Fictional Models in Science

Ah! sachez-le: ce drame n'est ni une fiction, ni un roman. *All is true*, il est si véritable, que chacun peut en reconnaître les éléments chez soi, dans son coeur peut-être.

 -- Honoré de Balzac, *P*é*re Goriot*

 All the world’s a stage,

 And all the men and women merely players;

 -- Shakespeare, *As You Like It*, II. vii

**1. Introduction**

I shall investigate the question of whether models in science can in general be properly understood as similar to works of fiction. And since the answer, as I shall argue, is “no, not in general,” I further inquire whether or not there are some models in science that are indeed fictional, or better which ones are obviously so and which ones may well turn out to be so despite their initial appearance to the contrary.

Before I go into the main argument, a brief summary of what has so far been ascertained in the recent studies of models and modeling should help set the ground for our discussion. This is especially important because to find out whether or not models are works of fiction without having a firm and clear idea of what models are may be all but impossible.

Whether scientific models are part of scientific theories (à la van Fraasssen (1980), Giere (1988), and their supporters) or “mediators” that are external to theories, as some philosophers of science would call them (à la Cartwright (1999) and her supporters), they are distinguished from theories by being non-truth-apt, i.e., they are not the sort of things that by themselves can be said to be true or false (cf. Godfrey-Smith 2009, Frigg 2010, Contessa 2009, 2010 & Levy 2010, 2012). Statements can be made about them or their parts that are truth-apt, and therefore, models are more like things and events in reality than statements or equations in theories or explanations. Whichever approach one adopts, our representation of the world around us is no longer, as traditionally conceived, essentially a “word-world” relationship, whose main component comprises meaning and reference. A different and apparently more opaque relationship between the models and the world appears on the scene that generates a new set of problems about representation that are different from the traditional challenges in semantics (cf. Godfrey-Smith 2009, Frigg 2010).

Models are of very diverse kinds: some are physical objects, such as a scale model of an airplane, and others are apparently non-physical, such as the mechanical model of luminiferous aether; some are used to represent systems that are of different kinds, such as using a plastic structure to represent an organism, but others are of the same kind as the represented, such as a model organism to represent the type of that organism (cf. Keller 2002, Rowbottom 2009; see also Goodman 1976 for a more general point). Some models are constructed to represent the whole target system, such as an elaborate scale model of a bridge, while others may only represent one or a few selected aspects, such as a mechanical model of an economy or a map of a metropolitan area. Some models are abstract, while others are concrete. The abstract-concrete pair can be distinguished at two different levels. Among the models that are physical objects, some may be abstract and some concrete. A fruit fly *qua* organism is a concrete system, and yet as a biological model, an exemplar for some salient aspects of biological organisms, it is an abstract model, while a wood model for the earth is concrete as a model, for it is not meant to represent a type of objects, but a particular one, the earth. Among the non-physical models, most of them are of course abstract; Mendel’s model for heredity in sexual reproduction is an abstract model and so is Maxwell’s model for electromagnetism. They may be realized in different physical copies with different initial and boundary conditions, and yet the copies let us visualize the model but are not the model itself, just as John Gielgud’s Hamlet is a physical realization of Hamlet but not Hamlet himself. But there are also concrete non-physical models in science, the Ptolemaic geocentric model of the universe being an example.

In spite of their diversity and ubiquity, it would, however, be a mistake, as Godfrey-Smith (2006, 2009) rightly pointed out, to regard all enterprises of science as essentially involving models and model building. Still, one couldn’t go wrong by saying that the “model-based” (Godfrey-Smith’s phrase) approach is one of the most effective and widely used strategies in science today, which cuts across all major disciplines from physics to economics. Now, are there any common characteristics of models that can help us to begin our study of them in general?

One common feature of all models is that they are vehicles of representation, a functional characteristic, if you will. However, this feature is so general that many more things, such as linguistic or symbolic vehicles of representation, share this feature with models. Some (cf. Callender and Cohen 2006) find this fact remarkable and argue for a deflationary view on scientific modeling or representation. According to this view, models are no different from other types of representational vehicles, such as symbolic ones, and while the suitability of different types of models for different jobs in science must be separately determined by pragmatic concerns (specifiable in their job descriptions), all models represent their targets in virtue of being conventionally chosen as representational vehicles (see also Teller 2001, van Fraassen 2008). Arguments against deflationism also surfaced recently (cf. Toon 2010b).

Another common feature of models is the tripartite nature of model representation. Instead of the traditional picture of scientific representation, which regards all representation, model-based or not, as a binary relation between symbolic systems and phenomena, we now have, according to Giere (1988), which is later modified by Godfrey-Smith (2009) (see also Frigg 2010), a three term structure of “description”, “models,” and “phenomena,” where the relation between the first two parts is a specification of models, and the relation between models and phenomena is non-semantic; and this latter relation remains mysterious until one gets a good grip on what models are ontologically and functionally. Note that the models in this picture do not have to be regarded as abstract entities; concrete physical systems can serve the role just as well (cf. Goodman 1976, Rowbottom 2009).

Adopting such an account raises the question concerning the ontology of models. If they are non-truth-apt and bear a relationship with reality or phenomena that is not part of logic and semantics, then what are they and how do they represent (cf. Contessa 2009, 2010 & Levy 2010, 2012)? Partly because of difficulties in answering such questions and partly because of the temptation from other quarters, a sizable literature has been generated in recent years in which mostly positive explorations have been made into the possibility that “scientific models are works of fiction” (cf. papers in Suárez 2009; Frigg 2010, 2011a,b; Godfrey-Smith 2006, 2009; Toon 2010a,b). Representations via models, according to the fictionalist view, are very much like the representations in art and literature: they “make fiction” of the target systems or phenomena, which yield fictional objects, i.e. models, on which scientists operate and learn. Idealization or something like it is often taken to be the means by which models are made (or reality is made fictional); and how models represent reality may be gleaned from how fictional characters and events relate to actual people and events, such as the case in the relationship between *War and Peace* and the Napoleonic War or between *Middle Earth* and Europe in the Middle Ages (cf, Godfrey-Smith 2006).

In this paper, I begin with a discussion of Giere’s recent work arguing against taking models to be works of fiction. I then move on to explore a spectrum of scientific models that scientists themselves regard as obviously fictional or fictional but not obviously so. And then I discuss the modeling of the unobservable and make a case for the idea that despite difficulties of defining them, unobservable systems are modeled in a fundamentally different way than observable systems. While idealization and approximation is key to the making of models for the observable systems, they are in fact not operable, at least not straightforwardly so, regarding models for the unobservable. And because of this point, which is so far neglected in the literature, I argue that fictionalism may have a better chance with models for the unobservable. However, this fictionalism is not the one defended in the above-cited literature; it belongs to an old tradition of fictionalism in philosophy of science that is incompatible with scientific realism (cf. Fine 1993 and references therein).

**2. No Works of Fiction**

In a recent article, Giere (2009) explained “Why Scientific Models Should Not Be Regarded as Works of Fiction.” As a conclusion for all models in science, I disagree with Giere, as I shall explain later; and yet I agree with him that many types should not be so regarded. Some of Giere’s arguments for his conclusion I cannot concur with, yet I found more and stronger reasons to support his conclusion (see also, Giere 2002, 2011).

Giere begins the article by claiming that models and fictional objects are ontologically the same but functionally different. “Theoretical models and works of fiction are, I will argue, ontologically on a par. It is their differing functions in practice that makes it inappropriate to regard scientific models as works of fiction.” (Giere 2009, 249) Because Giere has always regarded models as abstract entities (Giere 1988), this “ontologically on a par” might be interpreted as saying that both models and fictional objects are abstract entities of one sort or another. An immediate observation about this claim, given what I have said above, is that it does not apply to those models that are physical objects. If the fruit fly can be regarded as a model organism, it cannot be said to be ontologically fictional, at least not obviously so. So for those of us who believe that “model” is properly used in science to refer to abstract as well as concrete objects that are used to serve as representational vehicles, this claim of ontological identity between models and fiction is, *prima facie*, too strong.

Even with regard to abstract models, I still find ample reasons for doubting that models in general are ontologically fictional, because it does not fit into what we typically regard as the same type of things that do different jobs. Typical examples of things that are ontologically on a par but functioning differently are nouns and verbs in English, pistols and cannons, women and cats; and typical examples of those that are ontologically not the same are numbers and atoms, names and the things they name, and humans and angels (if they exist). When we think about our ontological commitment to a model of an ideal pendulum or gas, is it not more like our commitment to mathematical objects, such as numbers and equations, than our commitment to fictional characters such as Sherlock Holmes? Unless one thinks the ontology of fictional characters is also “on a par” with number and sets, etc., ontologically identifying models with fiction seems wrongheaded.

But wait, isn’t there a fictionalist approach to the ontology of mathematical and other abstract entities (Field 1989; Yablo 1998, 2010)? The idea of factionalism on abstract entities is roughly that, instead of being a Platonist or a nominalist one should treat such entities as fictional. An in-depth discussion on how such a fictionalist view on abstract entities would bear on the model-fiction literature has to wait for another occasion (but see Godfrey-Smith 2009). It suffices to mention here that complications begin almost on the first step into that discussion. It is not clear, first of all, that models in science are in the same league as numbers and propositions, and secondly, the grounds for a fictionalist approach to mathematics and such are far from being secure.

Be that as it may, there are *prima facie* differences between models and fictional characters/events that do not appear to be a difference in function alone. First off, the imagination of a simple pendulum or an ideal gas, for example, can be regarded as a natural extension of a method we use daily, namely coming up with an idea or image of something by omitting non-essential details. On the contrary, the imagining of a fictional character or event does not seem to be the result of such a method. While idealization is indispensible for building *good* models in science, it produces only *bad* characters or events in fiction making. True, bad fiction is still fiction and if model-building in science is analogous to bad fiction making in literature, the fictionalists can still bite the bullet and say, so what? Secondly, when we have a scale model for a simple pendulum, what it represents is no doubt real pendulums, not the abstract model for them, just as a scale model of Boeing 787 Dreamliners should be taken to represent the airplanes, not the model of the airplanes. However, there is no other way of conceiving any physical realizations of a fictional character, such as Sean Connery’s portrayal of James Bond, as anything other than representing the character (even if there was a real person on whom James Bond, the character, is based)[[1]](#footnote-1). But the fictionalists would argue that what the scale models represent are the abstract models, which are fictional objects. Yes, these are only *prima facie* differences that suggest but cannot prove the inadequacy of ontological identity; but the suggestions have force.

Arnon Levy (2010, 2012) suggests that we distinguish two different readings for acts of modeling: *de novo* modeling vs. *de re* modeling, and defends to some extent the latter. Very roughly (since Levy’s view will not be critically discussed here), a *de novo* modeling is an act that intends to make an imaginary object out of a particular system or phenomenon and treats the result as such, while a *de re* modeling is one that operates directly on the system and generates idealized or simplified statements about its relevant aspects. Although inclined to the *de re* reading, Levy did not use it to argue against the idea that scientific models are works of fiction. I think we could and should use it to do so.

Literary genres such as historical novels, in which entirely fictional details are attributed to actual individuals, appear to suggest that *de re* modeling could still be regarded as fiction making, if additional reasons convince us that model building is somewhat analogous to the writing of historical novels. But given the simple fact that scientific models, however idealized or abstract, are still subject to empirical testing, while for historical novels, it makes no sense to check their main characters’ sayings and acts with historical facts (although there may be factual constraints on the description of historical background). Some (cf. Frigg 2010, 2011a) may disagree with this point, for there must be enough verifiable features about the fictionalized figure, e.g., a Washington or a Lincoln. However, if the work is indeed a historical *fiction* of, say, Lincoln, the important stuff, the stuff that readers care the most, the stuff that is going to make or break it as a fictional account of Lincoln, cannot be something that should be held accountable by historical facts. If it is, then it is simply no fiction and needs no pretense when we read it (cf. Walton 1990).

To conclude, there is really no obviously good reason to declare defeat to the fictionalists on the ontological front; no good reason to think that when talking about diluted gas as ideal gas (as in Boyle’s ideal gas model), we are not talking about *real, albeit very diluted, gas* and *its idealized behavior* but rather some *abstract object* (and therefore a fictional one) and *its true and actual behavior*. In other words, there is good reason *not* to say that “scientific models should not be regarded as works of fiction” *ontologically*.

 Giere’s main argument comprises three components: scientific models should be compared to works of non-fiction rather than fiction; model-making involves “[i]dealizations, abstractions, and approximations, yes. Fictions, no[;]” (Giere 2009, 254) and conceiving models as fictional helps the enemies of science, such as creationists, which is not something a philosopher of science should do with good conscience. I shall not comment on the last argument in this essay but will focus on the first two.

It is a bit of a mystery to me that invoking the fiction vs. non-fiction distinction, vague though it is and borderline cases abound notwithstanding, has not stopped the fictionalists on scientific modeling in their tracks. The comparison is so stark that unless the fictionalists are actually touting a line that regards all creative representations, verbal or otherwise, as fictionalizing reality, and there is no real difference between the fictional and non-fictional depiction of events (i.e. history and historical fiction are fundamentally the same enterprise), it is difficult for me to see how anyone could argue for fictionalism for *all acts* of scientific modeling. The reason that fiction and non-fiction are fundamentally distinct categories of writing is clearly given by Giere: while non-fictional writings are judged, *inter alia*, by empirical evidence for details of what is written, it makes no sense to demand the same level of verifiable factual details for fictional writings.[[2]](#footnote-2) This is true even when we take into account the fact that fictional writings do in a sense represent reality; but factual details, such as a particular meeting between Newton and Huygens, may make or break a biography of Newton or of Huygens but can be entirely disregarded when judging a fictional life of one or of the other or of both. If the meeting is crucial in making the fictional story of Newton and Huygens more attractive, all things being equal, it should “happen.”

 It is equally false, as shall be seen, to say that all acts of legitimate or good scientific modeling are squarely analogous to non-fiction rather than fiction. This is so even when we notice that on many occasions scientists would call with good reason a model “a piece of fiction” that fails to qualify as a legitimate model. For we shall see in the next section, there are straightforwardly fictional models in science, which are often regarded as such by the scientists who create and use them, and there are borderline cases (but never dismissively called a piece of fiction by scientists). All of them are perfectly good models and some disciplines often cannot do without them. Those are the models that it would make no or not a whole lot sense to regard in the *de re* mode. However, even if these are fictional models in science, we may still agree with Giere that most models are not, especially not those models that are intended for representing corresponding target systems in reality.

To Giere’s second point about models being results of idealization, approximation, and/or abstraction, but not of fictionalization, I want to add a further observation. While idealization when constrained by good approximation is justly regarded as the essential ingredient in model building, it is not at all so regarded in fiction making, as I mentioned in an earlier point. In fact, although highly idealized characters or events may be valued in advertising and political propaganda, reputable fiction makers, which include writers, painters/sculptors, and moviemakers, inevitably shy away from idealization. It is a virtue for them to make their imaginary creations as concrete or particular, as unidealized, as possible. Models, because they represent real things, need to be appropriately “unreal;” while fictional characters or events, because they don’t represent anything real, need to be as “real” as possible (so as to be effective in acts of make-believe).[[3]](#footnote-3)

For example, when a model population is conceived in epidemiology for the purpose of studying an outbreak of influenza, the actual population is stripped of, in the researchers’ mind, the inessential and irrelevant aspects and added standardized features such as “medium health” for every member and the population is conceived as infinitely large. The purpose of such a maneuver is to allow the researches to concentrate on salient properties of a population, which usually helps to simplify and therefore expedite the study. Such idealizations are often necessary to the extent that without them no study is possible. The creation of fictional characters, including populations of them, is usually a very different process. Because the purpose of such a creation is to generate imaginary people whom the consumers of the fiction are able to imagine as actual in their acts of make-believe, the creator, if she is any good, is supposed to create individual as concrete, vivid, and real as possible (cf. Walton 1990). It is true that whatever description a writer could possibly give to her creations, the result is always far from being detailed enough; but one should not mistake the sketchiness of literary or artistic creations for the sketchiness of idealized models: in the former enough characteristics are added by imagination to create particular characters and/or events in the mind of a reader or viewer to realize acts of make-believe, while in the latter enough characteristics of the target systems or events are removed[[4]](#footnote-4) by a principled scientific method – idealization – so that something simple and abstract is created for the purpose of theoretical investigations. Even if both come to the same thing at the level of depiction, what is suggested (as an implicature?) are quite different between them: even if the descriptions of both Sherlock Holmes and “the average man” do not include the mentioning of their toes, toes of a particular sizes and shape are part of the character of Holmes, while there is no need to imagine such things for the average man who frequents works of economics.

Godfrey-Smith (2006, 2009) has argued for regarding scientific models as imaginary concrete systems that might have existed, and used the point to support the idea that models are fictional systems. There is an ontological view of fiction that takes fictional characters as non-actual possible people, people who don’t actually exist but exist in some possible world (cf. Kripke 1971). Godfrey-Smith’s view appears to go with such a view about fictional characters and events. This view does not seem plausible without a lot of heavy padding (cf. Kripke 1972; Thomasson 1999) and besides, if Sherlock Holmes is supposed to be a possible person, existing in some non-actual possible world, then there is no need for make-believe when we read Conan Doyle’s works or any other fictional works. If we couple this view with Lewis’s realist view on possible worlds, we should *actually believe, not make ourselves believe*, that Holmes is a real person, period. This does not seem to agree with our normal practice of reading fictional works. A fictional realm is not a possibly real realm but a non-real, non-actual one that readers may pretend to be real and actual; and what is required in reading fiction is to suspend our disbelief that Holmes is not an actual person and did not actually live in 221B Baker Street. There is no sense of make-believe of this sort when we are dealing with scientific models. It would not make good sense in which we could regard scientists, when studying Rutherford’s model of hydrogen atoms and the Crick-Watson model of DNA molecules, as imagining them as concrete objects *existing alongside* hydrogen atoms and DNA molecules.

Moreover, fictionalists along the Godfrey-Smith and Frigg line (see also Toon 2010b) usually borrow from Walton (1990) the pretense theory for fiction as their basis for viewing models as fictional. A *prima facie* problem of such a move is the following. There is no good evidence to indicate that modelers in science, when creating or using their models, pretend that the models rather than what the models represent are real. It might be more reasonable to say that they pretend that the real systems their models represent are the same or nearly the same as their models. But this is an entirely different sort of pretense from pretending that fictional characters or events are real. There is a perfectly good *de re* reading for the former, while there is none for the latter; and the reason is fairly obvious. It does not make good sense to pretend that your model of DNA molecules exists *alongside* the real DNA molecules, while nothing in reality is preventing fictional characters or events from being imagined as real and actual in acts of make-believe.[[5]](#footnote-5)

**3. Typically Fictional Models**

By now we should agree that there are strong arguments against taking scientific models in general to be works of fiction. The strongest reason or the best argument comes down to the simple fact that for many models in science, their details often must match corresponding facts with appropriate levels of approximation, while it makes no sense to require that for fictional characters and/or events.

It is equally obvious that science does allow for models or elements of models that are purely fictional.[[6]](#footnote-6) Let me now give some detailed evidence for this point. Giere (2009) discussed a model that Teller (2009) used to illustrate an aspect of model building. It is a case in electrostatics, where in order to calculate the induced charge distribution on a large metal plate (modeled as of infinite size) by a unit charge above it at a distance, *d*, one is asked to replace in one’s imagination the metal plate with a negative charge on the opposite side of, and at distance *d* to, the surface where the plate is. [[7]](#footnote-7) This imaginary charge can best be seen as *ontologically* as well as *functionally* fictional. It is a prop, in the sense of an imaginary replacement of one object by another non-existing object. It is also a case of make-believe in that one can pretend that instead of an infinite metal plate, a negative charge exists in its place and proceeds to calculate the effect. Very much like in the cases of fiction, especially in staged fiction as in films and plays, we proceed *as if* there is a negative charge in the supposed location. Following through this line of argument, we may very reasonably conclude that whatever ontological and functional status a fictional character has, the same is true for this and other similar imaginary models that are used for convenience or for equivalent effects.

To add a further point for this conclusion, we may again use Levy’s *de novo* vs. *de re* reading of modeling building as a test. If the case can admit a *de re* reading, it is not analogous to works of fiction, and if it does not, if it *only* admits *de novo* reading, then it is very much analogous. Does it make sense to think of a particular piece of metal plate (with a positive charge hovering above it) as a negative point charge and proceed to seriously talk about a charge distribution on the plate in terms of an imagined negative charge at an imagined location? If that is possible *de re*, then it is equally possible to talk about an able (actual) detective as Sherlock Holmes *de re*, if the description of Holmes better illustrates her. I assume the latter is not appropriate, and therefore our test is negative: there is no way of giving a *de re* reading of Teller’s case and many other similar cases. These models are just like works of fiction proper.

However, Giere doesn’t think this model involves any work of fiction, his reason being that there are two models involved here. An actual (or concrete) system of a charge above a metal plate is first *idealized* into a model of a charge above an *infinite* model plate, and then this model is replaced by a effectively equivalent second model, and that is the model with the imaginary negative charge on the opposite side of the infinite plate. This analysis is certainly correct and yet I do not see how the second model is not a work of fiction, unless Giere’s point is that the first model, which only involves idealization, is the real and the only significant model and it does not involve fiction. However, without the second entirely imaginary model, the idealization in the first model is in vain; in fact, the idealization taken to make the metal plate infinite makes sense only if one is going to introduce the imaginary negative unit charge.[[8]](#footnote-8) So, the two models taken as a whole involve idealization and fiction.

There are similar cases in geometric optics, such as the virtual object in the two-lens system (see Virtualobject). Scientists who invent and teach such models have the good sense of correctly calling them “virtual” objects or models, which in our sense, the sense used in the model-fiction literature, means “fictional.” (Also see Rowbottom 2011 for another interesting case: the introduction of virtual particles to explain the Casimir Effect.)

However, there are examples of scientific models that obviously do not belong to the type of imaginary or “virtual” objects, but are they like the common sort of models, such as the simple pendulum and ideal gas, which should not be regarded as fictional, as we have argued along with Giere in the previous section? Are they *sui generis* and if so, are they fictional in any proper sense?

Harmonic oscillators as a type of models might be thought of as posing some difficulty. One might think on behalf of Giere that no difficulty exists because “harmonic oscillator” names a class of different systems, such as the pendulum system and the electric circuit, each of which is a model that represents its target in a normal (i.e. nonfictional) way. This may appear to be the right diagnosis if the matter stops at that. However, when computer simulation technology becomes available, scientists can easily construct and study a “harmonic oscillator” in a simulation that is neither a pendulum nor an electric circuit nor anything that exists in reality but simply a harmonic oscillator. There is the concrete model system that the term refers to that does not exist in reality, nor is it an obvious idealization of something that does exist in reality. The computer-simulated harmonic oscillator is obviously neither an idealized pendulum nor an idealized electric circuit nor any sort of ordinary (or recognizable) physical oscillators. And there are plenty of simulated or simulatable models in science, especially in today’s science, that are like the harmonic oscillator. They are conjured up by scientists to study a wide variety of systems whose behavior exhibit sufficient similarities to one another such that a general/generic description is given and a virtual object as a particular thing is generated by a computational device.

 The second sort of models that may create problem is a grab bag of items. We couldn't help but notice that in Teller’s example, an infinite metal plate is first introduced to set up the model in which the charge distribution of an actually large but finite metal plate is represented and calculated. The size is obviously an idealization but it is clearly introduced for convenience. In other words, one could just as well use a very large but finite metal plate for the calculation, even though the task is more difficult and the result so close to the ideal case that introducing the infinite plate, though not strictly necessary, makes a lot more sense. There is a type of model in science in which taking the limit of infinity – call them infinity models – is *necessary*, at least necessary for the theoretical framework in which such models are invented and used. For the Teller example, the charge distribution won’t be “ill-defined,” or simply indefinable, even if the plate is not imagined to be infinitely large; and yet there are phenomena such as phrase transitions in condensed matter physics where without an infinity model, the target phenomenon, such as the boiling of water through which the liquid turns into vapor wouldn’t even “occur” in its theoretical framework. The problem with not having such phenomena occurring in the framework is that the framework cannot provide any explanation for why such simple events as watering boiling and turning into steam occur in nature. And if the framework is deemed with good reason the only plausible option, then we’ve got a problem.[[9]](#footnote-9)

 However, suppose we ask why this type of models should be thought of as special. Some sense of “infinity” seems to be implicit in all idealization cases; for example, isn’t making a surface frictionless the same as making the fiction infinitely small? Or isn’t making the earth a point and its orbit a curve the same as reducing the size of the planet and its orbit to infinitely small? Here are the important differences. First, relaxing the ordinary “infinities” – restoring small sizes and thin tracks – results in messier but in principle manageable and similar outcomes. That’s why we say the results of such idealizations are approximate. Some such idealizations are indeed later relaxed theoretically, as with the model of van der Waals’s “real” gas. This maneuver is not possible for the infinity models for phase transitions and critical phenomena (PT&CP henceforth). No finite model that provides non-rigorous explanation, such as the “mean-field” model, can be regarded as the result of relaxing the infinity idealization (cf. Stanley 1971, Liu 1999, Callender 2001). Second, no model of the ordinary infinity sort needs to introduce the infinity in order to even “have” the actual phenomenon, such as boiling water, it represents. When friction is completely removed, the rolling ball will move on forever in the same velocity, which is no actual phenomenon that Galileo needs to account for with his theory; it is rather a principle that may be displayed in the ideal situation.

To see these points clearly, let us look at one of the simplest infinity models for PT&CP in some details. To some extent this model resembles the harmonic oscillator I mentioned earlier. Different systems or phenomena, such as gases and magnets or evaporation and ferro-magnetization, have different models and equations, and yet the idea and structural features of this model applies to all such systems that undergo PT&CP. And very much like in the case of the harmonic oscillator, a computer-simulated system can be created that is independent of the details of the actual systems involved. What is different and distinguishes this model (and those of its type) from other abstract models is the necessity of taking the limit of infinity for the *possibility* of the actual phenomena (i.e., PT&CP) and for supplying explanations for them.

 The model is known as the Ising model (cf. Stanley 1971), and the same mathematical structure can be applied to magnets as well as to fluids (e.g. lattice gas). One may construct such a model of any dimension, but the least complex Ising model for studying PT&CP is the two dimensional one. Imagine a large two-dimensional spatial region in which N “sites” (positions in space) are spread out at equal distance, where N is a large integer. Each site is endowed with one simple binary property, *si,* and between any two sites a coefficient, *J*, such that for any distribution, d, of *si* (*i ∈ N*), we can define a “moment” function,

, (1)

and a near-neighbor “connection” function

, (2)

for all the adjacent pairs *<i, j>* of sites in the lattice. This function has the same dimension as the Hamiltonian of the system.

Imagine again a global parameter T that is associated with the sites’ ability to switch from one to the other value of *si*, such that it and *J* are the only two global parameters of the lattice that determine the probability of any given distribution of the values. With such a model, it is known that the Boltzmann distribution of the values of *si* applies, and therefore, the probability of a given distribution, d, should be,

, (3)

where *k* is the Boltzmann constant, and *Z* “the partition function,” a special function that provides the weight to the probability such that it adds up to unity. This model can be used to study a magnet (e.g. for its ferromagnetism) if the binary values of the sites have + or -; or we can use it to study fluids if the values are 1 or 0 (occupied or not occupied). And the model is only good for thermal systems in equilibrium *near the critical temperature*, for it does not hold for anything far from that temperature regime. It is a remarkable fact that near the critical temperature, systems that are otherwise radically different in physical composition and structure are remarkably similar or essentially the same thing, endorsing the cliché: “it’s nothing but a bunch of molecules.”

 Here is in a nutshell what the “problem of PT&CP” is and how it is resolved in mathematical rigor. And it also shows why the “infinity models” are rather perculiar. [[10]](#footnote-10) Thermodynamic quantities of a system are represented in thermo-statistical physics as the weighted (e.g., with a probability measure as in eq. (3)) averages of the system’s molecular quantities. Mathematically, we can express them as various derivatives of the partition function *Z* for the system. (For instance, the pressure *p* is  (i.e. partial derivative under constant temperature T), where  is the free energy and the main connection via *Z* to the molecular quantities.) Phase transitions happen at a critical temperature and are expressed as singularities (in terms of divergent derivatives) in the thermodynamic quantities. Translating this into statistical mechanics, it turns out that phase transitions are possible only if there are positive solutions to the equation, *Zgran = 0*, (which will make, e.g., *dp/dV,* at the critical temperature divergent).[[11]](#footnote-11) However, it is proven that for any finite models of the Ising type, no such solutions are possible (known as the “no-go” theorem of PT&CP). And such a solution appears when we take N to infinity (while keeping the model’s density finite). This becomes known as taking the thermodynamic limit so as to make sense of PT&CP in statistical mechanics. What is special about this and other infinity models, what distinguish them from the other typical idealized models, such as the frictionless plane and nonviscous fluids, is shown by the “no-go” theorems attached to them: *without going to infinity, one cannot even “find” the phenomena in question much less to begin studying them and look for explanations*.[[12]](#footnote-12)

Another crucial area in physics that needs infinity models is that of quantum measurement. When a quantum system in an entangled state of some observable, such as its momentum or spin, is measured for the values of that observable, the state “collapses” into a particular eigenstate of the observable in which a definite value is obtained (e.g. spin up or down). This so called collapse that destroys the coherence of a quantum entanglement, which constitutes the quantum measurement “process,” is no ordinary physical or causal process a quantum theory can account for, and has generated over the years competing interpretations of quantum theory in which the process is either explained away or made more realistic. Among the many alternative interpretations, the decoherence solution to the quantum measurement (QM) problem has, for what it worth, garnered the most support from working physicists (cf. Joos et al. 2003). The best version of the decoherence model of QM is to conceive the environment of any QM experiment, which according to the model produces a complete dissipation possible of the coherent state, as an infinite system. The disentanglement as expressed mathematically is an asymptotic process that approaches its completion only as the size of the environment approaches infinity. Just as no transition in PT&CP is possible without taking the infinite limit, no definite values can emerge from QM unless a similar sort of limit of infinity is taken.[[13]](#footnote-13)

These *infinity models* (models that carry “no-go” theorems for any of their finite versions)[[14]](#footnote-14) are certainly not like the virtual models simply because they are impossible systems, while the latter, though obviously unreal, are all ordinary systems that are imagined to be where they are not. We *pretend* that the charge is there for some equivalent effects, and that’s why such models are so much like the fictional characters. The infinity models seem to be the opposite: we know that PT&CP is real and QM actually happens regularly, and yet what makes them happen, if the models are literally believed, is impossible.

Again, when we are dealing with the sort of idealization that amounts essentially to *neglecting the negligible*, such as ignoring the small effect of friction on a smooth surface or through thin air and ignoring the sizes of, and interactions among, the molecules in a diluted gas, the resulting “unrealistic” models can be modified towards more realistic models with specifiable rules. In most cases, what needs to be done mathematically is to introduce modification factors in the equations of motion (or of state) such that their adjustable values may be obtained empirical (i.e. through matching with the experimental data). The prime example of this can be clearly seen in the transition from Boyle’s equation of state for ideal gas to van de Waals’s equation for “real” gas: , where the “a” and “b” are the factors for interaction and volume, respectively.

To generalize a bit, here seems to be two necessary conditions for this and other similar types of idealized models.

1. The modification factors must be introducible at the same level of description that the original idealized models are on.

2. If the models are mathematically given, the factors must be introducible into the same equations we get from the original models.

These are necessary simply to ensure that what is “idealized away” is indeed negligible and the resulting models of such idealizations are close to being correct.

None of the infinity models I discussed above satisfy either of these conditions. The only alternative to the Ising model and its derivatives, as I mentioned above, is the mean-field type models for PT&CP. It begins with a quantum mechanical model and its Hamiltonian, but then going beyond the quantum level, a “mean,” i.e. average, field is added to mimic the intermolecular interaction that is of long-range. This field is *macroscopic* (i.e. not quantum-mechanical) and the equations that show CP below the critical temperature are not the same type of equations as Ising type models give. The situation is even worse for the QM problem. Apart from the Bohmian Mechanical Interpretation, which adds non-quantum mechanical elements to quantum mechanics, no solution to the problem exists without an infinity model.[[15]](#footnote-15)

Moreover, we can think of describing real but diluted gases as ideal gas in the *de re* mode, but it does not seem that we can describe phase transition or quantum measurement in the same way.

**4. Microscopic Models: Idealization or Fictionalization?**

 When philosophers of science talk about modeling and idealization they often assume that one cannot do the former without the latter. Degrees of idealization may vary greatly from one job of modeling to another, but some amount must be involved, for otherwise there wouldn’t be a point of model building. However, if one seriously reflects on such models as the Crick-Watson model of the DNA molecule or Rutherford’s model of the hydrogen atom, it is not clear that specific idealizations, as I explained earlier, are taken there at all. We can probably safely assume that the models in these and other similar cases are simpler than their target systems, but what we don’t know and should really not assume that we know is whether the simplification is gotten through *idealization* (cf. Lakhtakia 1996, Watson 2001, and also Karp 2013, ch. 13).

 People who are not convinced that anything can be said intelligently, if intelligibly at all, about the division of the observable and the unobservable, people who tout a hardline version of scientific realism, may object by saying that we can and do observe the structure of a DNA molecule or a hydrogen atom, and it is of such observable structures that the models are made as a result of precise idealization. The objection is flawed in that the Crick-Watson model of DNA is a mechanical/combinatorial model while the target system is a biological/living thing. We may be able to “observe” the combinatorial patterns of the bases in a DNA molecule, but how the bases are chemically and biologically connected and what makes such connections work is not represented in the model. There is no sense in which neglecting these aspects in the model is the result of idealization, anymore than my daughter’s use of a piece of Paz candy dispenser as her dad in a play, which very much simplifies the interactions among family members, may be counted as an act of idealization. If we are supposed to also regard these modeling practices as no more than the results of idealization, then I think it is fairly obvious that we couldn’t simply agree with Giere, as I quoted him earlier, that we should say, “Idealizations, abstractions, and approximations, yes. Fictions, no.” (Giere 2009, 254)

 The point may be more obvious for Rutherford’s model of hydrogen atoms. The “solar-system” model that Rutherford advocated sometime in early 20th century can hardly be viewed as a model of idealization or abstraction. True, we have some experimental observations regarding the interior of atoms from Rutherford and his research group. When the alpha particles from high-speed bombardments of gold film are scattered afterwards in a certain pattern, the interior of the atoms that creates such a pattern must be of a certain sort and the “solar-system” simile fits quite well. A piece of brilliant analogical reasoning, perhaps, but obviously not a carefully constructed idealization or abstraction.

 One may object at this point by asking: what is the difference between analogy in modeling and idealization or abstraction? Are they not more or less the same sort of practice? No, they should not be taken as the same sort of scientific method (broadly construed), and the models we obtain by using them do not appear to be of the same type. To see this point, let us begin with Rutherford’s solar-system model for hydrogen atoms (cf. Lakhtakia 1996). In a rough and ready manner, let us reflect for a moment on how that model might have been conceived.[[16]](#footnote-16) There was evidence for the existence of electrons as small particulars that are freed from atoms; and since atoms are neutral in charge, there must be positively charged elements in them. Rutherford’s scattering experiments seemed to show that most of the space in an atom is “empty,” which implies that the positive charge must also be concentrated in small particles. The nature of electric charges, namely, how opposite charges attract and same charges repel, was also well known. Given the size and the empty space of an atom, the electrons must be moving rapidly around the nucleus of positive charges in order to maintain that space. From these pieces of evidence and perhaps the unconscious awareness that the same patterns are often repeated at different scales in Nature, Rutherford’s model for atoms was born. Nowhere in this process is idealization or abstraction involved. The fact is that there couldn’t be observable data that directly show what how exactly are the charges distributed inside the hydrogen atom. Therefore, the conjecture that the distribution must be similar to the mass distribution in a one-planet solar system has no base to be idealized and abstracted from.[[17]](#footnote-17)

The Rutherford model is clearly a brilliant piece of Analogical Reasoning, and this is modeling in the conception of Mary Hesse (1966).

 According to Hesse, the quintessential character of analogical modeling is setting up a system that resembles something we are already familiar, or at least know better, and that share properties with the modeled system that appear to be essential to it. That is how electromagnetic waves in the luminiferous aether (according to the 19th century conception of aether) are modeled by waves in fluid (cf. Hesse 1966, 11, also see Whittaker 1910). The problem of what the medium is that carries light through space emerged after unequivocal experimental evidence appeared to support the wave theory of light. However, like space itself, the optic aether is not observable and therefore it is not possible to find out what light waves are like in the same way we can find out what waves in fluids are like. Because aether transmits a stuff that produces comparable effects as produced, e.g., by waves in fluid, analogical reasoning suggests that a model of aether be constructed from our knowledge of fluid. If we bring in the Maxwell equation for light waves and compare it to the mechanical equation of waves in fluid; and couple that with the measureable effects of both types of waves, we have what Hesse defined as the positive analogy. Assuming the general causal connection between a wave and its medium, we can set up a model, as Lord Kevin did, for the optic aether that goes beyond those aspects that it shares with the fluid waves.

It is obvious that idealization (and approximation) is not the method by which this type of modeling is done: what small bumps must be taken away from the aether or small gaps or holes be filled or viscosity among parts that renders it less than perfectly rigid along the direction perpendicular to light beams, what anything of this sort could be carried out in order to come up with an aether model for electromagnetic waves?

 The same can be said and must be true in equal measure regarding the modeling of Rutherford’s atoms. Rutherford and his colleagues (Hans Geiger and Ernest Marsden) did get glimpses of what the interior of atoms is like from how particles passing through them behave, and yet his model can only be viewed as the result of analogical reasoning. And it had to be so primarily because it was not feasible to come up with such a model by, among other things, acts of idealization.

 Again, this is radically different from how models for pendulums or the solar system are made. With Boyle’s model of ideal gas, different options are possible, because it may be a borderline case. It all depends on whether it is plausible to regard the idea of diluted gas as comprising mostly free molecules as deriving from “observation” or from speculation by means of analogy. I regard the former as most reasonable and therefore with good reason we should take the “ideal gas” model for what its name signifies: a product of idealization. The mechanical differences among different molecules are neglected, their sizes are made to vanish, any interactions among them are also removed, and so on. Voila, out drops the model, a perfect product of idealization.

 However, one should not take the above point to be that there are no *actual* acts of idealization/abstraction in modeling the unobservable and there are no *actual* analogy used in modeling the observable. The point is the following.

1. Whether or not a modeler thought she has got her model of an unobservable system directly from idealization/abstract, she couldn’t possibly have succeeded if she did.

2. Whatever reason by analogy a modeler used in coming up with a model of an observable system, she could have gotten an equally legitimate model through idealization/abstraction.

Hence, my point is about possibility not about what is actually done, which often includes misidentifications. It is not my intention to argue that idealization and analogy are the only methods by which models in science are built. But one thing seems true enough, namely, if idealization can properly be used for the modeling of the unobservables, there must be a separate hypothesis about what the objects are like from which the idealization is taken, which is independently well confirmed. To put the point dramatically, Boyle’s model would not have been a good model had there been good evidence that gas is a continuous fluid.

Let me now return to our central question about which models in science are fictional. After the foregoing analysis should we say that models of the apparently unobservable systems, which cannot be gotten from idealization, should be regarded as works of fiction? To answer this question in any clarity, let us first reflect on the senses in which we can attribute fictionality to a model without getting into obvious trouble with ontology. To begin with, there is no such trouble with the obviously fictional models of imagery charge and virtual objects. With such cases, “fictional” simply means ontologically nonexistent: the charge does not actually exist nor does it represent anything that actually exists; it is there to stand in for an equivalent physical effect. This point is similar to what we regard fictional things ontologically: Orwell’s Animal Farm (to use one of Godfrey-Smith’s examples 2009) neither actually exists nor represents any actual places, or anything else, for that matter.[[18]](#footnote-18)

The infinity models are very different, for though physically impossible, they can be understood as representing something real, namely, the *actual* *finite* systems in which the critical phenomenon or the quantum measurement takes place. But they are marked off by a subtle and yet nontrivial feature. There is little doubt (i.e. for independent reasons) that the actual systems they are supposed to represent are finite, and yet according to the model, no PT&CP or QM can take place in such systems (because of the “no-go” theorems). If the theories which contain the infinity models are true or approximately true, it cannot be about the actual systems; it can only be about the infinity models, which in turn represent what happens in the actual PT&CP or quantum measurements in some indirect and unspecifiable manner. Again, it is similar to the fact that the Middle Earth neither actually exists nor represents any actual place, and yet the fictional story tell us about Medieval Europe in a way not easily specifiable exactly. (Think about the inscrutability of the many alternative literary theories about what and why we learn from fiction.)

 Models for the unobservable, even if fictional, are not fictional in the same sense as the virtual models, nor do they appear to be similar to the infinity models. They are in general by no means physically impossible. Were it not for the generic feature of representing the unobservable, they are just like regular models. Imagine that there are, or we can create, intelligent beings that can change their sizes at will and therefore could on demand shrink themselves to the size of electrons and get into an atom and obtain a sense impression of its interior. Afterwards, they grow back to our sizes and show us verbally or by pictorial depiction what the interior of an atom is like. A model based on such a report would indeed be an ordinary model from idealization and have nothing to do with fiction, as Giere has so convincingly argued – they would have to answer to the facts about the atom’s interior that the creatures provide us. The same thing could be imagined for any other models for the unobservables, and such models would not be ones from analogy but from standard idealization/abstraction procedures.[[19]](#footnote-19) In other words, models for the unobservable could have been regular models in a world of make-believe. As is, such models are more akin to the infinity models than to the regular ones.

**References**

Callender, Craig (2001) Taking Thermodynamics Too Seriously *Studies in History and*

*Philosophy of Science Part B* **32**:539-553

Callender, Craig & Jonathan Cohen (2006) There Is No Special Problem About Scientific Representation *Theoria* **55**: 7-25

Cartwright, Nancy (1999) *The Dappled World: A Study of the Boundaries of Science*

Cambridge: Cambridge University Press

Contessa, Gabriele (2009) Scientific Models and Representation, in Steven French and J.

Saatsi eds. *The Continuum Companion to the Philosophy of Science*

Contessa, Gabriele (2010) Scientific models and fictional objects *Synthese* **172**:215–229

Field, Hartry (1989) *Realism, Mathematics and Modality* Oxford: Blackwell

Fine, Arthur (1993), "Fictionalism", Midwest Studies in Philosophy 18:1-18.

Frigg, Roman. (2010a). “Models and Fiction,” *Synthese*. **172** 251-268.

Frigg, Roman. (2010b). “Fiction and Scientific Representation,” in R. Frigg, M.C. Hunter (eds.), Beyond Mimesis and Convention, Boston Studies 97 in the Philosophy of Science 262, Springer Science+Business Media B.V., 97-138.

Frigg, R. (2011). Fiction in Science, in Woods, J. ed. *Fictions and Models: New Essays.* Munich: Philosophia Verlag (forthcoming).

Giere, Ron (1988). *Explaining Science: A Cognitive Approach*. Chicago: Chicago

University Press

Giere, Ron (2002)How Models Are Used to Represent Reality *Philosophy of Science* S742-

S752

Giere, Ron (2009) [Why Scientific Models Should not be Regarded as Works of Fiction](http://www.tc.umn.edu/~giere/WSMSNRWF.pdf),

In Mauricio Suárez ed.*Fictions in Science: Philosophical Essays on Modeling and Idealization* 248-258 (Routledge)

Giere, Ron (2011) Representing with Physical Models, in Paul Humphreys & Cyrille

Imbert eds. *Models, Simulations, and Representations* (Routledge)

Godfrey-Smith, Peter (2006) The Strategy of Model-Based Science *Philosophy of Biology*

**21**:725–740

Godfrey-Smith, Peter (2009) Models and Fiction in Science *Philosophical Studies* **134**:

101-116

Goodman, Nelson (1976) *Languages of Art: An Approach to a Theory of Symbols*

Indianapolis: Hackett Publishing Company, Inc.

Hesse, Mary G. (1966) *Models and Analogies in Science* Notre Dame: University of Notre

Dame Press.

Joos, E. at el. (2003) *Decoherence and the Appearance of a Classical World in Quantum*

*Theory* 2nd ed. Berlin: Springer-Verlag

Karp, Gerald (2013) *Cell and Molecular Biology: Concepts and Experiments* 7ed. Wiley and

Sons

Keller, Evelyn Fox (2002) *Making Sense of Life: Explaining Biological Development with*

*Models, Metaphors, and Machines* Cambridge, MA: Harvard University Press

Kripke, Saul (1971) Semantical Considerations on Modal Logic, in Linsky, L ed. *Reference*

*and Modality* Oxford: Oxford University Press

Kripke, S.aul (1972) *Naming and Necessit,* Cambridge: Cambridge University Press

Lakhtakia, A. ed. (1996) *Models and Modelers of Hydrogen* Singapore: the World Scientific

Levy, Arnon (2012) Models, Fictions, and Realism: Two Packages *Philosophy of Science* **79**:

738-748

Levy, Arnon (2010) Fictional Models *De Novo* and *De Re* (preprint)

Liu, Chuang (1999) Explaining the Emergence of Cooperative Phenomena *Philosophy of*

*Science* **66**: S92-S106.

Liu, Chuang and Gerard Emch (2005) Explaining Quantum Spontaneous Symmetry

Breaking *Studies in History and Philosophy of Modern Physics* **36**: 137-163

Rowbottom, Darrell P. (2009) Models in Biology and Physics: What’s the Difference?

*Foundationsof Science,* **14**: 281-294.

Rowbottom, Darrell P. (2011) The Instrumentalist’s New Clothes *Philosophy of Science* **78**:

1200 - 1211

Ruetsche, Laura (2011) *Interpreting Quantum Theories* Oxford: Oxford University Press.

Stanley, H. Eugene (1971) *Introduction to Phase Transitions and Critical Phenomena* Oxford:

Clarendon Press

Suárez, Mauricio (2004) An Inferential Conception of Scientific Representation *Philosophy of*

*Science* **71**: 767-779

Suárez, Mauricio (2009a) Fictions in Scientific Practice, in Mauricio Suárez ed. *Fictions in*

*Science: Philosophical Essays on Modeling and Idealisation* Routledge: 1-15

Suárez, Mauricio (2009b) Scientific Fictions as Rules of Inference, in Mauricio Suárez

ed. *Fictions in Science: Philosophical Essays on Modeling and Idealization* Routledge:

158-178

Thomasson, Amie (1999) *Fiction and Metaphysics* Cambridge: Cambridge University Press

Teller, Paul (2001) Twilight of the Perfect Model Model *Erkenntnis* **55**: 393-415

Teller, Paul (2009) Fictions, Fictionalization, and Truth in Science, in Mauricio Suárez

ed. *Fictions in Science: Philosophical Essays on Modeling and Idealization* Routledge: 253-247

Toon, Adam (2010a) The Ontology of Theoretical Modelling: Models as Make-Believe

*Synthese* **172**: 301-315

Toon, Adam (2010b) Models as Make-Believe, in Roman Frigg and M. Hunter eds. *Beyond*

*Mimesis and Convention, Boston Studies in the Philosophy of Science* 71-96, Dordrecht: Springer

van Fraassen, Bas (1980) *The Scientific Image* Oxford: Clarendon Press

van Fraassen, Bas (2008) *Scientific Representation: Paradoxes of Perspective* Oxford: Clarendon Press

Virtualobject: http://science.sbcc.edu/~physics/flash/optics/virtualobject.html

Walton, Kendall L. (1990) *Mimesis as Make-Believe* Cambridge, Mass: Harvard University Press

Watson, James D. (2001) *The Double Helix: A Personal Account of the Discovery of the Structure of DNA* Touchstone

Whittaker, E. T. (1910) *A History of the Theories of Aether and Electricity: From the Age of Descartes to the Close of the Nineteenth Century* London: Longmans, Green, and Co.

Yablo, Stephen (1998) Does Ontology Rest on a Mistake? *Supplement to Proceedings of the*

*Aristotelian Society* **72**/1: 119-37.

Yablo, Stephen (2010) Go Figure: A Path through Fictionalism, in *Things: Philosophical*

*Papers 2* Oxford University Press, 177-199.

1. This statement is only true when we are comparing the original or near original acts of model-making and fiction-making. If we are thinking about a secondary act of descriptively reporting on what one read in a textbook in which a pendulum is given as an example as oppose to reporting on reading the “Adventure of Sherlock Holmes,” then there is indeed little difference. However, we can rarely give any evaluation of ontological commitments by looking at such secondary acts. [↑](#footnote-ref-1)
2. Essentially identical reasons can be found in Walton (1990, 70-73), where scientific textbooks are simply included in the category of non-fiction. Note, “[w]orks of nonfiction do not, in general, qualify as representation in our special sense. (70)” [↑](#footnote-ref-2)
3. Regarding idealization in science or in fiction, there may well be a difference between the practitioners’ attitudes towards it and their actual usage of it. It might be argued that with respect to what they actually do in their works, fiction writers use just as much idealization as modelers in science. However, there is no question that writers condemn idealization while modelers extol it. Try to imagine asking Philip Roth to tell you how much he cleaned up one of his characters, David Kepesh, to please his readers or critics. Wouldn’t you be kicked out of his house? While Stephen Hawking might take great pleasure to tell you how cleverly he idealized in getting his blackhole model so that it yields critically acclaimed results. [↑](#footnote-ref-3)
4. It may seem that we often add things to effect idealization, such as when we add points to make an otherwise discontinuous object a continuous one in a model; however, one can easily conceive of that as “taking away” the *gaps* between the parts of the object. For the sake of conceptual uniformity, we should always regard acts of idealization as removing characteristics from actual systems so as to create uniformity and abstraction. [↑](#footnote-ref-4)
5. One may object to this point by saying that modeling in science is more like historical fiction, where real people are fictionalized, just as in science real things are fictionalized in models. This is indeed a valid point, but then the further point about being held accountable against facts, as I have pointed out earlier, would prevent models from being compared or identified with works of historical fiction. [↑](#footnote-ref-5)
6. Frigg (2011a) distinguished “Two Kinds of Fiction” in science, and what is discussed in this section may in some sense be seen as belonging to the first kind. Since my overall conception of fictional models in science is different from Frigg’s, a simple identification is not appropriate. [↑](#footnote-ref-6)
7. The fictional negative charge is supposed to be where the “lines” of the electric field from the positive charge above the metal plate would “end up.” By imagining its presence at that location simplifies the finding of the distribution of the “field-lines” on the surface of the metal plate. [↑](#footnote-ref-7)
8. If the metal plate is conceived as having edges, the “field-lines” from the positive charge will bundle up at the edges, and therefore replacing the plate with the negative below its surface would no longer be a good model. [↑](#footnote-ref-8)
9. There is a controversy over whether the infinity model is necessary for understanding PT&CP (cf. Liu 1999, Callender 2001). But there is no doubt that within the mathematical physicists community, the infinity models are currently the best rigorous models. So the philosophical question is not what these infinity models are and signify but whether modeling finite system with infinite models is on sound foundations. [↑](#footnote-ref-9)
10. For details of how a thermodynamic function is related to a function in statistical mechanics, see any standard textbooks on the subject or see Liu 1999. [↑](#footnote-ref-10)
11. This is not strictly correct, but it conveys the idea. *Zgran* is the partition function of the grand canonical ensemble; for details see Liu 1999.

 [↑](#footnote-ref-11)
12. A qualification is here in order. There are finite models (albeit still idealized) that exhibit PT&CP (and other phenomena that require the infinity models), for instance, the mean-field models, but interestingly, all such finite models require the introduction of some essentially non-statistical-mechanical elements in order to reproduce the phenomena in question. All exact microscopic models require going to infinity. For a different view on this issue, see Callender 2001. [↑](#footnote-ref-12)
13. There is also a “no-go” theorem for QM cases, which is known as the von Neumann-Stone theorem and which roughly says that for quantum systems represented in a Hilbert space, no physical processes can reduce an entangled state to a mixture of pure states. [↑](#footnote-ref-13)
14. For many excellent examples of such models, see Ruetsche 2011. [↑](#footnote-ref-14)
15. The solution attempted in the algebraic approach to quantum theory in terms of quantum spontaneous symmetry breaking (cf. Liu & Emch 2005) also requires taking the infinite limit. [↑](#footnote-ref-15)
16. The argument here is necessarily speculative for two main reasons. First, it is very unlikely that Rutherford or any of his collaborators would have left any remarks on whether it was “idealization” or “analogy” or any other method that he actually used in coming with the model. Second, that is probably because he and his collaborators didn’t even think about such a question when they were constructing the model. They might be aware that some sort of analogous reasoning was involved, but what sort exactly and whether is might be regarded as a species of idealization couldn't possibly be on their mind at any time of their career. [↑](#footnote-ref-16)
17. True, the electron and the nucleus might be idealized as point particles and there are some other such idealization being taken into consideration, but they are subsequent to an already constructed model, the solar-system-like model, and they are not essential to the model because nobody can use the point-and-curve-orbit structure to calculate, e.g. how fast the electron revolves around the nucleus. [↑](#footnote-ref-17)
18. Godfrey-Smith (2009) believes that fiction represents actual people or places in a more straightforward manner: ‘Tolkein's "Middle Earth" is fairly similar to the world of Malory's King Arthur tales (Morte D'Arthur)’; and ‘the events in Orwell's Animal Farm are similar to those in Russia in the first part of the 20th century (2009, 5-6).’ But these are not the sense in which models in analogy represents their target systems. Fictional characters or events may have some original “models,” but they are by no means what fictional creations represent or even about. If the Animal Farm is, like Rutherford’s model being about hydrogen atoms, only about early 20th century Russia, Orwell’s fiction would have been in the dustbin of literature and few people would have known its existence. [↑](#footnote-ref-18)
19. For the aether model of electromagnetic waves, the imagination needs to be more fanciful than most science fiction writings. The creature would have to be able to change its characters from normal material made of atoms, say, to extraordinary material made of aether such that it could perceive the medium in the way we perceive regular material. And then it has to be able to change back to tell its story. Unlike changing sizes, this may not be physically possible. [↑](#footnote-ref-19)