sign aspects of the processes of life itself' gleaned through the relationships between sign, object and interpretant. According to biosemiotics, what organisms sense also has a meaning (food, predator, escape, sexual mate and so on). All organisms are born into a system of signs—a semiosphere—consisting of the totality of movements, odors, colors, chemical signals, touch and so on."[64] Hird raises a very crucial point here. Similar to Parisi, by suggesting that bacteria like all organisms are born into a system of signs, Hird is enacting a critical posthumanist move that works to decentralize the human. By turning to semiotics to explain the communicative behavior of bacteria, Hird is further engaging in a molecular politics that works to include bacteria and other nonhumans as users and participants in the practices of communication, language, and meaning-making.

What I find interesting here is that even while making this radical and immanent gesture, Hird herself is cautious about anthropomorphizing the communicative abilities of bacteria. What if while describing the collective epigenetic memory of bacteria, she did not place quotations around the word "talk" and instead merely stated that bacteria talk to each other?[65] If bacteria can indeed communicate, why do we feel the need to hesitate or somehow differentiate between what we do and what they do by saying that they "talk," but that we humans simply talk? In the same vein, can we say that bacteria write or do they only "write"? Questions such as these bring me to the last binary distinction that I wish to analyze in this chapter. What can we come to know differently about the relationship between the material and the semiotic, or between matter and language? The question is not whether bacteria communicate, but rather

how we as humans learn to orient our encounters with bacteria when they communicate.

Conjugating Matter and Language

In *Meeting the Universe Halfway*, Barad lamented the following with regards to the relationship between matter and language:

> Language has been granted too much power. The linguistic turn, the semiotic turn, the interpretive turn, the cultural turn: it seems that at every turn lately every "thing"—even materiality—is turned into a matter of language or some other form of cultural representation. The ubiquitous puns on "matter" do not, alas, mark a rethinking of the key concepts (materiality and signification) and the relationship between them. Rather, they seem to be symptomatic of the extent to which matters of "fact" (so to speak) have been replaced with matters of signification (no scare quotes here). Language matters. Discourse matters. Culture matters. There is an important sense in which the only thing that doesn't seem to matter anymore is matter.[66]

I have often wondered about the audience that Barad was targeting when she wrote that statement. Likely, she was appealing to feminist theorists influenced by poststructuralism and cultural studies, or radical social constructivists who, at least since the days of the science wars if not before then, have been attempting to confront and unravel several binaries including that between matter and language.

I have also wondered if scientists working in a lab—a biology lab, for example—who may be ideal users for the *Gendered Innovations* website, would lament over the status of matter in the same way that Barad does. Would they say that matter doesn't matter any longer when they are setting up their experiments to work with animals, when they are killing animals, harvesting tissues, incubating cells, or isolating DNA and proteins? I don't think so. When the scale, space, and timeline of animals' sleep and wake cycles, hormone pulsatility, or peaks in protein synthesis dictate your daily activities as a scientist in a biology wet lab, it is "matter" and not language that seems to have been granted more power. In fact, this is precisely why in the *Gendered Innovations* epigraph, a reverse

warning is put into place. Scientists who get their hands dirty with tissues, cells, molecules, and other physical properties of matter on a daily basis have to actually be reminded that language and representations matter. Indeed, some days as an interdisciplinary scholar with one foot in the humanities and the other in the biological sciences, the constant back and forth I experience while trying to deal with the binaries that are drawn between matter and language (or between matter and text) is enough to give me whiplash.

In their book *New Materialism: Interviews and Cartographies*, Rick Dolphijn and Iris van der Tuin describe new materialism as a new metaphysics, which reinterprets previous work and creates a "new tradition" that alters understandings of the past, present, and future. Characterizing new materialism as a "transversal" cultural theory, they suggest that it "does not privilege matter over text or culture over biology. It explores a monist perspective, devoid of the dualisms that have dominated the humanities (and sciences) until today, by giving special attention to matter, which has been so neglected by dualist thought." Although I would argue that matter has not been neglected in all forms of dualist thought, I am drawn to the ontological univocity that is implied with such a transversal theory. Claiming to provide an "immanent answer to transcendental humanism," new materialists are intent on disassembling powerful dualisms (including sex and gender) to "do justice to the 'material-semiotic' or 'material-discursive' character of all events."[67]

Multiple strands of feminist theory contribute to the new materialisms. Feminist philosopher van der Tuin situates new materialism in relation to older forms of feminist materialisms that championed monism and vitalism. Positioning new materialisms as "the inheritor of feminist standpoint theory," she traces continuities in feminist epistemological debates and philosophical engagements with materiality including historical materialism.[68] The term "new materialism" or "neo-materialism" has been credited to Rosi Braidotti, whose work on posthumanism and feminist theories of subjectivity provides a basis for a new materialist thinking.[69] New materialism also traces its origin to Haraway's conceptualization of the material-semiotic.[70]

Despite these long trajectories, it could be argued that recent scholarship under the name of feminist new materialism also grows out of cultural theory's more recent engagement with decades of work in feminist

STS. In fact, the material turn, as conceived in relation to poststructuralism and cultural theory, stems from a very specific conversation within feminist theory. The particular conversation I am referring to here is the one that supposedly privileged postmodern constructivism and the significance of language to such an extent that matter itself appeared to be discursively constituted. Judith Butler's work is often taken as emblematic of feminist theory's "flight from nature" or indeed its "failed materiality.[71] Criticizing the preoccupation with the discursive elements of bodies and power, material feminists as well as feminist new materialists have sought to mitigate the influence of poststructuralism's linguistic idealism on feminist theory and have turned in many cases to the "hard" sciences in an effort to get closer to matter.[72] In her efforts to illuminate the cultural and constructed aspects of "sex," Butler suggests that the body cannot be known outside of inscription or discourse. "To posit by way of language a materiality outside of language is still to posit that materiality," she famously wrote, "and the materiality so posited will retain that positing as its constitutive condition."[73] Critics have claimed that Butler's refusal of any distinction between sex and gender precludes the possibility of material expressions of and by the body.[74]

Correctly or incorrectly, many feminist new materialists have interpreted this emphasis on language, or on text, as an inherent inability to think about matter—whether that matter is coded as sex, biology, atoms, or nature. Although Butler's work has served as fertile ground for this criticism, several European feminist scholars have suggested that her work is emblematic of a larger problematic characteristic of a dominant strand of US feminist theory. Articulating a Eurocentric approach to new materialism, Braidotti, for example, has advanced a "friendly but firm criticism of American hegemony in feminist theory, . . . attempt[ing] to develop other perspectives, drawn from historical and situated European traditions."[75] Braidotti and other European new materialists point specifically to misleading interpretations of Simone de Beauvoir's work on sex, gender, and sexual difference spurred by Butler's article "Sex and Gender in Simone de Beauvoir's Second Sex."[76] In contrast to Beauvoir's complex account, critics have charged Butler with installing "a strict dualism" by overemphasizing the sex/gender split and attributing to Beauvoir "an oversimplified idea of language."[77] European new materialists seek to rescue Beauvoir's work by foregrounding the undecidability of sexual difference

in her works and by promoting her ideas of "sexual differing" and a "performative understanding of ontology."[78]

Vicky Kirby has also raised a number of critical challenges for feminist theory through her close readings of Butler's analyses of nature/culture, discursive ontology, and conceptions of materiality. Turning Butler's proposition that sex is "always already gender" on its head, Kirby asks the risky question, "What if culture was really nature all along?" She explores the possibility that signs are "substantively or ontologically material."[79] In a piece that can be found in several places, Kirby shares an exchange that she had with Butler that pushes up against questions of language, matter, nature, and biology.[80] In her interview with Butler, Kirby states that she is interested in thinking about what it is that prevents us from considering "signs as substantively or ontologically material."[81] She asks Butler: "In the face of contemporary medical research on the body in genetics, the cognitive sciences (I'm thinking of the similarity between neural-net behavior and Saussurean linguistics), immunology, and so on, there is a serious suggestion that 'life itself' is creative encryption. Does your understanding of language and discourse extend to the workings of biological codes and their apparent intelligence?"[82]

Butler replies:

> I take it that [you] want to know from this question and the earlier one what my engagement with science is. And here the question seems to be: does my view of discourse include "biological codes." I confess to not knowing the literature to which [you] refer. [You] may need to take me through the theory that interests [you] here so that I might more intelligently respond. From my recent exposure to the work of Evelyn Fox-Keller, I would, however, say the following, reiterating what I take [your] view to be. There are models according to which we might try to understand biology, and models by which we might try to understand how genes function. And in some cases the models are taken to be inherent to the phenomena that is being explained. Thus, Fox-Keller has argued that certain computer models used to explain gene sequencing in the fruit fly have recently come to be accepted as intrinsic to the gene itself. I worry that a notion like "biological code," on the face of it, runs the risk of that sort of conflation. I am sure that encryption can be used

> as a metaphor or model by which to understand biological processes, especially cell reproduction, but do we then make the move to render what is useful as an explanatory model into the ontology of biology itself? This worries me, especially when it is mechanistic models which lay discursive claims on biological life. What of life exceeds the model? When does the discourse claim to become the very life it purports to explain? I am not sure it is possible to say "life itself" is creative encryption unless we make the mistake of thinking that the model is the ontology of life. Indeed, we might need to think first about the relation of any definition of life to life itself, and whether it must, by virtue of its very task, fail.[83]

Kirby has followed up, in later reiterations of this exchange, by adding more background to the question she originally posed to Butler. Referring to the workings of "biological codes" and their intelligence, Kirby states: "On this last point, I was thinking of the code-cracking and encryption capacities of bacteria as they decipher the chemistry of antibiotic data and reinvent themselves accordingly. Aren't these language skills?"[84] In another reference to this interview, Kirby elaborates the point further by explaining:

> In a bid to illuminate why Butler's manoeuver will authorize the iteration of the problem she so carefully unpacks for us, namely, that ~~Nature~~ (now under erasure) is incapable of cognizing or reinventing itself, I asked her to consider a rather simple phenomenon. My question directly relates to the theme of this issues' problematic, namely, how to engage with science and its "objects." I was thinking about the cryptographic skills of bacteria as they decipher the chemistry of antibiotic data and reinvent themselves accordingly. When ciphering skills are exhibited by boffins such as Alan Turing of Enigma Code fame, Steve Wozniak, cofounder of Apple Computer, or the infamous "black hat" hacker in the nineties, Kevin Mitnick, we interpret this capacity for abstract thinking as an exemplary instance of intelligent reasoning. Although we are unlikely to describe the growing number of superbugs in terms of these same special talents, it could nevertheless be suggested that these single-celled microorganisms with no nucleus (or "head") have actually outsmarted their human interlocutors.[85]

No matter how many times I read it, I will be honest and admit that even with my undergraduate training in microbiology and graduate and postgraduate work in molecular biology, I struggle to grasp what Kirby means by the ability of bacteria to "decipher the chemistry of antibiotic data." I consider myself somewhat fluent in the characteristics and functions of bacteria that can be found in any standard microbiology or bacteriology textbook. I am also familiar with the processes by which antibiotics target peptidoglycan synthesis to break down bacterial cell walls.[86] I am aware that bacteria have several mechanisms for developing resistance to antibiotics including the modification of protein structures that interfere with antibiotic carriage into the cell, that there are changes that occur in bacterial genomes that can cause antibiotic resistance by spontaneous mutation, and that these beneficial mutations can be passed through both horizontal and vertical genetic exchange.[87] Yet, without a single reference to the vast scientific literature on bacterial resistance to antibiotics, what Kirby means by "the chemistry of antibiotic data" (which was meant to further clarify her original question to Butler) remains unclear to me.

Despite this lack of scientific clarity, I am convinced that Kirby is doing vital work by suggesting that life itself is creative encryption and by calling our attention to the capabilities of bacteria and the intelligence behind their biological codes.[88] By asking whether the skills that bacteria have are language skills, Kirby is attempting to use scientific knowledge to contribute to the evolution of key concepts in feminist theory that are grounded in the sex/gender binary. She is trying to force a particular audience of feminist theorists who have been trapped in a transcendent humanistic frame, and who have moved away from directly addressing questions of biological and physical matters, into rethinking their approach to matter. Following Jacques Derrida, Kirby forces the question of whether a distinction can be made at all between matter and language, matter and text, and matter and writing (writing understood here in a broad sense).

Interestingly, in order to support this posthumanist effort to acknowledge the communicative capacities of nonhumans, and to consider life itself as a text, Kirby compares two contrasting interpretations of Derrida's claim that "there is no outside of text."[89] The first interpretation reflects the view of many critics of poststructuralism who assert that "we are caught in an endless slide of referral that leads from one signifier

to another signifier, one meaning to yet another meaning, in a vertiginous spiral of implication that never quite arrives at its destination. As a consequence, we can never retreat or advance to some natural, prediscursive, or extratextual space in order to test the truth or adequacy of our representations because, as we have seen, intelligibility is reckoned through such systems."[90]

As an alternative interpretation, Kirby appeals to Derrida's claim "there is no outside of text" rather as an attempt to grasp "the worlding of the world" by thinking about writing in a more general sense. She argues that "'writing in the general sense' articulates a *differential* of space/time, an inseparability between representation and substance that rewrites causality. It is as if the very tissue of substance, the ground of Being, is this mutable intertext—a 'writing' that both circumscribes and exceeds the conventional divisions of nature and culture. If we translate this into what is normally regarded as the matter of the body, then, following Derrida, 'the most elementary processes within the living cell' are also a 'writing' and one whose 'system' is never closed."[91] Thus Kirby makes a compelling case that cells write and that "it is in 'the nature of Nature' to write, to read and to model."[92] The ontological openness of this stance, treating writing as a process that exceeds the divisions of nature and culture, accommodates feminist theories such as Haraway's conception of naturecultures and Braidotti's accounts of posthumanism that have also had formative impacts on the field of feminist STS.[93] In my estimation, thinking about the communicative capacities of bacteria via their writing skills has several hallmarks of being a project for molecular feminisms.

Thanks to my years in the lab and to experiences of "engaging with science and its 'objects'" such as neurons and microorganisms including bacteria, I am also absolutely on board with the idea that bacteria have special talents, including the ability to write, and not just "write." I am persuaded not only by Kirby's posthumanist gesture to extend capacities for language to nonhumans but also by her idea of seeing language, writing, and text itself as life. In fact, in chapter 5, I go one step further and extend these capacities to a concept of life that is not reduced to the organism or to the organic.[94] I am more than willing to go here with Kirby. However, I suggest that if we want to consider her claim of bacterial writing through biophilosophies of becoming and microphysiologies of desire, we must begin to connect such an ontological gesture to an applied ethics of matter.

The Microprocesses of Bacterial Ethics

As Nancy Tuana has stated, "It is easier to posit an ontology than to practice it."[95] Saying that bacteria write is important, but our work does not end here. The challenge lies in learning how to identify and appreciate the material consequences that accompany such an ontological position. At its best, feminist STS is immersed in analyzing the practices of and data generated by specific sciences, along a wide array of different scales. In fact, the richness and credibility of STS itself depends on developing systematic knowledge of the minute details of specific fields in the sciences while also keeping an eye on the larger organizational, institutional, and political structures associated with the circulation of power. Many of the scholars who engage more closely with the sciences are keenly aware that there are material consequences of our particular ontological conceptions of the material world, which have profound implications for species other than our own. As Stacy Alaimo and Susan Hekman poignantly state in their introduction to *Material Feminisms*:

> Redefining the human and nonhuman has ethical implications: discourses have material consequences that require ethical responses. Ethics must be centered not only on those discourses but on the material consequences as well. . . . A material ethics entails . . . that we can compare the very real material consequences of ethical positions and draw conclusions from those comparisons. We can, for example, argue that the material consequences of one ethics is more conducive to human and nonhuman flourishing than that of another. Furthermore, material ethics allows us to shift the focus from ethical principles to ethical practices. Practices are, by nature, embodied, situated actions. Ethical practices, which unfold in time and take place in particular contexts, invite the recognition of and response to expected as well as unexpected material phenomenon. Particular ethical practices, situated both temporally and physically, may also allow for an openness to the needs, the significance, and the liveliness of the more-than-human world.[96]

With this emphasis on considering the needs and liveliness of the more-than-human world, let us return to the ontological status of bacteria that write and to possible microphysiologies of desire that can serve as an

applied ethics of matter as we go forward. What happens when a notion of language is extended to Nature? How do we begin to encounter this Nature? How do we encounter bacteria that we now acknowledge as having the capability to write? There are good reasons for recognizing that bacteria have special talents, of which writing may be one. However, as Alaimo and Hekman suggest, the statement Kirby makes, that "it is in 'the nature of Nature' to write, to read and to model," has ethical implications, precisely because it redefines the human as well as the nonhuman.[97] If it is accepted that Nature writes, reads, and models and that signs are "substantively or ontologically material," we should also be equally concerned with the outcomes or consequences of this ontology.[98]

It is one thing to say that bacteria write. It is another to learn how to pay attention to how bacteria write, why they write, and what they are writing. In fact, although Butler's response to Kirby's initial question regarding "life itself" as encryption and the "workings of biological codes" reveals Butler's belief in a materiality but our ultimate inaccessibility to this materiality through language, we must also point out that Kirby does little to address the questions about context that Butler posed back to her during their exchange. It is this emphasis on looking for both specificity as well as keeping an eye on broader contexts that I wish to extend to Kirby's references to the "code-cracking," "encryption capacities," and "cryptographic skills" of bacteria. Perhaps in a way it is an attempt to address Butler's poignant question that she posed to Kirby: namely, "What of life exceeds the model?"[99]

If we turn toward bacteria that write by *feeling around for the organism*, we begin to explore what a bacterial ethics might look like. We might ask, for example, how are bacteria changed, how are labs changed, how are institutions changed, and how are we as human scientists changed when bacteria begin to write? We might ask, for example, if genetic engineers, who think that do-it-yourself (DIY) synthetic biology represents a democratic science, are willing to extend coauthorship and co-ownership not only to other human scientists but also to the bacteria that perform most of the writing and biolabor in synthetic biology. We can begin to see that the model that presents DNA as code has already become the ontology of life. A molecular line of questioning would have us ask whether we are willing to work within this ruin. Are we willing to work with bacterial DNA as code to better understand how bacteria alter their immune systems in

order to help humans fight their own diseases through genome editing? Biologists, geneticists, and bioengineers have long afforded bacteria with the capabilities of writing. They are beyond asking the question of what bacterial writing *is* and are more attuned to the question of what bacterial writing *can do*. In fact, they have built entire disciplines and biotechnologies based on the ontological premise that life, in the form of DNA, is text and that organisms such as bacteria not only write; they also transcribe, translate, and edit. Indeed, the model has long been accepted as the ontology, and although I am aware that this ontology needs to be constantly interrogated, I am also aware that biotechnologies that are based on the writing and editing capabilities of bacteria already exist.

By following our inquiries and engagements with bacteria through microphysiologies of desire, we may begin to ask different kinds of questions regarding these intimate encounters with bacteria. We could begin to ask whether in the specific case of bacteria, writing, reading, and modeling "allow for an openness to the needs, the significance, and the liveliness of the more-than-human world," or whether our acknowledgment of bacterial writing works to support, promote, and benefit only the most humanist of causes?[100] Are we at all concerned with the different genres of bacterial writing that might exist? If we can think about bacterial writing, can we also start to think about bacterial poetry? Or is bacterial writing only valued for its mechanistic appeal?[101] Can we only learn to recognize or appreciate bacterial writing when it serves a mechanistic function such as building antibiotic resistance and interrupting genes that contribute to human diseases, or when it is aligned with militarized or highly gendered skills such as cryptography, hacking, and code-cracking? Does this new ontology ultimately serve as a "reshaping" for "productionist purposes?"[102]

Trying to address the inseparability between representation and substance, Kirby suggests writing as a mutable "intertext." Although I read this mutability as a feature resonating with the molecular capacities for changefulness and nonhuman becomings, I want to keep in mind that biophilosophies of becoming prompt us to examine the specific "contexts" in which such moments of "intertext" occur. To gain more insights into the importance of thinking with bacteria and to better contextualize the worlding of the world through bacterial writing, it is perhaps helpful to return one more time to Derrida. It could be argued that Derrida's phrase written in French, "*il n'y a pas de hors-texte*," is better translated in English

as "there is no outside-text," rather than "there is nothing outside of the text," or Kirby's use of the phrase "there is no outside of text."[103] In his own later work *Limited Inc*, Derrida noted that "the phrase which for some has become a sort of slogan, in general so badly understood, of deconstruction ('there is nothing outside the text' [*il n'y a pas de hors-texte*]), means nothing else: 'there is nothing outside context' or that 'nothing *exists* outside context.'"[104] It could be that Kirby's use of a particular translation of Derrida's phrase has influenced her interpretation of Derrida and where she chooses to turn her thoughts in relation to bacteria, bacterial writing, and the "worlding of the world."

Kirby's ontological intervention in extending language, reading, and writing skills to the nonhuman is crucial. However, in the worlding of the world that biophilosophies of becoming would have us bring forward, context matters. We must realize though that just as one cannot fix the meaning of a text, of course what counts as context also cannot be fixed. It depends on how an event is oriented. The final section of this chapter treats bacterial writing as an event, one that can be reframed and understood through postcolonial and decolonial haecceities. It interrogates the implications that follow when we say that bacteria have the capabilities to write. As Parisi reminds us, we must keep in view the full range of consequences that accompany the microprocesses of becoming, whether we are talking about bacterial sex or bacterial writing. As crucial and productive new ontological approaches evolving out of the interrogations of sex/gender, biology/culture, and matter/language binaries can be, we must remember that they don't exist outside context.

Bacterial Writing as an Event

Postcolonial and decolonial STS work to decolonize relations and practices. While raising the question of whose interests are served by venturing toward new ontological terrains, they emphasize the importance of giving voice to a broader range of knowledge bases as we produce these accounts. Despite all the recent attention to the so-called "material turn," many postcolonial and decolonial scholars recognize that certain bodies—such as people of color, reproductive bodies, disabled bodies, animals, plants and others subjected to colonialism, racism, capitalism, patriarchy, and science—have been inextricably tied to "nature" and never had the

opportunity or the interest to join the so-called feminist "flight from nature."[105] Postcolonial and decolonial STS emphasize that all technologies should be contextualized. In fact, every technology, including bacterial writing, can be thought of as an event that is connected to specific traditions and practices of knowledge production. To decolonize these relations and practices, we can begin by reframing bacterial writing as an event. This event can be placed within postcolonial and decolonial haecceities, which encourage us to consider all technological events in relation to (1) transnational processes of colonialism and imperialism; (2) capitalist practices of production, consumption, and commodification; (3) gendered and raced labor of production and reproduction and the abstraction of this labor; (4) neoliberal forms of individualism and imperialism; and (5) effects of technology on global as well as local scales.

Recent work on the role of bacteria in the new life sciences demonstrates why thinking about bacterial writing as an event is crucial. For instance, in *Biocapital: The Constitution of Postgenomic Life*, Kaushik Sunder Rajan analyzes two important domains of current global consciousness. The first includes the life sciences, which he argues are "increasingly becoming information sciences." The second is capitalism, which he suggests has "defeated alternative economic formations such as socialism or communism and is therefore considered to be the 'natural' political economic formation, not just of our time but of all times." As an STS scholar, Sunder Rajan insists that the life sciences and capitalism are coproduced, stressing that the "life sciences are *overdetermined* by the capitalist political economic structures within which they emerge." He explains: "'Overdetermination' is a term used by Louis Althusser to suggest a *contextual* relationship, but not a *causal* one (Althusser 1969 [1965]). In other words, even if a particular set of political economic formations do not in any direct and simplistic way lead to particular epistemic emergences, they could still disproportionately set the stage within which the latter take shape in particular ways."[106] Sunder Rajan's argument can be read to suggest that to discuss bacteria as writers, readers, and modelers, is to also discuss them in a contextual relationship—one that is structured by the domains of the life sciences and capitalism. Similar to their human, animal, and plant counterparts, in the purview of life sciences, bacteria not only carry information, they *are* information. This particular ontological

formation has influenced epistemic emergences for bacteria. For bacteria the sign does become ontologically material, but as humans it appears that we are only willing to recognize this through bacterial labor.

However attractive it might be to imagine the bacterial capabilities of writing, in the life sciences that are driven by contemporary forms of capitalism, these capabilities are perceived through a highly mechanistic view of life. A view that not just figuratively but literally forces bacteria to write. In the realm of synthetic biology, for example, bacteria such as *Escherichia coli* are being purposely bred for their writing capabilities. This writing consists of transcribing DNA and translating RNA for human interests alone. In one case, students participating in the annual iGEM (the International Genetically Engineered Machine) competition in synthetic biology have designed *E. coli* to produce a wintergreen scent during their exponential growth phase, and a banana scent during their stationary phase to address the olfactory challenge that scientists in molecular biology labs often have to face while working with bacteria. To be clear, it is precisely because of humans, who work in molecular biology labs with bacteria and do not want to be offended by their odor, that bacteria have been forced to rewrite their own genomes. As Sunder Rajan reminds us, even though the political economic formations that have led to genetic engineering technologies themselves may not have caused this event directly, we can begin to see the epistemic climate that these very formations produced, which have led to the design and emergence of banana-scented *E. coli*.

In another bacterial writing event, Melinda Cooper has suggested that the skills of lateral gene transfer through transformation, transduction, and conjugation have made bacteria of utmost interest to humans. This interest goes beyond studying bacteria for the human diseases they cause and for their antibiotic resistance. As Cooper notes, the observed ability of bacterial plasmid exchange and transformations led to the advent of recombinant DNA and genetic engineering technologies in the 1970s. Indeed, synthetic biology (discussed further in chapter 5) is but the latest face of genetic engineering. Instead of combining a single gene of interest into a bacterial plasmid, synthetic biologists have created entirely human-designed genomes of human interest that they have then inserted into "surrogate" bacterial cells. These bacterial cells, created explicitly for their writing capabilities are mass (re)produced in the lab. In her book *Life as*

Surplus: Biotechnology and Capitalism in the Neoliberal Era, Cooper poses the pivotal question, "Where does (re)production end and technical invention begin, when life is put to work at the microbiological or cellular level?"[107] She argues:

> Recombinant DNA (rDNA) differs from previous modes of biological production in a number of ways. First, while microbial biotechnologies such as fermentation are among the oldest recorded instances of biological production, recombinant DNA constitutes the first attempt to mobilize the specific reproductive processes of bacteria as a way of generating new life forms. Moreover, recombinant DNA differs from the industrial mode of plant and animal production in the sense that it mobilizes the transversal processes of bacterial recombination rather than the vertical transmission of genetic information. This is a technique that lends itself to the specific demands of post-Fordian production—flexibility and speed of change—to a degree that was impossible in traditional plant breeding.[108]

Discussing "biological growth" in the context of neoliberal biopolitics, Cooper argues that "neoliberalism reworks the value of life" by "effac(ing) the boundaries between the spheres of production and reproduction, labor and life, the market and living tissues."[109]

In the event that is bacterial writing, it is impossible to isolate and appreciate this skill outside of the political and economic formations of production, reproduction, and labor. It is important to keep in mind that in most cases, once bacteria have performed their tasks of transcription, recombination, or gene editing, they are promptly snuffed out for the valuable proteins they carry inside of them. This is not the high-profile secret life of cryptographers and code-breakers that we would like to imagine. More akin to the value that was assigned to "natives in the jungle" during colonial science, bacterial writing becomes bacterial labor, which is "harnessed and controlled," and "its products managed and turned into profitable use through the imposition of order and predictability."[110]

New ideas, politics, and practices can emerge at the intersections of molecular biology and feminism when we attempt to think with bacteria. By reflecting on what bacteria are capable of doing, we begin to change our understanding of some dominant binary relationships such as sex/

gender, biology/culture, and matter/language. We begin to see that bacterial desires, responses, experimentation, and communication skills such as writing can change how we frame our ontological, epistemological, and ethical questions in the lab. We begin to see the importance of thinking about our technological futures through bacterial lives. We may never come to know bacteria completely, but at least we can try to reframe our encounters with them.