

PART I  
ENTANGLED  
BEGINNINGS

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## INTRODUCTION

# The Science and Ethics of Mattering

Matter and meaning are not separate elements. They are inextricably fused together, and no event, no matter how energetic, can tear them asunder. Even atoms, whose very name, *ατομος* (*atomos*), means “indivisible” or “uncuttable,” can be broken apart. But matter and meaning cannot be dissociated, not by chemical processing, or centrifuge, or nuclear blast. Mattering is simultaneously a matter of substance and significance, most evidently perhaps when it is the nature of matter that is in question, when the smallest parts of matter are found to be capable of exploding deeply entrenched ideas and large cities. Perhaps this is why contemporary physics makes the inescapable entanglement of matters of being, knowing, and doing, of ontology, epistemology, and ethics, of fact and value, so tangible, so poignant.

## SETTING THE SCENE

In September 1941, when Nazi empire building had reached its pinnacle, the German physicist Werner Heisenberg paid a visit to his mentor Niels Bohr in Nazi-occupied Denmark. Bohr, who was of Jewish ancestry, was head of the world-renowned physics institute in Copenhagen that bears his name. Heisenberg, Bohr’s protégé and a leading physicist in his own right, was at that time head of the German effort to produce an atomic bomb. Filled with nationalist pride for his homeland, Heisenberg decided to stay in Germany despite offers from abroad, but by all accounts he was not a Nazi or a Nazi sympathizer. Bohr and Heisenberg were two of the great leaders of the quantum revolution in physics. Their respective interpretations of quantum physics—complementarity and uncertainty—constitute the nucleus of the so-called Copenhagen interpretation of quantum mechanics. The two Nobel laureates had a special bond between them—a relationship described as that between father (Bohr) and son (Heisenberg)—that was broken apart by the events of this inauspicious visit. Although the details of what transpired during their fateful exchange in the autumn of 1941 are still a matter of controversy, it is clear that matters of the gravest consequences, including the prospect of a German atomic bomb, were discussed.<sup>1</sup>

Why did Heisenberg come to Copenhagen? What was he hoping to talk

with Bohr about? What were his intentions? Did Heisenberg hope to find out what Bohr knew about the Allied bomb project? Did he come to warn Bohr about the German project and reassure him that he was doing everything in his power to stall it? Did he want to see if he could convince Bohr to take advantage of their shared status as authorities on atomic physics to convince both sides to abandon their respective projects to build atomic weapons? Did he hope to gain some important insight from his mentor about physics or ethics or the relationship between the two?

This question—why Heisenberg went to see Bohr in 1941—is the focal point of a recent Tony Award-winning play that considers the controversy surrounding this fateful meeting. The play doesn't resolve the controversy; on the contrary, the play itself has gotten caught up in its very orbit. In Michael Frayn's play *Copenhagen*, the ghosts of Bohr, Heisenberg, and Bohr's wife, Margrethe, meet at the old Bohr residence to try to reconcile the events of that fateful autumn day. As if working out the details of a problem in atomic physics, Bohr, Heisenberg, and Margrethe make three attempts to calculate Heisenberg's intentions, by enacting and at times stopping to reflect on three possible scenarios of what might have occurred. Each attempt to resolve the uncertainty is foiled. But that is precisely the point Frayn wishes to make: drawing an analogy with Heisenberg's uncertainty principle, Frayn suggests that the question of why Heisenberg came to Copenhagen in 1941 does not remain unresolved for any practical reason, such as some insufficiency in the historical record that can be straightened out with newfound evidence or some new clarifying insight, but rather is unresolvable in principle because uncertainty is an inherent feature of human thinking, and when all is said and done, no one, not even Heisenberg, understands why he came to Copenhagen.

Frayn's uncertainty principle—the one that says that “we can [in theory] never know everything about human thinking”—is not an actual consequence of Heisenberg's uncertainty principle but an invention of the playwright, created purely on the basis of analogy. Frayn is not applying the Heisenberg uncertainty principle—which concerns the limits to our knowledge of the behavior of physical objects, like atoms or electrons—to the problem of what it is possible to know about human behavior; he is simply drawing a parallel. Using this analogy, Frayn moves rapidly from the realm of epistemology (questions about the nature of knowledge) to the domain of morality (questions about values), from the uncertainty of intentionality to the undecidability of moral issues. On the basis of his own uncertainty principle, he reasons, or perhaps moralizes, that because we can never really

know why anyone does what he or she does, moral judgments lose their foundation. We'll never know whether Heisenberg was actively trying to build an atom bomb for Germany or whether he purposely foiled these efforts to prevent Hitler from getting his hands on new weapons of mass destruction. We are placed face-to-face with a question of profound moral significance where nothing less than the fate of humanity was at stake, and uncertainty foils our efforts to assign responsibility—uncertainty saves Heisenberg's tormented soul from the judgments of history. The play thereby raises more specters than it puts to rest.

*Copenhagen* is an engaging, clever, and beautifully written play. It has all the allure of a romance with its bold display of explicit intimacy between science and politics, peppered with the right amount of controversy. It also has its share of critics. While many critics have taken issue with important historical inaccuracies that haunt the play, my focus is on Frayn's portrayal of quantum physics and its philosophical implications, a portrayal, I will argue, that is fraught with difficulties.

Frayn's play serves as a useful counterpoint to what I hope to accomplish in this book. On the surface, the subject matter may appear similar. Questions of science, politics, ethics, and epistemology are among the key concerns taken up in this book. Indeed, quantum physics and its philosophical implications and differences in the approaches of Bohr and Heisenberg figure centrally here as well. But this is where the similarity ends. We diverge in purpose, approach, methodology, genre, style, audience, backgrounds, interests, values, level of accountability to empirical facts, standards of rigor, forms of analysis, modes of argumentation, and conclusions. Crucially, we also sharply diverge in our philosophical starting points and the depth of our respective engagements with the physics and the philosophical issues.

In an important sense, Frayn's viewpoint is more familiar and fits more easily with common-sense notions about the nature of knowing and being than the view I will present here. Frayn presents his audience with a set of binaries—the social and the natural, the macroscopic and the microscopic, the laws of man and the laws of nature, internal states of consciousness and external states of being, intentionality and history, ethics and epistemology, discourse and materiality—and his approach to relating the two sets is to draw analogies across the gap. He also presupposes a metaphysics of individualism for both the micro and macro scales: humans, like atoms, are assumed to be discrete individuals with inherent characteristics (such as intelligence, temperament, and intentional states of mind). And at times he

freely mixes issues of being and knowing, ontology and epistemology, as if they were interchangeable isotopes in a chemical brew.

What, if anything, does quantum physics tell us about the nature of scientific practice and its relationship to ethics? Before this question can be approached, two prior issues must be addressed. First of all, there is an important sense in which the question is not well defined. The interpretative issues in quantum physics (i.e., questions related to what the theory means and how to understand its relationship to the world) are far from settled. When questions about the philosophical implications of quantum physics arise, no definitive answers can be given in the absence of the specification of a particular interpretation. Moreover, public fascination with the subject has been met with a plethora of popular accounts that have sacrificed rigor for the sake of accessibility, entertainment, and, if one is honest, the chance to garner the authority of science to underwrite one's favorite view.<sup>2</sup> As a result the public is primed to accept any old counterintuitive claim as speaking the truth about quantum theory. These factors, taken together, pose serious difficulties for anyone trying to make sense of, let alone answer, this potentially important question. Clearly any serious consideration of this question must begin by disambiguating legitimate issues from fancy and taking a clear stand with respect to the interpretative issues.

Public fascination with quantum physics is probably due in large part to several different factors, including the counterintuitive challenges it poses to the modernist worldview, the fame of the leading personalities who developed and contested the theory (Einstein not least among them), and the profound and world-changing applications quantum physics has wrought (often symbolized in the public imagination, fairly or unfairly, by the development of the atomic bomb). But can it be this factor alone—this public hunger to know about quantum physics—that accounts for the plethora of incorrect, misleading, and otherwise inadequate accounts? What is it about the subject matter of quantum physics that it inspires all the right questions, brings the key issues to the fore, promotes open-mindedness and inquisitiveness, and yet when we gather round to learn its wisdom, the response that we get almost inevitably seems to miss the mark? One is almost tempted to hypothesize an uncertainty relation of sorts that represents a necessary trade-off between relevance and understanding. But this is precisely the kind of analogical thinking that has so often produced unsatisfactory understandings of the relevant issues.

We cannot hope to do justice to this important question—the implications of quantum physics for understanding the relationship between sci-

ence and ethics—on the basis of mere analogies. That’s one important lesson we should understand from the plethora of failed attempts. Frayn’s *Copenhagen* is a case in point. In this sense the play can be used as an important teaching tool. In what follows, I examine the play in some detail to draw some important contrasts and to help set the stage for introducing some of the main themes of this book. This interlude provides a dramatic introduction to some of the relevant historical background, main characters, and key ideas and enables me to highlight some of the important ways in which my approach differs from the more common analogical approaches.

“Does one as a physicist have the moral right to work on the practical exploitation of atomic energy?”<sup>3</sup> Heisenberg’s haunting question to Bohr hangs in the air throughout *Copenhagen*. But for its playwright, Michael Frayn, this moral question is a side issue. The one that really interests him is the metaethical question of how it is possible to make moral judgments at all. Frayn puts it this way: “The moral issues always finally depend on the epistemological one, on the judgment of other people’s motives, because if you can’t have any knowledge of other people’s motives, it’s very difficult to come to any objective moral judgment of their behavior.”<sup>4</sup> But how does this dilemma arise? Why can’t we have any knowledge of other people’s motives and intentions? According to Frayn, the root of the dilemma derives from the analogy he wants to draw with Heisenberg’s uncertainty principle. The Heisenberg uncertainty principle says that there is a necessary limit to what we can simultaneously know about certain pairs of physical quantities, such as the position and momentum of a particle. (The momentum of a particle is related to its velocity; in particular, momentum is mass times velocity.) Frayn suggests that by way of analogy there is a necessary limit to what we can know about mental states (such as thoughts, intentions, and motivations), including our own. But if the goal is to set up an uncertainty principle for people in analogy with the famous one that Heisenberg proposes for particles, and one is committed to doing so with some care, then it does not follow that “we can’t have any knowledge of other people’s motives.”

Let’s look more closely at what Heisenberg’s uncertainty principle says. Heisenberg does not say that we can’t have any knowledge about a particle’s position and momentum; rather, he specifies a trade-off concerning how well we can know both quantities at once: the more we know about a particle’s position, the less we know about its momentum, and vice versa.<sup>5</sup> So if, as Frayn suggests, he is interested in constructing an analogous principle for people that specifies a trade-off between a subject’s actions and the subject’s motivations behind those actions, it would have to say something more

along the lines of: we can't have full knowledge of people's motives and know something about their actions that enact those motives; that is, we can't be fully certain about both a person's actions and what motivated those actions. (Which is not to say that I endorse such a principle. I am simply trying to tidy up the analogy Frayn wants to make.) But the fact that knowledge of motivations is not *prohibited*, but rather *limited*, has enormously important consequences for thinking about the question of moral judgment. Frayn argues that since there is no way in principle to get around the limits of our knowledge, and we are therefore forever blocked from having any knowledge about someone's motives, it is not possible to make any objective moral judgments. However, as we just saw, a more careful way of drawing the analogy does not in fact undermine any and all considerations of moral issues based on knowledge of the motivations behind a subject's actions, as long as those considerations do not require full and complete knowledge but can instead be based on partial understandings.

Now, Frayn is the first to admit that the analogy that he draws is not an exact parallel, but his admission has nothing to do with the crucial fault in his analogical reasoning that we just discussed. Rather, Frayn's concession is of a different sort: he readily acknowledges that he is not making an argument for the limits of moral judgment on the basis of quantum physics. But he does see his play as a means of exploring a parallel epistemic limit for discerning the content of mental states (like thoughts, motives, and intentions). Hence his overstatement of the principled limitation poses a fundamental difficulty that goes to the core issue of the play. But rather than stop here, it is instructive to continue our considerations of Frayn's analogical methodology. Before we examine how Frayn exploits this parallel in the play, it's important to understand what is at stake in the way he frames the issues. (Another specter haunts the play: questions of the playwright's motivations.)

The stakes are these. The controversy about the matter of Heisenberg's intentions in visiting Bohr in Nazi-occupied Copenhagen in 1941 has never been settled. Indeed, the question about why Heisenberg went to visit Bohr during the war is a pivotal clue in a much larger puzzle that history yearns to (re)solve: What role did Heisenberg play as a leading German scientist and head of the Nazi bomb project during World War II? Did Heisenberg, as he claimed after the war, do his best to foil the German bomb project? Or was the actual stumbling block that undermined the German project the fact that Heisenberg had failed to get the physics right, a conclusion drawn by the majority of the physics community? Frayn is clearly sympathetic to Heisenberg's postwar rendering. And Frayn also doesn't hide the fact that his uncertainty principle for psychological states of mind is a means of attempt-



ing to get history to back off from issuing any harsh judgments against Heisenberg. “I find it very difficult to judge people who lived in totalitarian societies,” Frayn says. “You can admire people who acted heroically, but you can’t expect people to behave that way.”<sup>6</sup>

It’s important to note that the play itself generated a considerable amount of controversy, especially following its opening in the United States. Its enthusiastic reception in London notwithstanding, American scientists and historians of science have criticized the play for its gross historical inaccuracies and its far-too-sympathetic portrayal of Heisenberg. Frayn acknowledges that Thomas Powers’s Pulitzer Prize-winning book *Heisenberg’s War: The Secret History of the German Bomb* (1993) was the inspiration for his play. Inspiration is one thing, but when a discredited account forms the primary basis for drawing the outlines and details of a dramatization of an important historical encounter, does the artist not have some obligation to history? What are the moral obligations and responsibilities of the artist? Questions of this nature have been asked of Frayn. But even with the emergence of new historical evidence that flies in the face of Frayn’s reconstruction, he remains resolutely unrepentant. In his responses to his critics, he insists that he doesn’t feel any obligation to hold himself responsible to the historical facts. Perhaps we shouldn’t be surprised, since he claims to have offered a principled argument to absolve Heisenberg from any responsibility to history. (Perhaps Heisenberg does indeed deserve absolution, but Frayn’s argument is that we have no ground to make such a determination.)

Significantly, the journalist Thomas Powers’s rendition is based on the discredited thesis of the Swiss-German journalist Robert Jungk. Initially published in German, Jungk’s reconstruction of the historical events, *Brighter than a Thousand Suns* (German edition, 1956; English edition, 1958), exculpates the German scientists for their involvement in the war effort, Heisenberg foremost among them, and argues that they were secretly engaged in resistance efforts against Hitler. In Powers’s book we find this myth of heroic resistance expanded into a highly embellished “shadow history” of the German atomic bomb project. Significantly, Robert Jungk has publicly repudiated his own thesis. For his part, Jungk admits to having been far too impressed with the personalities involved. Jungk takes his inspiration from a letter Heisenberg sent to him after the war detailing his recollection of the famous 1941 meeting with Bohr. Jungk includes a copy of the letter in his book. He notes that “if one could interpret the content of [the] conversation [between Bohr and Heisenberg] in psychological terms, it would depend on very fine nuances indeed.”<sup>7</sup>

Frayn was clearly impressed by the possibility of considering the “very

fine nuances” in psychological terms, but Bohr was not. Bohr was enraged by Heisenberg’s recasting of the story. Upon encountering the letter in Jungk’s book, Bohr drafted a letter to Heisenberg denouncing his misleading account. But Bohr never sent the letter. Following his death in 1962, the Bohr family discovered several drafts of the letter and deposited them with the Niels Bohr Archive in Copenhagen with instructions to have them sealed until 2012, fifty years after Bohr’s death. Historians could only speculate about Bohr’s version of the encounter. But then, in 2002, the Bohr family agreed to the early release of all documents pertaining to the 1941 visit, including different versions of Bohr’s unsent letter to Heisenberg.<sup>8</sup> The early release was precipitated by public interest in the controversy generated by Frayn’s *Copenhagen*.

What do the documents reveal? In his response to Heisenberg, Bohr makes it clear that he was shocked and dismayed by the news Heisenberg brought to Copenhagen in 1941 “that Germany was participating vigorously in a race to be the first with atomic weapons.” Bohr writes to Heisenberg:

You . . . expressed your definite conviction that Germany would win and that it was therefore quite foolish for us to maintain the hope of a different outcome of the war and to be reticent as regards all German offers of cooperation. I also remember quite clearly our conversation in my room at the Institute, where in vague terms you spoke in a manner that could only give me the firm impression that, under your leadership, everything was being done in Germany to develop atomic weapons and that you said that there was no need to talk about details since you were completely familiar with them and had spent the past two years working more or less exclusively on such preparations. I listened to this without speaking since [a] great matter for mankind was at issue in which, despite our personal friendship, we had to be regarded as representatives of two sides engaged in mortal combat. (Niels Bohr Archive)

And in a draft written in 1962, the year of Bohr’s death, Bohr tells Heisenberg it is “quite incomprehensible to me that you should think that you hinted to me that the German physicists would do all they could to prevent such an application of atomic science,” in direct contradiction of the story Heisenberg tells to Jungk, which is later embellished by Powers.

How does Frayn react to this revelation? He remains steadfast in the face of this crucial addition to the historical record. Frayn has indicated that the release of these important historical documents has had little effect on his thinking about the relevant issues and would not affect any future editions of the play. He admits only one inaccuracy: that he portrays Bohr as having

forgiven Heisenberg too readily.<sup>9</sup> This dismissive stance toward history is completely consistent with Frayn's privileging of psychological ("internal") states over historical ("external") facts throughout the play, a point, as we will see, that reaches a crescendo in the play's final scene. For Frayn, no historical fact can trump psychological uncertainty; we are not accountable to history, in principle.

With this background, let's return to the play and see how Frayn handles the metaethical dilemma he poses. Miming Bohr's propensity for working through physics problems by writing multiple drafts of a paper, Frayn offers his audience three possible scenarios—three complementary "drafts" exploring different points of view—for what occurred during the conversation between Bohr and Heisenberg on the occasion of Heisenberg's visit to Bohr in 1941. The first draft is largely a presentation of Heisenberg's point of view, replete with embellishments compliments of Jungk and Powers. Bohr's wife, Margrethe, is a major figure in the second draft. She represents the informed majority public opinion, consonant with the majority view of the physics community, which rejects Heisenberg's claim to have been consciously working to thwart the German bomb project, and largely sees the failure of the project to be the fortunate result of Heisenberg's failure to appreciate the relatively small amount of fissionable material needed to make a bomb. The third draft is where Frayn's philosophical interests in the play come to the fore.

There are two important elements to the third draft, which delivers the play's conclusions: one brings the analogy between the unknowability of physical states and psychological states to its climax, and the other explores the limits of the analogy. This final draft highlights Frayn's point that we are prohibited, in principle, from knowing our own thoughts, motives, and intentions. The only possibility we have of catching a glimpse of ourselves is through the eyes of another.

*Heisenberg:* And yet how much more difficult still it is to catch the slightest glimpse of what's behind one's eyes. Here I am at the centre of the universe, and yet all I can see are two smiles that don't belong to me. . . .

*Bohr:* I glance at Margrethe, and for a moment I see what she can see and I can't—myself, and the smile vanishing from my face as poor Heisenberg blunders on.

*Heisenberg:* I look at the two of them looking at me, and for a moment I see the third person in the room as clearly as I see them. Their importunate guest, stumbling from one crass and unwelcome thoughtfulness to the next.

*Bohr:* I look at him looking at me, anxiously, pleadingly, urging me back to the old days, and I see what he sees. And yes—now it comes, now it comes—there's someone missing from the room. He sees me. He sees Margrethe. He doesn't see himself.

*Heisenberg:* Two thousand million people in the world, and the one who has to decide their fate is the only one who's always hidden from me. (87)

Just as Margrethe has explained in an earlier scene, on his own, Heisenberg cannot really know why he came to Copenhagen because he doesn't know the contents of his own mind; his own mind is the one bit of the universe he can't see. On the heels of this scene, Heisenberg and Bohr go outdoors for their walk, a chance to have their momentous conversation out of earshot of any bugs planted in Bohr's house by the Gestapo.

*Bohr:* With careful casualness he begins to ask the question he's prepared.

*Heisenberg:* Does one as a physicist have the moral right to work on the practical exploitation of atomic energy?

*Margrethe:* The great collision.

*Bohr:* I stop. He stops . . .

*Margrethe:* This is how they work.

*Heisenberg:* He gazes at me, horrified.

*Margrethe:* Now at last he knows where he is and what he's doing.

There we have it, a moment of knowing: Heisenberg can glimpse his own intentions, but only through the horror Bohr's face reflects as he gazes back at Heisenberg. As soon as this knowing interaction has taken place, Bohr uses the momentum of his anger to fly off into the night. But he stops short. He has an idea for how to get at this issue once and for all. He suggests a thought experiment.

*Bohr:* Let's suppose for a moment that I don't go flying off into the night. Let's see what happens if instead I remember the paternal role I'm supposed to play. If I stop, and control my anger, and turn to him. And ask him why.

*Heisenberg:* Why?

*Bohr:* Why are you confident that it's going to be so reassuringly difficult to build a bomb with [the isotope uranium] 235? Is it because you've done the calculation?

*Heisenberg:* The calculation?

*Bohr:* Of the diffusion in 235. No. It's because you haven't calculated it. You haven't considered calculating it. You hadn't consciously realized there was a calculation to be made.

*Heisenberg:* And of course now I have realized. In fact it wouldn't be that difficult. Let's see . . . Hold on . . .

*Bohr:* And suddenly a very different and very terrible new world begins to take shape . . .

And then (in the productions I've seen) the terrible sound of a shattering bomb blast fills the theater. As the blast subsides, once again a clarification of the issues comes from Margrethe.

*Margrethe:* That was the last and greatest demand that Heisenberg made on his friendship with you. To be understood when he couldn't understand himself. And that was the last and greatest act of friendship for Heisenberg that you performed in return. To leave him misunderstood.

Better for everyone that Heisenberg, like all of us, is shielded from shining a light on all the dark corners of the mind. For if Heisenberg's conscious mind had had access to all its subconscious thoughts, then Hitler might have been in possession of an atomic bomb, and after the dust settled, the world might have found itself in a vastly different geopolitical configuration. A good thing that we have this limitation—it's the uncertainty at the heart of things that saves our weary souls.

*Bohr:* Before we can lay our hands on anything, our life's over.

*Heisenberg:* Before we can glimpse who or what we are, we're gone and laid to dust.

*Bohr:* Settled among all the dust we raised.

*Margrethe:* And sooner or later there will come a time when all our children are laid to dust, and all our children's children.

*Bohr:* When no more decisions, great or small, are ever made again. When there's no more uncertainty, because there's no more knowledge.

*Margrethe:* And when all our eyes are closed, when even our ghosts are gone, what will be left of our beloved world? Our ruined and dishonoured and beloved world?

*Heisenberg:* But in the meanwhile, in this most precious meanwhile, there it is. The trees in Faelled Park. Gammertingen and Biberach and Mindelheim. Our children and our children's children. Preserved, just possibly, by that one short moment in Copenhagen. By some event that will never quite be located or defined. By that final core of uncertainty at the heart of things.

In the end it's because of our humanity—because of our limitations, because we can't ever truly know ourselves—that we survive.

This is how the play ends. But where, you might wonder, does this conclusion leave us with respect to the question of moral judgment and accountability? Frayn makes another important move in the final draft that can perhaps shed further light on this key question. In the final draft, Frayn drives home the point that he sets out to make (at least he speaks about the play as if he knows something of his own intentions): because we can't fully know Heisenberg's intentions, we can't fairly judge him. Ironically, however, Frayn plants his own judgments about Bohr throughout the play. It is Bohr, not Heisenberg, Frayn tells his audience, who wound up working on an atom bomb project that resulted in the deaths of tens of thousands of innocent people (a reference to Bohr's contributions to the U.S. bomb project at Los Alamos following his close escape from the Nazis in 1943).<sup>10</sup> It is Bohr (along with his student John Wheeler) who helped to develop a theory of nuclear fission. Bohr is the one who shot another physicist . . . with a cap pistol. (Only well into the scene do we learn the true nature of the weapon and the fact that it was all part of a playful interchange among colleagues. The cap pistol reappears near the end of the play as Heisenberg suggests that Bohr could have killed him in 1941 if he really thought Heisenberg was busy devising a bomb for Hitler, without even having to directly pull the trigger, by a simple indiscretion that would have tipped off the Gestapo about some detail of their meeting and resulted in Heisenberg being murdered by the Gestapo for treason.) More than once Frayn has us watch Bohr relive an unspeakably horrible moment in his life: Bohr stands aboard a sailing vessel and watches his oldest son drown. What role does this series of repetitions within repetitions play?

*Heisenberg:* Again and again the tiller slams over. Again and again . . .

*Margrethe:* Niels turns his head away . . .

*Bohr:* Christian reaches for the lifebuoy . . .

*Heisenberg:* But about some things even they never speak.

*Bohr:* About some things even we only think.

*Margrethe:* Because there's nothing to be said.

One shudders to think that an author would be willing to wield this deeply painful personal tragedy for the purpose of layering Bohr with every (un-)imaginable kind of life-and-death responsibility, but this unthinkable hypothesis fits all too neatly with the sleight of hand by which Frayn attempts to shift responsibility from Heisenberg to Bohr. Yes, we are told that Bohr was held back from jumping in and going after Christian, but as we watch Bohr's ghost being haunted by the memory over and over again, the terrible

suggestion that some things shouldn't be said floats in the air. Can it be . . . isn't it the case that in the reiteration of the unspeakable, the unspeakable is spoken? And then there are the loving, yet all too facile, denials of Bohr's responsibility by Margrethe, which, of course, only serve to highlight his responsibility.

*Heisenberg:* He [Oppenheimer] said you made a great contribution.

*Bohr:* Spiritual, possibly. Not practical.

*Heisenberg:* Fermi says it was you who worked out how to trigger the Nagasaki bomb.

*Bohr:* I put forward an idea.

*Margrethe:* You're not implying that there's anything that Niels needs to explain or defend?

*Heisenberg:* No one has ever expected him to explain or defend anything. He's a profoundly good man.

All these subcritical pieces, these suggestions of Bohr's guilt planted throughout the play, come to an explosive climax just near the end when Frayn unleashes the idea of a "strange new quantum ethics," proposing its implications for the moral dilemma we are faced with:

*Heisenberg:* Meanwhile you were going on from Sweden to Los Alamos.

*Bohr:* To play my small but helpful part in the deaths of a hundred thousand people.

*Margrethe:* Niels, you did nothing wrong!

*Bohr:* Didn't I?

*Heisenberg:* Of course not. You were a good man, from first to last, and no one could ever say otherwise. Whereas I . . .

*Bohr:* Whereas you, my dear Heisenberg, never managed to contribute to the death of one single solitary person in all your life.

This powerful scene is one that remains imprinted in the minds of many audience members. And it's not surprising that it would: finally there is some resolution—a moral ground to stand on—something definite and concrete to hold onto amid the swirl of ghosts and uncertainties. And so is it any wonder that even though Frayn proceeds to disown this conclusion, audiences leave the play with the impression that if anyone should be held accountable for moral infractions, it is Bohr, not Heisenberg.

Surely Frayn is right to remind the audience that while the play focuses on German efforts to build the bomb, the United States had its own highly organized and well-funded wartime bomb project in the desert of Nevada,

and the collective work at Los Alamos produced two different kinds of bombs—"fat man" (a plutonium-based device) and "thin man" (a bomb based on the fissioning of uranium-235)—and one of each kind was dropped on two cities in Japan, killing tens of thousands of innocent people. (What of the possibility that, whatever the nature of Heisenberg's intentions, his visit to Bohr in 1941 helped accelerate the U.S. bomb project, resulting in the use of atomic weapons against the Japanese before the war's official end?<sup>11</sup> Are things really so cut and dry that the dropping of atomic bombs on Japanese cities implicates Bohr while absolving Heisenberg?) But Frayn doesn't raise the issue to help us confront these relevant historical facts and the moral concerns they raise; rather, he uses it only to turn the tables so that we direct our moral outrage away from Heisenberg.

Frayn doesn't directly endorse this conclusion (at least not in the play).<sup>12</sup> In fact, he accuses audience members who leave with this impression of having made the embarrassing mistake of taking this "faux" conclusion seriously when he was obviously being ironic. Let's take a look at how Frayn (says he) accomplishes this ironic twist. Immediately following the foregoing exchange (where Bohr is held accountable for the deaths of one hundred thousand people, and Heisenberg is judged as innocent), Frayn has Heisenberg explain in an ironic passage that to judge people "strictly in terms of observable quantities" would constitute a strange new quantum ethics. Now, since the audience has been anticipating a new quantum-informed ethics all along and the passage itself involves a rather subtle point about quantum physics (what's this talk about restricting considerations to "observable quantities" all of a sudden?), it's perhaps not surprising that the irony has been lost on many a spectator, including some reviewers.

In other words, the move that Frayn makes to distance himself from the conclusion he throws out as bait to a hungry audience filled with anticipation (a conclusion that fingers Bohr instead of Heisenberg) is this: using irony, Frayn has Heisenberg question the application of a rather subtle aspect of his uncertainty principle (which is neither explained nor raised elsewhere in the play) to the situation of moral judgment. Here's the crucial exchange:

Bohr: Heisenberg, I have to say—if people are to be measured strictly in terms of observable quantities . . .

Heisenberg: Then we should need a strange new quantum ethics.

The physics point that Bohr begins to speak about is that Heisenberg, the historical figure, insisted (according to the positivist tenet) that one



shouldn't presume anything about quantities that are not measurable, indeed that one should restrict all considerations to observable quantities. The way Frayn wields this point is this: if we follow the uncertainty principle, we would conclude that we shouldn't presume *anything* about intentions (since we can't know anything about them) and therefore all we have to base our moral judgments on is our actions. This is what Frayn calls a "strange new quantum ethics." And the cue we are given that this is not the conclusion we should walk away with is Heisenberg's lengthy homily on how if we made judgments only on the basis of actions, then the SS man who didn't shoot him when he had his chance near the war's end would go to heaven (presuming, of course, this was the only moral decision this particular devotee of Hitler faced during the long war). That's it. A bit too quick, perhaps? If Frayn had spelled out this key point more directly, he might have put it this way: we shouldn't rely on "observables"—that is, mere actions stripped of all intentions—to make moral judgments. (Surely you didn't expect that Frayn would have us rely strictly on historical facts about what happened to sort things out?) So where are we now? We can't judge people on either their intentions or their actions. Is there anything we can hold on to as the play ends and we gather up our belongings to leave the theater?

Frayn ends the play by presuming to help us take solace in the fact that uncertainty is not our undoing but our savior: it is the very unknowability of intentions, that is, our principled inability to truly judge one another, that saves our weary souls. This final conclusion—the "real conclusion"—harkens back to the earlier scene when Bohr turns around and helps Heisenberg to bring his unconscious intentions to light with the apocalyptic result that Heisenberg does the calculation and Hitler winds up with atomic weapons. Better that we don't know.

And so in the end, after a whirlwind of moral questions and uncertainties that surround, inhabit, and haunt the characters and the audience, we are left only with the slim and rather pat suggestion that the inherent uncertainty of the universe is our one salvation. All our moral searching is abruptly halted, frozen at a moment of time before Armageddon, and left as a mere shadow of itself cast on the wall that denies us access to our own souls. We are left wandering aimlessly through a barren landscape with no markers, no compass, only an empty feeling that quantum theory is somehow at once a manifestation of the mystery that keeps us alive and a cruel joke that deprives us of life's meaning. Given the recent reinvigoration of nuclear weapons programs around the globe, the suggestion that the absence of a moral or ethical ground will inevitably, or could even possibly, forestall the

apocalypse portended by the play's end falls flat, to say the least. But need we follow the reasoning we've been offered into the despair of a moral wasteland laid bare by the explosion of absolute certainty? Is it true that quantum physics envelops us in a cloud of relativist reverie that mushrooms upward toward the heavens and outward encompassing all the earth, leaving us with no remedy, no recourse, no signpost, no exit?

I would argue, on the contrary, that quantum theory leads us out of the morass that takes absolutism and relativism to be the only two possibilities. But understanding how this is so requires a much more nuanced and careful reading of the physics and its philosophical implications than Frayn presents. I first review some of the main difficulties and then proceed to map out an alternative.

As we have seen, by Frayn's own admission, the parallel that he draws between physical and psychological uncertainties is limited and poorly specified. As with many such attempts to discern the implications of quantum mechanics on the basis of mere analogies, the alleged implications that are drawn, such as the assertion that our knowledge of ourselves and of others is necessarily limited, ultimately do not depend in any deep way on understanding the lessons of quantum physics. Surely there is no reason to invoke the complexities of this theory to raise such a conjecture about the limits to human knowledge. (Freud, for one, does not rely on quantum physics for his theory of the unconscious.) It would have been one thing if, for example, we had been offered a more nuanced or revised understanding of the nature of intentionality or causality. But ultimately it seems that such methods (intentionally or otherwise) are only out to garner the authority of science for some theory or proposition that someone wanted to advance anyway and could have advanced without understanding anything at all about quantum physics. (Of course, when the stakes are coming to Heisenberg's rescue, a clever use of the uncertainty principle is perhaps too much to resist.)

Another crucial point that I have yet to discuss is the fact that Frayn continually confuses the epistemological and ontological issues—issues concerning the nature of knowledge and the nature of being. And yet these are central elements in a heated debate between Bohr and Heisenberg concerning the correct interpretation of quantum physics, as I will explain. Before moving on to specify the nature of my own (nonanalogical) approach, I want to explore this issue further, since it entails a key point that is crucial for any project that seeks to understand the wider implications of quantum physics: the fact that there are multiple competing interpretations of quantum mechanics. One point that is particularly relevant for *Copenhagen*

(and for my project) is the fact that there are significant differences between the interpretations of Bohr and Heisenberg. Frayn raises this point in the play but then proceeds to confuse the important differences between them.

Quite unexpectedly, Frayn brings to light the little-known and seldom-acknowledged but crucial historical fact that Heisenberg ultimately acquiesced to Bohr's point of view and made his concession clear in a postscript to the paper on his famous uncertainty principle. And yet, bizarrely, Frayn then proceeds to follow Heisenberg's (self-acknowledged) erroneous interpretation. It is not simply that this is yet one more source of tension between these two giants of the physics world; rather, the point is that there are significant, indeed far-reaching, differences between their interpretations and their respective philosophical implications. The question of what implications follow from *complementarity* (not uncertainty) is a specter that haunts this play. Frayn inexplicably buries the difference without putting it to rest.<sup>13</sup>

Let's take a brief look at some of the crucial issues.

In a key scene in the play, the audience learns about the intense disagreement between Bohr and Heisenberg concerning Heisenberg's uncertainty principle.<sup>14</sup> The nature of the difference between their views is not clearly laid out in the play, but it can be summarized as follows: For Bohr, what is at issue is not that we cannot know both the position and momentum of a particle simultaneously (as Heisenberg initially argued), but rather that particles do not have determinate values of position and momentum simultaneously. While Heisenberg's point—that in measuring any of the characteristics of a particle, we necessarily disturb its premeasurement values, so that the more we know about a particle's position, the less we will know about its momentum (and vice versa)—seems at least believable, Bohr's point is utterly counterintuitive and unfamiliar. In essence, Bohr is making a point about the nature of reality, not merely our knowledge of it. What he is doing is calling into question an entire tradition in the history of Western metaphysics: the belief that the world is populated with individual things with their own independent sets of determinate properties. The lesson that Bohr takes from quantum physics is very deep and profound: there aren't little things wandering aimlessly in the void that possess the complete set of properties that Newtonian physics assumes (e.g., position and momentum); rather, there is something fundamental about the nature of measurement interactions such that, given a particular measuring apparatus, certain properties become determinate, while others are specifically excluded. Which properties become determinate is not governed by the desires or will of the experimenter but rather by the specificity of the experimental apparatus.<sup>15</sup>

Thus there is still an important sense in which experiments can be said to be objective. Significantly, different quantities become determinate using different apparatuses, and it is not possible to have a situation in which all quantities will have definite values at once—some are always excluded. This makes for two “complementary” sets of variables: for any given apparatus, those that are determinate are said to be complementary to those that are indeterminate, and vice versa. Complementary variables require different—mutually exclusive—apparatuses (e.g., one with fixed parts and one with movable parts) for their definition, and therefore these variables are reciprocally determinable (when one is well defined, the other can’t be). (I discuss these issues in detail in chapter 3.) Significantly, as Frayn points out, Heisenberg acquiesced to Bohr’s interpretation: it is complementarity that is at issue, not uncertainty.

With this important difference in mind, it’s hard to resist the temptation to contemplate a new play, a rewriting of Frayn’s *Copenhagen* using Bohr’s complementarity principle rather than Heisenberg’s uncertainty principle as a basis for analysis. I want to be clear that I am not suggesting that the difficulties with Frayn’s play can be rectified by simply substituting one principle for the other and performing the same kind of analogical thought experiment to consider the moral and epistemological issues at hand. But I do want to briefly indulge in this exercise in a limited fashion, recognizing that there is no expectation of providing a rigorous analysis of the important issues at hand simply by making this shift. The point of the exercise is to get a sense of what a more careful consideration of quantum physics and its implications might bring to the surface. In this way we can at least get some feel for *what* philosophical issues are raised and *what* concepts might need to be rethought if we take quantum physics seriously, even though this method may not help us to understand *how* the issues can be resolved and the relevant concepts reconceptualized.

Let’s return to the question of Heisenberg’s intentions in visiting Bohr in the autumn of 1941. Interestingly enough, there is already an important hint in *Copenhagen* that suggests how we might proceed if we want to take Bohr’s complementarity principle as the basis for our analysis. We can zoom in on just the right passage by thinking of Margrethe not “merely” as Bohr’s wife but as an integral part of Bohr (as Bohr says in reference to his partner, “I was formed by nature to be a mathematically curious entity: not one but half of two”).<sup>16</sup>

*Margrethe*: Complementarity again. Yes?

*Bohr*: Yes, yes.

Margrethe: I've typed it out often enough. If you're doing something you have to concentrate on you can't also be thinking about doing it, and if you're thinking about doing it then you can't actually be doing it. Yes?

Ironically, Frayn draws the conclusion from this statement of complementarity (by Margrethe) that doing something and thinking about what you're doing means that Heisenberg doesn't know why he came to Copenhagen in 1941. But, in fact, it (or actually the relevant elaboration of the point) has quite different and much more far-reaching and profound implications. Frayn takes quite a leap here, and we would do well to go more slowly. Suppose that the activity that you're engaged in doing happens to be thinking. Then it follows (from Margrethe's statement of complementarity) that what you are prohibited from doing is both thinking about something and thinking about thinking about it. That is, you can't both think about something and also reflect on your own thinking about the matter. This is because you need to make a choice between two complementary situations: either you think about something, in which case that something is the object of your thoughts, or you examine your process of thinking about something, in which case your thoughts about what you are thinking (about something), and not the something itself, are the object of your thoughts.<sup>17</sup>

Now let's assume that one of the things you're interested in discerning (by attempting to observe your thoughts) is your intentions concerning the thing you're thinking about. We can then deduce that there is a reciprocal or complementary relationship between thinking about something and knowing your intentions (concerning the matter). Now, the implication of this reciprocal relationship we've uncovered is *not*, as Frayn suggests, that we can't know them simultaneously but rather that we can't *have* definite thoughts about something and definite intentions concerning that thing simultaneously. That is, the point is that *there is no determinate fact of the matter* about both our thoughts and our intentions concerning the object of our thoughts. What we learn from this is that the very notion of intentionality needs to be reevaluated. We are used to thinking that there are determinate intentional states of mind that exist "somewhere" in people's brains and that if we are clever enough we can perform some kind of measurement (by using some kind of brain scan, for example) that would disclose the intentions (about some determinate something) that exist in a person's mind. But according to Bohr, we shouldn't rely on the metaphysical presuppositions of classical physics (which Bohr claims is the basis for our common-sense perception of reality); rather, what we need to do is attend to the actual experimental conditions that would enable us to measure and make sense of the notion of intentional states of

mind. In the absence of such conditions, not only is the notion of an “intentional state of mind” meaningless, but there is no corresponding determinate fact of the matter. To summarize, the crucial point is not merely that intentional states are inherently unknowable, but that *the very nature of intentionality needs to be rethought*.

Frayn’s whole play is structured around the attempt to determine Heisenberg’s intentions, as if there were determinate facts of the matter about them at all times. By contrast, Bohr’s point is that the very notion of an intentional state of mind, like all other classical properties, cannot be taken for granted. To speak in a meaningful way about an intentional state of mind, we first need to say what material conditions exist that give it meaning and some definite sense of existence. But what would it mean to specify such conditions? What, for example, would constitute the appropriate set of material conditions for the complex political, psychological, social, scientific, technological, and economic situation that Heisenberg finds himself in, where matters of race, religion, nationality, ethnicity, sexuality, political beliefs, and mental and physical health are material to Nazi thinking? And this is surely an abbreviated list. And what does “material” mean?

Furthermore, with such a complex set of apparatuses at work, we are led to question whether it makes sense to talk about an intentional state of mind as if it were a property of an individual. Let’s return to the play for a brief moment. While Heisenberg struggles to get his point across that he tried desperately to stay in control of the nuclear physics program in Germany and slow down the progress of the development of an atom bomb, Bohr points out that there was an important sense in which he was not in control of the program, but rather the program was controlling him: “Nothing was under anyone’s control by that time!” But if the program is controlling Heisenberg rather than the reverse, what accounts for his intentional states? Whom do they belong to? Is individualism a prerequisite for figuring accountability? Are the notions of intentionality and accountability eviscerated? Despite these fundamental challenges to some of our core concepts, according to (the historical) Bohr, objectivity and accountability need not be renounced. (See especially chapters 3 and 4 for an in-depth discussion of Bohr’s views on objectivity and accountability.)

In summary, the shift from Heisenberg’s interpretation to Bohr’s undermines the very premise of the play. Frayn structures the play around the assumption that moral judgments are tied up with questions of an individual’s intentions. But in Bohr’s account intentionality cannot be taken for granted: intentions are not preexisting determinate mental states of individ-

ual human beings. A sophisticated argument needs to be given here, but this exercise provides an important hint of what a more rigorous analysis may reveal: that attending to the complex material conditions needed to specify “intentions” in a meaningful way prevents us from assuming that “intentions” are (1) preexisting states of mind, and (2) properly assigned to individuals. Perhaps intentionality might better be understood as attributable to a complex network of human and nonhuman agents, including historically specific sets of material conditions that exceed the traditional notion of the individual. Or perhaps it is less that there is an assemblage of agents than there is an entangled state of agencies. These issues, however, cannot be resolved by reasoning analogically; they require a different kind of analysis.

This thought experiment also suggests that moral judgment is not to be based *either* on actions or on intentions alone; rather, the very binary between “interior” and “exterior” states needs to be rethought, and both “internal” and “external” factors—intentionality and history—matter. But this exercise alone does not reveal *how* they matter and *how* they stand in relationship to one another. We learn *what* issues may arise in considering the implications of Bohr’s interpretation, but we need a much more careful, detailed, and rigorous analysis to really get a handle on them. For example, questions of causality are surely significant in coming to terms with these important issues, but further exploration of Bohr’s ideas reveals that the very notion of causality must be reconsidered, since the traditional conception—which presents only the binary options of free will and determinism—is flawed. But if causality is reworked, then power needs to be rethought. (Power relations cannot be understood as either determining or absent of constraints within a corral that merely limits the free choices of individuals.) Agency needs to be rethought. Ethics needs to be rethought. Science needs to be rethought. Indeed, taking Bohr’s interpretation seriously calls for a reworking of the very terms of the question about the relationship between science and ethics. Even beyond that, it undermines the metaphysics of individualism and calls for a rethinking of the very nature of knowledge and being. It may not be too much of an exaggeration to say that every aspect of how we understand the world, including ourselves, is changed.

In summary, this thought experiment only provides us with the briefest glimpse of the momentous changes in our worldview that Bohr’s interpretation of quantum physics entails. It gives us some indication of *what* needs to be rethought, but not a basis for understanding *how* to rethink the relevant issues. Also, reasoning by analogy can easily lead one astray. And furthermore, it posits separate categories of items, analyzes one set in terms of the

other, and thereby necessarily excludes by its own procedures an exploration of the nature of the relationship between them. Indeed, even Bohr erred in trying to understand “the lessons of quantum physics” by drawing analogies between physics and biology or physics and anthropology. Ultimately Bohr was interested not in specifying one-to-one correspondences between these components but in focusing our attention on the conditions for the use of particular concepts so that we do not fall into complacency and take them for granted; but he often lost his way, and he was only able to hint at the implications he sensed were implicit in his work. What is needed to develop a rigorous and robust understanding of the implications of Bohr’s interpretation of quantum physics is a much more careful, detailed, and thorough analysis of his overall philosophy.

In this book I offer a rigorous examination and elaboration of the implications of Bohr’s philosophy-physics (physics and philosophy were one practice for him, not two). I avoid using an analogical methodology; instead, I carefully identify, examine, explicate, and explore the philosophical issues.<sup>18</sup> I am not interested in drawing analogies between particles and people, the micro and the macro, the scientific and the social, nature and culture; rather, I am interested in understanding the epistemological and ontological issues that quantum physics forces us to confront, such as the conditions for the possibility of objectivity, the nature of measurement, the nature of nature and meaning making, and the relationship between discursive practices and the material world.

I also do not assume that a meaningful answer to the questions about the relationship between science and ethics can be derived from what physics alone tells about the world. Physics can’t be bootstrapped into giving a full account of the social world. It would be wrong to simply assume that people are the analogues of atoms and that societies are mere epiphenomena that can be explained in terms of collective behavior of massive ensembles of individual entities (like little atoms each), or that sociology is reducible to biology, which is reducible to chemistry, which in turn is reducible to physics. Quantum physics undercuts reductionism as a worldview or universal explanatory framework. Reductionism has a very limited run.

What is needed is a reassessment of physical and metaphysical notions that explicitly or implicitly rely on old ideas about the physical world—that is, we need a reassessment of these notions in terms of the best physical theories we currently have. And likewise we need to bring our best social and political theories to bear in reassessing how we understand social phenomena, including the material practices through which we divide the world



into the categories of the “social” and the “natural.”<sup>19</sup> What is needed is an analysis that enables us to theorize the social and the natural together, to read our best understandings of social and natural phenomena through one another in a way that clarifies the relationship between them. To write matter and meaning into separate categories, to analyze them relative to separate disciplinary technologies, and to divide complex phenomena into one balkanized enclave or the other is to elide certain crucial aspects by design. On the other hand, considering them together does not mean forcing them together, collapsing important differences between them, or treating them in the same way, rather it means allowing any integral aspects to emerge (by not writing them out before we get started).

### OVERVIEW OF THE BOOK

This book demonstrates how and why we must understand in an *integral* way the roles of human and nonhuman, material and discursive, and natural and cultural factors in scientific and other practices. I draw on the insights of some of our best scientific and social theories, including quantum physics, science studies, the philosophy of physics, feminist theory, critical race theory, postcolonial theory, (post-)Marxist theory, and poststructuralist theory. Based on a “diffractive” methodological approach, I read insights from these different areas of study through one another. My aim in developing such a diffractive methodology (chapter 2) is to provide a transdisciplinary approach that remains rigorously attentive to important details of specialized arguments within a given field, in an effort to foster constructive engagements across (and a reworking of) disciplinary boundaries. In particular, this approach provides important theoretical tools needed to move conversations in science studies, feminist studies, and other (inter)disciplinary studies beyond the mere acknowledgment that both material and discursive, and natural and cultural, factors play a role in knowledge production by examining *how* these factors work together, and how conceptions of materiality, social practice, nature, and discourse must change to accommodate their mutual involvement. I also show that this method is sufficiently robust to build meaningful conversations between the sciences and other areas of study and to contribute to scientific research.

This book contributes to the founding of a new ontology, epistemology, and ethics, including a new understanding of the nature of scientific practices. In fact, I show that an empirically accurate understanding of scientific practice, one that is consonant with the latest scientific research, strongly

suggests a fundamental inseparability of epistemological, ontological, and ethical considerations. In particular, I propose “agential realism” as an epistemological-ontological-ethical framework that provides an understanding of the role of human and nonhuman, material and discursive, and natural and cultural factors in scientific and other social-material practices, thereby moving such considerations beyond the well-worn debates that pit constructivism against realism, agency against structure, and idealism against materialism. Indeed, the new philosophical framework that I propose entails a rethinking of fundamental concepts that support such binary thinking, including the notions of matter, discourse, causality, agency, power, identity, embodiment, objectivity, space, and time.

The starting point for this transdisciplinary engagement is the philosophically rich epistemological framework proposed by the physicist Niels Bohr. I extend and partially revise his philosophical views in critical conversation with current scholarship in science studies, the philosophy of science, physics, and various interdisciplinary approaches that might collectively be called “critical social theories” (e.g., feminist theory, critical race theory, queer theory, postcolonial theory, (post-)Marxist theory, and poststructuralist theory). Bohr’s philosophy-physics is a particularly apt starting point for thinking the natural and social worlds together and gaining some important clues about how to theorize the nature of the relationship between them, since his investigations of quantum physics open up questions not only about the nature of nature but also about the nature of scientific and other social practices. In particular, Bohr’s naturalist commitment to understanding both the nature of nature and the nature of science according to what our best scientific theories tell us led him to what he took to be the heart of the lesson of quantum physics: *we are a part of that nature that we seek to understand*. Bohr argues that scientific practices must therefore be understood as interactions among component parts of nature and that our ability to understand the world hinges on our taking account of the fact that our knowledge-making practices are social-material enactments that contribute to, and are a part of, the phenomena we describe.

Ultimately, however, the far-reaching implications of Bohr’s epistemology and his posthumanist insights are cut short by his unexamined humanist commitments—his anti-Copernicanism, as it were, which places the human back at the center of the universe. In particular, Bohr cements human concepts and knowers into the foundations of the ontological relations of knowing. This creates difficulties for developing a coherent interpretation of quantum physics, as well as for examining its larger implications. As I

explain in chapter 7, while the majority of physicists claim allegiance to the so-called Copenhagen interpretation of quantum physics, which is largely based on contributions from Bohr and other members of the Copenhagen circle, physicists and philosophers of physics who are interested in issues in the foundations of quantum physics have expressed discomfort with Bohr's remnant humanism. The "distasteful" presence of human concepts and human knowledge in the foundations of the theory has been a major stumbling block.

I imagine that poststructuralist theorists and scholars in science studies will also find much to embrace in Bohr's philosophy-physics, but there is good reason to believe that they too will balk at his humanism for their own (very different) reasons. For example, both groups of scholars will most likely find sympathy with Bohr's position that neither the subjects nor the objects of knowledge practices can be taken for granted, and that one must inquire into the material specificities of the apparatuses that help constitute objects and subjects. Indeed, poststructuralists would be quick to point out that a commitment to understanding the differential constitution of the human subject does not sit easily with humanism's essentialist conception of the human. On the contrary, humanism takes for granted much of what needs to be investigated. Scholars in science studies have a very different set of concerns. Their disavowal of humanism is based on an interest in the ways in which the "human" and its others (e.g., including machines and nonhuman animals) are conceptualized, produced, and reworked through scientific and technological practices. Needless to say, they don't have to dig very far to find justification for their rejection of humanism, since the news serves up daily reminders that science and technology are actively remaking the nature of the "human." Indeed, the recent convergence of biotechnologies, information technologies, and nanotechnologies reconfigures the human and its others so rapidly that it is already overloading the circuits of the human imagination.

At the same time, I will argue that Bohr's insights can be helpful in revealing and explicating difficulties in these other areas of study, and in posing possible remedies and directions for revision or further elaboration. In particular, some important poststructuralist, science studies, and physics insights are also cut short by their own remnant anthropocentrist and representationalist assumptions. Reading these insights through one another can be helpful in dislodging these unwanted remnants, thereby providing more refined tools that can be useful for addressing a host of different (inter)disciplinary concerns.

Chapter 1 presents the main problematic of the book: the challenge and necessity of adequately theorizing the relationship between discursive practices and the material world. I begin with a discussion of representationalism—the idea that representations and the objects (subjects, events, or states of affairs) they purport to represent are independent of one another. I discuss some of the problems, difficulties, and limitations of representationalism. I then consider a class of alternative approaches to representationalism that can collectively be designated as “performative.” Performative approaches call into question the basic premises of representationalism and focus inquiry on the practices or performances of representing, as well as on the productive effects of those practices and the conditions for their efficacy.

In recent years, both science studies scholars and critical social theorists have pursued performative alternatives to social constructivist approaches (which, much like their scientific realist counterparts, are based on representationalist beliefs). The move toward performative alternatives to representationalism changes the focus from questions of correspondence between descriptions and reality (e.g., do they mirror nature or culture?) to matters of practices or doings or actions. By and large, performative accounts offered by science studies scholars, on the one hand, and social and political theorists, on the other, have led parallel lives with surprisingly little exchange between them. I point out some of the strengths and weaknesses of these different performative approaches and (in chapter 4) put them in conversation with one another in an effort to sharpen both sets of tools, or rather to develop a performative account that takes both sets of insights seriously.

Chapter 2 serves two seemingly disparate purposes: it introduces the important physical phenomenon of diffraction, and it discusses questions of methodology. I will explain what these issues have to do with each other shortly, but first I want to offer a brief description of the physical phenomenon of diffraction. Diffraction is a phenomenon that is unique to wave behavior. Water waves exhibit diffraction patterns, as do sound waves, and light waves. Diffraction has to do with the way waves combine when they overlap and the apparent bending and spreading out of waves when they encounter an obstruction. Diffraction phenomena are familiar from everyday experience. A familiar example is the diffraction or interference pattern that water waves make when they rush through an opening in a breakwater or when stones are dropped in a pond and the ripples overlap. (While some physicists continue to abide by the purely historical distinction between diffraction and interference phenomena, I use the terms “diffraction” and

“interference” interchangeably. That is, I side with the physicist Richard Feynman and others who drop this distinction on the basis that what is at issue in both cases is the physics of the superposition of waves.)<sup>20</sup>

As I explain in chapter 2, diffraction is an apt overarching trope for this book. Diffraction plays a crucial role in sorting out some key issues in quantum physics. Perhaps one of the most well known dilemmas in quantum physics is the “wave-particle duality paradox”: experimental evidence at the beginning of the twentieth century exhibited seemingly contradictory features—on the one hand, light seemed to behave like a wave, but under different experimental circumstances, light seemed to behave like a particle. Given these results, what can we conclude about the nature of light—is it a particle or a wave? Remarkably, it turns out that similar results are found for matter: under one set of circumstances, electrons behave like particles, and under another they behave like waves. Hence what lies at the heart of the paradox is the very nature of nature. As the book progresses, I develop deeper and deeper insights about this profound set of issues, and diffraction phenomena play a key role all along in helping to illuminate the nature of nature.

Furthermore, as I explain in chapter 2, diffraction turns out to be an apt (material and semiotic) figuration for the methodological approach that I use and develop. There is a long history of using vision and optical metaphors to talk and theorize about knowledge. The physical phenomenon of reflection is a common metaphor for thinking—a little reflection shows this to be the case. Donna Haraway proposes diffraction as an alternative to the well-worn metaphor of reflection. As Haraway suggests, diffraction can serve as a useful counterpoint to reflection: both are optical phenomena, but whereas reflection is about mirroring and sameness, diffraction attends to patterns of difference. One of her concerns is the way reflexivity has played itself out as a methodology, especially as it has been taken up and discussed by mainstream scholars in science studies. Haraway notes that “[reflexivity or reflection] invites the illusion of essential, fixed position, while [diffraction] trains us to more subtle vision” (1992). Diffraction entails “the processing of small but consequential differences,” and “the processing of differences . . . is about ways of life” (ibid.). In this book, I further develop and elaborate these ideas, drawing on quantum understandings of diffraction phenomena and the results of some recent experiments. Ultimately, I argue that a diffractive methodology is respectful of the entanglement of ideas and other materials in ways that reflexive methodologies are not. In particular, what is needed is a method attuned to the entanglement of the

apparatuses of production, one that enables genealogical analyses of how boundaries are produced rather than presuming sets of well-worn binaries in advance. I begin this elaboration in chapter 2, but the full display of its intricate patterns and reverberations with all the vibrancy, richness, and vitality of this remarkable physical phenomenon is manifest only in diffracting these insights through the grating of the entire set of book chapters.

One important aspect that I discuss is that diffraction does not fix what is the object and what is the subject in advance, and so, unlike methods of reading one text or set of ideas against another where one set serves as a fixed frame of reference, diffraction involves reading insights through one another in ways that help illuminate differences as they emerge: how different differences get made, what gets excluded, and how those exclusions matter.

For example, as I suggested earlier, if the goal is to think the social and the natural together, to take account of *how* both factors matter (not simply to recognize that they both do matter), then we need a method for theorizing the relationship between “the natural” and “the social” together without defining one against the other or holding either nature or culture as the fixed referent for understanding the other. What is needed is a diffraction apparatus to study these entanglements. One way to begin to build the needed apparatus is to use the following approach: to rethink the nature of nature based on our best scientific theories, while rethinking the nature of scientific practices in terms of our best understanding of the nature of nature and our best social theories, while rethinking our best social theories in terms of our best understanding of the nature of nature and the nature of scientific theories. A diffractive methodology provides a way of attending to entanglements in reading important insights and approaches through one another.

In chapter 3 I offer a unique interpretation of Bohr’s philosophy-physics. Interpretations of Bohr’s epistemological framework have been widely divergent. Bohr has been fashioned a positivist, an idealist, an instrumentalist, a (macro)phenomenalist, an operationalist, a pragmatist, a (neo-)Kantian, and a scientific realist by various mainstream historians and philosophers of science. In contrast, I argue that Bohr’s philosophy does not fit neatly into any of these categories because it questions many of the dualisms on which these philosophical schools of thought are founded. For example, while Bohr’s understanding of quantum physics leads him to reject the possibility that scientists can gain access to the “things-in-themselves,” that is, the objects of investigation as they exist outside human conceptual frameworks,

he does not subscribe to a Kantian noumena-phenomena distinction. And while Bohr's practice of physics shows that he holds a realist attitude toward his subject matter, he is not a realist in any conventional sense, since he believes that the interaction between the objects of investigation and what he calls "the agencies of observation" is not determinable and therefore cannot be "subtracted out" to leave a representation of the world as it exists independently of human beings.

Significantly, Bohr's epistemological framework, based on empirical findings in the atomic domain in the early twentieth century, offers a new understanding of fundamental philosophical issues such as the relationship between knower and known, the role of measurement, questions of meaning making and concept use, the conditions for the possibility of objective description, correct identification of the objective referent for measured properties, the nature of causality, and the nature of reality. Bohr's philosophy-physics contains important and far-reaching ontological implications, but unfortunately he stays singularly focused on the epistemological issues and does not make this contribution explicit or explicate his views on the nature of reality. He is explicit in stating that in his opinion quantum physics shows that the world surely does not abide by the ontology of Newtonian physics. One of the goals of this chapter is to extract the implicit ontological implications and explicate a consistent Bohrian ontology. Ontology, as much as epistemology, plays a crucial role in my agential realist elaboration of Bohr's philosophy-physics (see chapter 4).

In chapter 3 I suggest that there is an important sense in which Bohr's framework can be understood as offering a proto-performative account of scientific practices, including an account of the production of bodies and meanings. I develop this suggestion further in chapter 4 and further elaborate the performative dimensions of Bohr's account. In what sense is Bohr's account "proto-performative"? First of all, Bohr's careful analysis of measurement leads him to reject representationalism. Remarkably, Bohr calls into question representationalism's taken-for-granted stance toward both words and things. That is, unlike (some of) the poststructuralist and science studies accounts, which fully explicate and emphasize either the discursive or material nature of practices, Bohr takes hold of both dimensions at once. It is not unreasonable (although surely not expected) for a physicist to question accepted ideas concerning the nature of things, but Bohr also concerns himself with the nature of words, including questions of the nature of meaning, practices for making meaning, the conditions for the possibility of intelligibility, and the co-constitution of an excluded domain, a domain of unintelligi-

bility—and this is a highly unusual line of questioning for a physicist. But even more remarkably, Bohr understands these issues—concerning word and world—to be inextricably linked. According to Bohr, our ability to understand the physical world hinges on our recognizing that our knowledge-making practices, including the use and testing of scientific concepts, are material enactments that contribute to, and are a part of, the phenomena we describe.

The details of Bohr's nuanced interrogation of the representationalist tenets embedded in Newtonian physics and concordant epistemologies are crucial. Therefore I do not skimp on the details of the physics issues involved, but I also do not assume that the reader has any background in physics. I have made every effort to make these ideas accessible even to readers who have no knowledge of physics. Bohr set the same standards for himself. He firmly believed that it was important to explain things using (extensions of) everyday concepts. This was as much a methodological and epistemological commitment on Bohr's part as it was about accessibility: too many important questions lay hidden in the mathematics, and it is crucial not simply to be able to calculate, but to understand what the physics is saying, what it means. It is also vital that I attend to the details of Bohr's philosophy-physics because in chapter 7 I turn my attention back to the physics and consider some of the foundational issues that continue to plague quantum physics. Only by rigorously attending to the details can we hear nature speak with any kind of clarity (as Einstein said, "God is in the details").

Chapter 4 is the core chapter of the book. Here I develop my central theoretical framework—agential realism. Agential realism is an epistemological, ontological, and ethical framework that makes explicit the integral nature of these concerns. This framework provides a posthumanist performative account of technoscientific and other naturalcultural practices.<sup>21</sup> By "posthumanist" I mean to signal the crucial recognition that nonhumans play an important role in naturalcultural practices, including everyday social practices, scientific practices, and practices that do not include humans.<sup>22</sup> But also, beyond this, my use of "posthumanism" marks a refusal to take the distinction between "human" and "nonhuman" for granted, and to found analyses on this presumably fixed and inherent set of categories. Any such hardwiring precludes a genealogical investigation into the practices through which "humans" and "nonhumans" are delineated and differentially constituted. A posthumanist performative account worth its salt must also avoid cementing the nature-culture dichotomy into its foundations, thereby enabling a genealogical analysis of how these crucial distinctions are materially and discursively produced.



A core section of the chapter explicates my proposed agential realist ontology. As I mentioned previously, Bohr keeps his focus on the epistemological issues throughout and unfortunately never spells out his ontological commitments or the ontological dimensions of his account. On the basis of the Bohrian ontology that I propose in chapter 3, as well as new experimental evidence discussed in chapter 7, and other considerations, I propose an agential realist elaboration in chapter 4.

As I argue in chapter 3, the primary ontological unit is not independent objects with independently determinate boundaries and properties but rather what Bohr terms “phenomena.” In my agential realist elaboration, phenomena do not merely mark the epistemological inseparability of observer and observed, or the results of measurements; rather, *phenomena* are the ontological inseparability of agentially intra-acting components. (The notion of intra-actions figures centrally here—see hereafter.) Significantly, phenomena are not mere laboratory creations but basic units of reality. The shift from a metaphysics of things to phenomena makes an enormous difference in understanding the nature of science and ontological, epistemological, and ethical issues more generally.

The notion of intra-action is a key element of my agential realist framework. The neologism “intra-action” signifies the mutual constitution of entangled agencies. 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. It is important to note that the “distinct” agencies are only distinct in a relational, not an absolute, sense, that is, *agencies are only distinct in relation to their mutual entanglement; they don’t exist as individual elements.*<sup>23</sup>

Crucially, as I explain in chapter 4, the notion of intra-action constitutes a radical reworking of the traditional notion of causality. I can’t emphasize this point enough. A lively new ontology emerges: the world’s radical aliveness comes to light in an entirely nontraditional way that reworks the nature of both relationality and aliveness (vitality, dynamism, agency). This shift in ontology also entails a reconceptualization of other core philosophical concepts such as space, time, matter, dynamics, agency, structure, subjectivity, objectivity, knowing, intentionality, discursivity, performativity, entanglement, and ethical engagement.

Performative accounts that social and political theorists have offered focus on the productive nature of social practices and human bodies. By contrast, agential realism takes account of the fact that the forces at work in the materialization of bodies are not only social, and the bodies produced

are not all human. Crucially, I argue that agential realism clarifies the nature of the causal relationship between discursive practices and material phenomena. That is, I propose a new understanding of how discursive practices are related to the material world. This is a significant result with far-reaching consequences for grasping and attending to the political possibilities for change, the responsible practice of science, and the responsible education of scientists, among other important shifts.

These proposed refigurations are explored by considering concrete examples. The third part of the book, “Entanglements and Re(con)figurations,” continues the elaboration of key agential realist ideas introduced in chapter 4 and works through several different case studies. Here I demonstrate the usefulness of an agential realist approach for negotiating difficulties in some of the fields that I draw on, such as feminist theory, poststructuralist theory, physics, and science and technology studies. I also show that agential realism makes visible a range of different connections between these disparate fields that have not previously been explored.

In chapter 5, I consider one of the ways in which agential realism can be useful for thinking about specific issues that have been central to feminist theory, activism, and politics. The development of new reproductive technologies, including new visualizing technologies, continues to play a crucial role in the public discourse as well as in feminist theories of the body. Using the example of new reproductive technologies, I explore the significance of my posthumanist performative understanding of the materialization of bodies by explicitly considering its ability to take account of crucial material dimensions, such as material agency, material constraints, and material exclusions, that other accounts, including other performative accounts, neglect. In particular, I further examine the implications of my sympathetic but critical reading of Butler’s theory of performativity begun in Chapter 4. Judith Butler’s provocative theory of performativity, which links gender performativity to the materialization of sexed bodies, has received widespread attention in academic circles, especially among feminist and queer theory scholars. I argue that Butler’s conception of materiality is limited by its exclusive focus on human bodies and social factors, which works against her efforts to understand the relationship between materiality and discursivity in their indissociability. I show how agential realism’s reconceptualization of the nature of matter and discursive practices provides a means for taking account of the productive nature of natural as well as cultural forces in the differential materialization of nonhuman as well as human bodies. It thereby avoids the privileging of discursive over material concerns and the

reinscription of the nature-culture dualism that Butler's account inadvertently enacts. Crucially, it also corrects Butler's underestimation of the possibilities for agentially reconfiguring who or what comes to matter, and makes evident a much larger space of possibilities for change. (Chapter 5 is a revised version of a previously published work. The original structure has been maintained so that it is available in the form of an autonomous text, suitable for classroom use or other forums for discussion.)

In chapter 6, I consider how agential realism can contribute to a new materialist understanding of power and its effects on the production of bodies, identities, and subjectivities. This chapter specifically engages Leela Fernandes's ethnographic study of relations of production at a Calcutta jute mill, where questions of political economy and cultural identity are both at work on the shop floor. Central to my analysis is the agential realist understanding of matter as a dynamic and shifting entanglement of relations, rather than as a property of things. Drawing on specific developments in political theory, cultural geography, political economy, critical race theory, postcolonial theory, and feminist theory, I consider the dynamic and contingent materialization of space, time, and bodies; the incorporation of material-discursive factors (including gender, race, sexuality, religion, and nationality, as well as class, but also technoscientific and natural factors) in processes of materialization; the iterative (re)materialization of the relations of production; and the agential possibilities and responsibilities for reconfiguring the material-social relations of the world.

After developing the ontological and epistemological framework of agential realism, I return in chapter 7 to the field of physics. I begin this chapter with a review of some of the unresolved interpretational difficulties that have plagued quantum mechanics since its founding three-quarters of a century ago. During the past decade, technological progress in experimental physics has opened up an entirely new empirical domain: the world of "experimental metaphysics." That is, questions previously thought to be a matter solely for philosophical debate have been brought into the orbit of empirical inquiry. This is a striking development because it allows scientists to explore metaphysical issues in the laboratory (so much for the category "metaphysical"). I include in this chapter a review of key experimental findings that have important implications for understanding quantum physics. I also consider the possibility of using agential realism as the basis for a new interpretation, examine its potential for resolving certain long-standing paradoxes in the field, and compare it to some of the newer interpretations that have recently been proposed.

Significantly, then, my project departs from mainstream and feminist science studies in that it does not merely offer insights about the nature of scientific practices but also makes a constructive contribution to the field of science being studied. That is, my project is not merely a reflection on science but takes these insights about scientific practices and about nature (the two key ingredients in Bohr's interpretation) and diffracts them back onto the science itself, thereby making a specific scientific contribution to an active scientific research field (i.e., the foundations of quantum physics). In particular, I argue that the conceptual shifts derived from my diffractive methodology not only reconfigure our understanding of the nature of scientific and other material-discursive practices but also are significant and robust enough to actually form the basis for a new interpretation of quantum physics.

Importantly, the metaphysical questions that the new experiments address have wide-ranging implications beyond the domain of physics. The implications will surely be of interest to philosophers, especially those with naturalist inclinations. And despite a growing distaste for metaphysics, poststructuralist and other critical theorists will no doubt find much food for thought in the discussion of experiments that directly address questions of the nature of identity, time, and matter. As before, I try to make this chapter accessible to readers who have no background in physics. Physicists will also find much to ponder in this chapter, which includes a systematic review and philosophical exposition of key interpretative issues.

The concluding chapter, chapter 8, brings together the major themes in the book and explicates some of the key issues. Concrete examples of nanotechnologies, information technologies, and biotechnologies provide an opportunity for fleshing out these ideas and for analyzing some of the important genealogical elements of the apparatus contemporary physics uses to study entanglements. These technologies are inextricably intertwined, as are the issues they bring into focus: the intra-activity of becoming, the ontology of knowing, and the ethics of mattering. The entanglement of ontology, epistemology, and ethics is emphasized in this chapter. As the book unfolds, the complexity and richness of the phenomenon of diffraction become increasingly evident. In this chapter, I bring into focus the overall pattern that has been created (i.e., a diffraction pattern of diffraction as a changing phenomenon) and explain how the pattern itself is a matter of entanglement. Indeed, I argue that diffraction is not merely about differences, and certainly not differences in any absolute sense, but about the entangled nature of differences that matter. Significantly, difference is tied up with responsibility, as I explain in a final section of the chapter.

In this last chapter, I develop the basic elements of an agential realist understanding of ethics. I explain that ethical concerns are not simply supplemental to the practice of science but an integral part of it. But more than this, I show how *values are integral to the nature of knowing and being*. Objectivity is simultaneously an epistemological, ontological, and axiological issue, and questions of responsibility and accountability lie at the core of scientific practice. The correct identification of the objective referent of scientific practices of theorizing and experimenting requires an accounting of the ethical (as well as epistemological and ontological) concerns. It is not possible to extricate oneself from ethical concerns and correctly discern what science tells us about the world. Realism, then, is not about representations of an independent reality but about the real consequences, interventions, creative possibilities, and responsibilities of intra-acting within and as part of the world.<sup>24</sup> (It is perhaps worth noting at this juncture that we have come a long way from Frayn's proposal. It seems unlikely that even very careful analogical reasoning would have led us to this conclusion about the nature of the relationship between science and ethics.)

Since this book is lengthier than is fashionable these days, I offer some suggestions for different possible paths through the book for different readers. A word of caution before I do: as I have indicated, this book works as a diffraction grating, illuminating important material differences, relationalities, and entanglements in the lively dance of mattering, and it may be difficult to appreciate the intricacies of the pattern that is produced if significant segments of the book are skipped over. That said, it is undoubtedly the case that interesting patterns arise nonetheless in sampling different chapters, and different readers may find different samplings particularly worthwhile. Physicists and philosophers of science may be particularly interested in chapters 3, 4, and 7. These chapters taken together constitute a detailed examination of Bohr's philosophy-physics and offer a coherent reconstruction of the interpretative issues together with an accessible and systematic presentation of some important experimental results from the past decade. Chapter 5 was originally published as a journal article, and I have retained its original structure so that it can continue to be usefully read as a separate stand-alone piece. Conversely, it could conceivably be skipped without losing the continuity of the argument (though surely risking some important insights). Chapter 4 is a key chapter. And in many respects so is chapter 7 (this is where the notion of "entanglement" takes on important nuances, textures, and crucial noncolloquial meanings). Less scientifically inclined readers, or readers who may think of themselves as not very interested in the details of

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