The Ramsey sentence as a philosophical tool: a viability study

MSc Thesis *(Afstudeerscriptie)*

written by

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Abstract

This thesis concerns itself with the device of Ramseyfication and the philosophical uses given to it. Via this device, we are able to quantify over the theoretical terms of our theories, subtracting content that otherwise could be problematic. The Ramsey sentence (RS) is commonly used in philosophy of science to tackle the problem of pessimistic meta-induction, as well as achieving indirect reference to theoretical terms. The aim of this thesis is to detail the uses of Ramseyfication and address the mathematical and philosophical concerns raised against them. The main goal will be to ascertain the viability of RS a philosophical tool, yet many other results will be reached along the way.

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1 Introduction

The aim of the present essay is to examine a tool employed in the philosophy of science, the Ramsey sentence (RS). What this device allows us to do, in short, is to substitute all theoretical entities in our scientific theories by existential quantifications. This is done by the defendants of certain forms of (structural) realism in order to bypass some difficulties that stem from the use of said entities. In following, my goal will be partly to elucidate what problems are these and whether they are surmounted by the Ramseyfication process. Additionally, it can be the case that the Ramsey sentence solves certain problems at the expense of bringing in others, so I also concern myself with the problems specifically derived from the use of RS.

Ramseyfication is used by the philosophers of science in order to be able to talk about theoretical entities without any commitment or direct reference to them. They see this as a way to bypass the concern of Pessimistic Meta-Induction(PMI) among others. Additionally, some authors find it controversial to refer directly to theoretical entities, so they employ the RS as a means to allude to them by description. Lastly, some consider RS as an apt tool to define the theoretical terms as members of a realisation of the theory. Chapter 2 formally defines the Ramsey sentence and explores these applications in depth, as well as the original use of Ramseyfication proposed by Carnap.

The third chapter goes on about the mathematical intricacies of the RS. In particular, I will explore Newman's objection, which especially threatens the prospects of any such definition of theoretical terms. Nonetheless, I will also explore how this poses difficulties to the defendants of structural realism in more than one way. Additionally, I will also explain one of the strategies to deflect the problem and how it fails, but not without providing us with some useful tools. Lastly, I conclude the chapter by providing a positive characterisation of

the model-theoretic significance of the Ramsey sentence.

This is, after all, a philosophy thesis, so following these mathematical results I undertake the task of examining their philosophical relevance. Chapter 4 is concerned precisely with how philosophers synthesize the mathematics into concrete theses and defend their positions against them. I will explore two types of defence of structural realism and one attempt at safeguarding the definition of theoretical terms. After evaluating these strategies I conclude the section by introducing and close-examining an additional result. By the end of the chapter I will have boiled down the main theoretical concerns to three, whose discussion will constitute the content of chapter 5.

My exposition finalises with a conclusion in which I take a stance as to whether a philosopher of science should or should not adopt Ramseyfication as a theoretical tool, relativising my response to the original position they would be trying to defend. Thus, by the end of this thesis I will have arrived at an answer concerning the viability of the Ramsey Sentence as a philosophical tool.

Lastly, a disclaimer. This thesis concerns itself with a formal tool employed in philosophy. My main goal will be to elucidate whether the applications of it in the field of philosophy of science are legitimate or not, and to do this I will be exploring different positions, in particular concerning the debate realism/anti-realism. Nonetheless, this should not mislead the reader. My aim is not to take a stance regarding this or any other debate, but to examine a device in sight of its applications.

2 Chapter 2: Ramsey Sentences

If I am to address the problem of the applicability of RS the first thing I ought to do is to formally define what are these and how they came to be. Therefore, the following chapter is dedicated entirely to that. Section 2.1 explores the genesis of the concept in relation to the philosophical issues it was conceived to address. I will talk about logical empiricism and the necessity Carnap had for a new understanding of scientific theories. And the same that there's no hammer without nails we can't understand Ramsey Sentences without their purposes. Thus, the remaining sections explore and outline the different uses of RS in the philosophy of science, relating them to the relevant authors and publications. In particular, I explore the relation between RS and structural realism and to the definition of theoretical terms. Additionally, I explore the idea of an 'upward path'. We wind up, finally, with a better understanding of the tool we are examining, as well as of the goals towards which it is employed.

But I can't talk about RS without first addressing the observational/theoretical distinction. Put in simple terms, there are some objects we can observe, like a table or a chair, and some we can not, like an electron. If a term refers to an observable entity then it is observational, and otherwise theoretical. While on some cases it is obvious whether an entity is observable, there are some others where discussion might arise. Is a DNA molecule observable? What about a erythrocyte? Some claim that observable is only what we can see with our bare eye (van Fraasen, [Van85]), whereas some have a different criteria and admit for cells to be observable, for example.

Ambiguous as this might be, it is not the aim of this thesis to address this problem. I will put this to the side and revisit it in further chapters. For now, let us just keep in mind that the Ramsey sentence procedure assumes some sort of o/t distinction. Our focus will be, rather, on the role of theoretical terms

in theories and the point up to which they are dispensable for the goals of science. That is, I will be concerned with whether we can attain the goals of scientific practice and certain philosophies of science when doing away with the theoretical terms.

2.1 What are RS?

The invention of the Ramsey Sentence is due to Frank Ramsey who introduced them in his article 'Theories' of 1929 [Plu31]. The idea was that one can get any finitely axiomatisable scientific theory and take the conjunction of all its statements $\varphi_1 \wedge ... \wedge \varphi_n$ and call that the sentence of the theory. Naturally, in said sentence (hereinafter referred to as T) all types of terms are going to figure. Therefore we can write

$$T(t_1, ..., t_n, o_1, ..., o_m) \tag{1}$$

where the t_i refer to unobservable entities and the o_i to the observable ones. For simplicity reasons I will equate $\vec{t} = t_1, ..., t_n$ and $\vec{o} = o_1, ..., o_m$, thus the notation resulting in:

$$T(\vec{t}, \vec{o}) \tag{2}$$

Now, I form the Ramsey Sentence simply by existentially quantifying over the theoretical terms $\vec{t}$.

$$\exists \vec{x} T(\vec{x}, \vec{o}) \tag{3}$$

However, there is are two difficulties arising from this procedure, and it is that Ramsey sentences can only be defined over finitely axiomatisable theories.

If a theory lacks this property then it is impossible to make a finite sentence out of the conjunction of all its statements[1] and therefore its Ramsey sentence can't be defined. Additionally, for simplicity I assume that the original theory is written in first order logic.

Secondly, it is worth noticing that even if the scientific theories we take are formalised in second order logic, their respective Ramsey sentences will be second order. Although this might seem counter-intuitive at first, the explanation is immediate. Imagine I have a theory that wants to make an assertion about the behaviour of electrons, the only way to do that is if I have the predicate 'x is an electron'. Otherwise I would need a non-observational term to refer to each and every electron. And even if the universe is finite, the prospect seems daunting. Let me explain through an example.

Imagine I have a very simple scientific theory stating that all atoms fulfil property ψ. This would be formalised very simply as the statement $\forall x(A(x) \rightarrow \psi(x))$. Ontologically speaking atoms are entities, but if we want to talk about them in general they become a property in our logic. Now when I make the Ramsey sentence of this theory I get $\exists X \forall x(X(x) \rightarrow \psi(x))$, which is clearly second order. Therefore it follows that, if the original T was first order, its RS will be second order given the existential quantification over predicates.

Let us then take scientific theories to be finitely axiomatisable first order theories and their Ramsey Sentences to be second order. I will now explore the first philosophical use given to them, namely the construction of a logico-linguistic framework attempted by Carnap in defense of the Received View.

[1] There are some classes of infinitary logics that allow for this, but that falls beyond my scope in this thesis

2.1.1 Carnap and RS

An account of the use of RS by Carnap can be found in Psillos [Psi00], where he elaborates on the historical and philosophical circumstances that led Carnap to reinvent the Ramsey Sentence. In the late 40' and early 50' the dominant understanding of scientific theories is what has come to be known as the Received View, according to which a theory is to be understood syntactically as a set of sentences T. From these we can infer a series of theorems, including observable predictions and explanations about states of fact. However, these sentences range over non-observable entities, whereas factual postulates refer both to observable and unobservable ones. Think for example of Bohr's atomic theory, the axioms would refer to subatomic particles, orbits and such, but the theory is used in order to make observable predictions whose success and accuracy can be measured.

Put formally, Carnap defended that the language of a scientific theory, L, could be divided between observational (L_o), which is fully interpreted by ostentive reference, and theoretical (L_t). The latter is formed by all the theoretical terms, V_t, together with a succession of domains $D_0, D_1, ...$, where D_0 is a series of sets $o, o', o", ...$ isomorphic to $\mathbb{N}$ and $D^{n+1} = \wp(D^n)$. We have implications between sentences in two different vocabularies, observational and theoretical. Therefore we require correspondence rules C, meaning postulates that relate observational and theoretical terms. Sort of a dictionary for translation between different languages. In recognition of the importance of this device, Carnap refers to a scientific theory as TC.

This is clearly defined and sufficiently clear for our purposes, but the problem arises when we encounter irreducible theoretical terms. What happens with this factually unaccounted for content? This opened a debate on the philosophy of science between two main positions. Realists defended that terms like 'electron'

or 'quark' have excess content because of their putative reference, that is, because they denote something that actually exists[Fei43]. Otherwise, they argue, our theories could not be true. On the other hand, instrumentalists sustained that the reference of theoretical terms is either nonexistent or irrelevant, since scientific theories are not truth seeking, but mere instruments of further human goals[Rei38]. As we will argue bellow, Carnap attempted by any means possible to maintain a neutral position with respect to this debate, aiming to prove that the Received View was independent of both ontological positions.

An attempt at this intermediate position came with the publishing of the *Methodological Character of Theoretical Concepts* (1956, onward MCTC). Here Carnap addresses what it means for a sentence to be true in the context of a theory. Within L_o, a sentence is true if and only if the state it describes is real. This is, at least in principle, possible to check and generates no problem. The difficulties arise when it comes to L_t. Any individual sentence regarding an event works like in L_o, but questions about the whole system are answered from a framework perspective. That is, the truth of any particular sentence containing theoretical terms will depend on the realisation of the event it describes, but the acceptance of the theory as a whole is a question of framework choice.

But one could wonder, and on some grounds, whether this is neutral enough. Within T, we endorse realism in accepting $\varphi \in L_t$ that commits us to the existence of the entities it describes. From outside of the theory we are instrumentalists, the question of its acceptance is decided in terms of the convenience of the framework, disregarding any ontological commitments. It is in this sense a controversial distinction, since it forces us to admit different ontologies depending on whether we are working inside or outside of the theory. What we have here is internal realism and external instrumentalism, not an actual middle ground.

This led Carnap to a completely different approach, one in which he reinvents the Ramsey Sentence, even though he acknowledges his mistake when it is pointed to him [Psi00]. First of all, it is worth noting that his understanding of theories was becoming more semantical. A theory can also be seen as a structure that is true if isomorphic to the world. Consequently, T is empirically adequate if the observable reduct of the world is embeddable into $M \vDash T$. Now, a realist understanding of a theory would commit us to the existence of some particular entities, whereas the RS ensure only that there are some entities, not specifying which, that satisfy the theory's structural requirements towards the observable entities. This way, he thinks, we should only stand ontologically behind the RS, as it leaves much more space for maneuver. The first thing he does now is to show that an observational statement follows from a theory T if and only if it also follows from its Ramsey Sentence. The proof is very simple and I reproduce it here:

$$\vdash \exists x T(x,o) \to S \iff \vdash \neg S \to \neg \exists x T(x,o) \iff \vdash \neg S \to \forall x \neg T(x,o) \iff$$
$$\vdash \forall x(\neg S \to \neg T(x,o)) \iff \vdash \forall x T(x,o) \to S \iff \vdash T(t,o) \to S$$

Where S is the observational statement and I simplify for the case of a single theoretical term. It is easy to see how this applies to the tuple case as well. The last step is justified because the theoretical terms don't appear in S.

However, this leaves us with new questions. We are committed to the RS, but in turn that commits us to the existence of some entities that realise the RS. Ramsey defended that the homonymous quantification had to be taken purely extensionally, that is, $\exists x T(x,o)$ literally means that there are some entities satisfying the theory. Nonetheless, Carnap will distinguish an extension and intension for the existentialised terms[2]. RS is only asking for some entities satisfying a certain structure with relation to themselves an the observational ones.

[2]Note that here we do not refer to intension and extension as understood by Frege, but to Carnap's interpretation of said terms that we explain in the following

Thus, the extension of the $\vec{x}$ will be some mathematical structure extracted from the succession of domains $D_0, D_1, ...$, which by construction is going to be able to accommodate any new or existing requirements made by the theory. As Carnap himself would put it:

> There are numbers, classes, etc. that are correlated with the events in a prescribed way and have certain relations among themselves. This is a factual statement. (1963,963)

The intensions, in turn, will be the unobservable physical entities that we have in mind when talking of the theory. Hence he conserves the unobservables as thoughts, which will lead some to question the alleged neutralism of this new position.

In conclusion, Carnap introduces the Ramsey Sentences with three goals in mind: preserve the observational consequences of TC, the ability to accommodate any existing data and new discoveries, and establishing a logico-mathematical structure in which to embed the phenomena. Analogously, in accepting the RS one is only committed to: (a) the observable consequences of TC, (b) a certain logico-mathematical structure in which the phenomena are embedded and (c) abstract existential claims stating that there are (mathematical) entities that satisfy the theory. Carnap's main motivation, in short, was the construction of a logico-linguistic environment for the development of scientific theories.

However, the Ramsey sentence has been used by many more authors and towards very different goals. Some have used to reformulate scientific realism, others to define theoretical terms. In consequence, the following sections are dedicated to explain precisely that, how one can employ RS towards these goals.

2.2 Structural realism and PMI

In order to understand the importance of RS in relation to Structural Realism we must first introduce the problem of the Pessimistic Meta-Induction (PMI), formally presented for the first time by L. Laudan in his paper *a confutation of convergent realism*(1980)[Lau81], although earlier versions can be attributed to Poincaré[Poi22] or Duhem[Dar02] . Scientific realism, broadly speaking, is the doctrine that our scientific theories are approximately true, not just observationally accurate. This concerns the non-observable too, the realist fends that the ontologies that our best theories describe are also (approximately) true. According to traditional accounts of realism, this implies that the entities depicted by our theories also exist, that is, that our theoretical terms are referential.

But here is where the PMI comes to play, which can be summarised as follows. If our theory is empirically successful then the realist will claim that its central terms are referential, that there are such entities as the described by the t-terms. However, many theories in the past were (relatively) successful, but have been later found out to be false, and/or their terms to be denotationless. Therefore, Laudan reasons, why would our current best theories be any different? What guarantees that the terms in our theories refer or that the theories themselves are true? A paradigmatic example is the Maxwell's aether theory to explain what today we call an electromagnetic field. The aether was conceived as an elastic intangible solid through which electromagnetic waves would propagate, but later empirical evidence supports the theory that such an entity does not exist. However, this theory managed to procure a series of accurate predictions in the field of optics in particular, so many scientists agree that it was successful at its time.

Formally speaking Laudan divides the realist claim in 4 parts:

R1) Theories of advanced and mature sciences are successful

R2) If the central terms of a theory refer it will be successful

R3) If a theory is successful, we can infer that its central terms do refer

R4) All central terms in current scientific theories do refer

Where (R1) and (R3) imply (R4), while (R2) and (R4) provide the warrant for (R1). However, Laudan will argue that only (R1) is acceptable. (R2) is false from the moment that we realise that, even if we somehow get our ontology right, we might err in the equations, thus the theory resulting inaccurate. (R3) is contested via the reasoning portrayed above, in can be pessimistically inferred that the statement is wrong. Therefore, (R4) turns out to be baseless, and therefore probably false.

In light of this there are many exits that the realist could explore. One could try to rebuke the thesis of PMI, claim that Laudan's argument is illegitimate or based on false premises and that therefore there is no problem for scientific realism. This is what philosophers such as Psillos would do [Psi94]. The alternative is to turn towards a different type of realism that does not need of its entities to prosper.

However, at this point the realist must also take into account the No Miracles Argument (NMA), according to which a non-realist position can't account for the empirical success of science. After all, how can it be that our theories predict so well if they are not true, if they don't actually depict reality? If the realist unreflectively dispenses with the unobservables she could run into a conundrum. Thus we need a philosophical framework that accommodates both the PMI and the NMA.

And this is precisely what structural realism is meant to do. This position is the strand of realism defending that our theories are approximately true in that they accurately describe the structure in nature, regardless of the any particular entities. By focusing on the structure we can avoid PMI in so far as

we claim that it survives theory change. By contrast, entities are dispensable and are often swapped or exchanged in new theories. This would be the case of Maxwell's aether theory compared to the more modern theory electromagnetic fields. Entities perish, but the equations and overall structure of the theory is the same. Looking at the very same example we can see how structural realism also surmounts NMA. Our theories make good predictions because they describe correctly the structure underlying the phenomena. In this sense, the aether theory made good optical predictions because the equations it used where very similar to the ones in the current EM-field theory.

However, if we want to understand how the RS come into play here, we need to dig a little deeper into the history of structural realism. A good account can be found in Newman's *Ramsey Sentences as an answer to PMI* [New05]. Worrall is for many the father of structural realism with his 1989 article *Structural realism, the best of both worlds?*[Wor89]. His position is summarised by Newman as Epistemic Structural Realism (ESR), and it is characterised for understanding 'structure' as exclusively mathematical. He can now answer theory change; particular entities might be gone, but mathematics obey the corresponding principle, according to which past equations are limiting cases of the new ones. Scientific success is also explained this way. Old theories predicted correctly because their equations where limiting cases, and therefore at least partially correct.

Moreover, this realism is epistemic in so far as it is formulated as a belief constraint. We are skeptical towards the existence of certain entities, but we believe in the mathematical structure underlying them. Bear in mind that structural realism can also be ontological (OSR), in which case structure is taken as a primitive instead of the objects [Lad98]. However, OSR does not interest us now beyond as an example.

However, Worrall's ESR faces a series of problems.

1. The notion of 'structure' is ambiguous here. If we take it in the abstract sense, as a set of relations holding between entities, then the notion is not thin enough to pick a unique set of relations. To do this, we would need to stipulate what relation this is, but this presuposes going beyond purely abstract description [3]

2. If, on the other hand, one opts for the concrete notion of structure, referring to specific relations between entities, then we are assuming the existence of a clear nature/structure distinction, point contested by Ladyman[Lad98] and Psillos [Psi95]

3. Mathematical continuity is not enough to answer PMI. We can claim that equations are preserved, but we have yet to prove their correctness, that they actually depict reality. We need a separate argument that identifies mathematics as the responsible for past and present theory success.

4. This approach hardly accounts for less mathematical sciences. What happens with biology, for example? Structure here is arguably not so much about equations, ESR falls short.

5. Regarding theory change, the notion of sharing a similar structure remains unclear. The corresponding principle does not always help. For example, it is not obvious that we can compare the equations in classical dynamics to the ones in quantum mechanics, they are mathematically very different.

2.2.1 Ramsey Sentence Realism

However, there is an interpretation of the realist thesis where the reference of the theoretical terms is irrelevant. Ramsey Sentence Realism (RSR) is owed

[3] This point was made by Demopolous and Friedman [DF85] in response to Russell's analysis of perception

to Cruse and Papineau [CP02], and it is as simple as claiming that 'structure' refers to the Ramsey Sentence of the theory. The way the position is defended by these authors RSR is an heir of the epistemic structural realism. It is epistemic since it understands RS as the belief, rather than ontological, constraint. And it answers the NMA in virtue of RS implying the same observational sentences as the original theory. The corresponding principle here is simple, the old and the new theory share the same (or very similar) Ramsey sentence.

But now, we have to see whether this is an improvement from ESR, and to do that means checking how well it fares against the five objections listed above.

1. 'Structure' is no longer ambiguous, it refers to RS. Thus this is no longer a problem.

2. This is more problematic. RS does not *a priori* presuppose a nature/structure distinction, but it does assume a O/T distinction. However, the RS includes reference to observable objects and it is taken to be the structural part of the theory, so we are in the same conundrum. Depending on where we draw the O/T line we will get a different RS (structure), hence the line between structure and nature (unobservables) also changes. In this sense, RSR is no improvement with respect to ESR.

3. In theory change the RS is preserved, which was the part in charge of making the correct predictions. The argument is ready since $T \vDash \varphi_o \leftrightarrow R(T) \vDash \varphi_o$, where φ_o is observational.

4. Non-mathematical theories can also be understood this way. Ramsey sentences presuppose no equations of any kind, to there is no reason why for example biology would escape this analysis.

5. 'Similar structure' just means same Ramsey sentence.

Therefore we can conclude that RSR is a solution to many problems of ESR, even if it is very far from being perfect itself. We will see the debate about RSR in chapters 4 and 5, but for a mere exposition of the matter this will suffice.

2.3 The upward path

However, this is only one of the many ways in which RS and SR can interact. To properly understand this I must draw a distinction between an *upward* and a *downward* path, applying to both SR and RS.

For structural realism the downward path is what I have just explained. We begin with traditional realism and we subtract entities in favor of the structure. But there is another way to arrive at SR, namely by starting with empiricist assumptions and proceeding upwards towards the construction of the whole theory. A good example of this is Maxwell's position, about which I will talk momentarily. Nonetheless, it is worth noting that this process does not necessarily reach a realist position. As of RS, a similar distinction can be made. A downward use of RS can be found in RSR, where we employ the Ramsey sentence to eliminate the undesired, PMI-sensitive content. Conversely, an upward use would be Maxwell's, employing RS to construct the minimal theory starting from empiricist claims.

However intertwined the two may be, not every use of RS arrives at a realist position, and not every structural realism makes use of Ramsey sentences. To this end we have elaborated the Table 1. The $\diamond_i$ represent positions that are possible but beyond our focus in this thesis and the $\emptyset$ stand for unsustainable ones.

$\diamond_1$) One could, in principle, arrive to SR via the upward path without using RS. It is only necessary to build a theory upwards committing exclusively to its structure.

	RS ↑	RS ↓	RS ∅
SR ↑	Maxwell	∅	$\diamond_1$
SR ↓	∅	RSR	Worrall's ESR
SR ∅	RSE	$\diamond_3$	$\diamond_2$

Table 1: Upwards and Downwards

$\diamond_2$) There are many positions that don't employ RS or arrive at structural realism, but they lay clearly besides our scope.

$\diamond_3$) This would be subtracting the theoretical entities from a realist position via a downward use of RS only to end up abandoning structural realism altogether. It is technically possible, but one can only wonder why would anyone do it.

In sight of this classification I now commence the analysis of the two remaining positions,G. Maxwell's structural realism and Ramsey sentence empiricism (RSE).

2.3.1 Maxwell and RSE

Maxwell's position can be summarised as the combination of Russell's principle of acquaintance with Ramsey sentences in order to procure a functioning understanding of whole theories and a realist view of theoretical terms. But in order to grasp any of this I must first elaborate on the the Russell-Maxwell theory of perception.

According to Russell's principle of acquaintance, we can only directly refer to what we are directly acquainted with[4]. Therefore, all descriptive (non-logical) terms in a sentence will exclusively denote observable entities. However, Russell (and Maxwell) will reject any form of direct realism, sustaining that what we call 'observable' is no other than internal events, or percepts, as he would call them [Rus15].

[4]See Demopoulos and Friedman for a detailed discussion of Russell's view [DF85].

Additionally, Russell admits only knowledge obtained by acquaintance, but here Maxwell disagrees and allows also knowledge by description. This way, the reference of all terms is fixed by acquaintance (or, we would say, ostension) or by description on the basis of purely logical items together with observational terms. Knowledge of non-observable entities is therefore knowledge by description.

Now let us transfer this to the case of a scientific theory. To do so, consider the following formalised scientific statement:

$$(x)[Ax \wedge Dx \rightarrow \exists y Cy]$$

Where 'Ax' stands for 'x is a radium atom', 'Dx' for 'x radioactively decays' and 'C' designates the property being an click in a properly constructed Geiger counter. The meaning of this sentence is abundantly clear in sight of the interpretation of the predicates. However, according to the principle of acquaintance only predicate 'C' has a reference, whereas 'A' and 'D' are meaningless in so far as they purport to refer directly to unobservable qualities. Nonetheless, the same principle does not prevent us from using the 'Ramseyfied' version of it.

$$\exists R \exists S(x)[Rx \wedge Sx \rightarrow \exists y Cy]$$

Therefore we employ the Ramsey sentence of a theory in order to be able to use it without having to directly referring to non-acquainted entities. However, this formulation is taken extensionally, thus implying the existence of such predicates satisfying the RS. The reference of theoretical terms is no longer direct, but the reference is there nonetheless. Maxwell maintains an ontologically realist view on theoretical entities, while also acknowledging them as epistemologically inaccessible. The knowledge we have of this theoretical predicates is

only structural, we know how this entities must behave in relation to the observable phenomena, but we ignore the intrinsic properties, precisely the ones that tell us about the nature of the object.

All in all, what Maxwell defends is a realist conception of theoretical entities while recognising their epistemologically inaccessible character. The knowledge of unobservable is then exclusively structural and is attained by means of the Ramsey Sentence. His position is realist with respect to the entities but structural regarding the knowledge of them.

But now bear in mind that a position of this form need not be realist. One could perfectly depart from a similar epistemological status of the non-observable and even employ RS upwards to construct our understanding of whole theories in Maxwell's fashion. As an example, take the position I am about to describe.

Imagine I am a decided scientific antirrealist who claims that, while our best theories are empirically adequate, the unobservable entities they describe do not exist. Moreover, I also endorse the principle of acquaintance and thus believe that the unobservable realm is decidedly inaccessible and that therefore any direct reference to its purported objects is inevitably viced. In these circumstances, I might opt for RS as a means to preserve the same observational consequences as the original theory without committing or directly referring to the entities it proposes. However, one might ask, the RS asserts the existence of certain predicates that satisfy the theory. There are two possible responses to this. The first is simple, I could answer that there must be some unobservable entities with precisely those structural properties, but deny that they are precisely the ones that our theory at hand suggests. The theory is just ontologically wrong, but I admit for another theory to be right.

The second rebuke is more complicated. The existential quantification in

RS only demands the existence of any entities if understood extensionally. In principle it should be possible understand it intensionally[5]. This way, RS would only state the belief on some satisfying entities by the defendants of T, very distinct to an existence claim. The quantification would then refer to the alleged entities, but without making any claim about their reality status.

It is in this vein that I consider possible a position in which we employ the RS departing from an empiricist stand without necessarily ending up in a form of structural realism, or realism whatsoever. I see no reason why this position would not be possible, even if I have not found a representative of it this far and our description of it is at best a general outline. Therefore, I have decided to name this position Ramsey sentence empiricism (RSE) (See Table 1) and characterise it as an upward use of RS but as no form of structural realism.

In conclusion, we have seen that the RS can be employed coming from a realist perspective as a tool to resist PMI, but also as a means to construct upwards a theory. Many of this positions end up in some form of structural realism, mostly of epistemic nature. Nonetheless, we have shown how this does not necessarily have to be the case, exemplifying both strands of structural realism that make no use of RS and uses of RS that do not arrive at realist positions.

2.4 Definition of theoretical terms

What Lewis had in mind when he published *How to define theoretical terms* is obvious from the title of the article. The idea, in short, is to define every t_i as a specific member of the *unique* realisation of T [6]. However, before jumping to that there's a few considerations worth making. First of all, Lewis has a different O/T

[5] It should be noted, although, that Ramsey himself defended that RS should be interpreted strictly extensionally

[6] The technique is owed to Carnap [CFB61] but for a more refined account I will focus on Lewis' work

distinction. An O-term is what is previously understood by a former theory, so the O stands for *old* rather than observational. Bear in mind that otherwise in certain circumstances electrons would be observational. Conversely, T-terms are the ones introduced by the theory at hand, hence referring to the so called hypothetical entities.

Additionally, Lewis assumes that for any postulate of theory to be true all its terms need to be referential. Therefore, for any given theory and T-term t_i, T implicitly includes the statement $\exists x(x = t_i)$. That is, our theory assumes all its terms are referential. Since he focuses on the theoretical terms alone, the o_i are omitted in the sentence of T, writing only $T(t_1, ..., t_n)$.

With this preamble in place he defines the RS as indicated above (except, of course, omitting the o_i). But now he reasons that this doesn't say anything about the T-terms in relation to the theory, just that the theory is realised. Thus he draws upon what he calls the Carnap Sentence (CS):

$$\exists x_1, ..., x_n T(x_1, ..., x_n) \rightarrow T(t_1, ..., t_n) \tag{4}$$

Meaning that if there is some realisation of T, then the t_i constitute one. CS can also be read as $RS \rightarrow T$, therefore T is logically equivalent to the RS and CS together. Additionally, the CS does not imply any observational statements, other than logical truths.

From a philosophical point of view Lewis argues that one should understand RS as the synthetic part of T, since it implies all observational consequences but says nothing about the nature of the T-terms. Conversely, CS would be the analytic side, sterile in what respects to predictions but specific about the reference of T.

Now, what happens with this when a theory has no realisation? And if it has more than one? In the first case CS becomes vacuously true and RS false, but

that doesn't tell us much. The T-terms don't name anything and our theory is false. However, Lewis also admits the notion of a near realisation, which is defined as follows. T is nearly realised by a tuple $\vec{a}$ when there is a slightly weaker T' such that $\vec{a}$ realises T'. In terms of physical theory, a near realisation would be one in which almost every property of our non-observational entities is accurate; there are some predictions that we cannot account for with the present ontology and therefore the need for some adjustments arises.

In case the theory is multiply realised he faces a dilemma. For the sake of the explanation assume we have theory $T(\vec{t})$ realised by both $\vec{a}$ and $\vec{b}$. Then what do the $\vec{t}$ refer to, the first or the second tuple? Some would claim that $\vec{t}$ pick out any of the options arbitrarily, or that they actually refer to either or, but we can't yet know to which[CFB61]. However, Lewis argues that they refer to none. If a theory is multiply realised then its terms are as good as denotationless. It might be that our theory is not (yet) good enough to decide between $\vec{a}$ and $\vec{b}$. For Lewis, scientific theories must strive for unique realisation, an thus we should aim to make our theories as strong as possible, even if at the risk of no realisation.

At this moment one would like to enquire as of the reason behind that choice. Well, one argument is his the special characterisation of O-terms, which need not be strictly observational but just refer to something 'known'. This way, the repertoire from which to fix the reference of a new term is much broader. There are not as many things in a certain relation with the observable phenomena as there are with said phenomena and the atomic structure. Thus we really narrow down the possible references. The other argument is of a more idealistic nature. Lewis wants to define his T-terms by means of the O-terms and their relationship in T, which is impossible if T leaves room for $\vec{t}$ naming two different tuples. Therefore we require T to be as strong as possible so that this doesn't

happen. In consequence he needs three new axioms:

- $\exists y_1, ..., y_n \forall x_1, ..., x_n (T(x_1, .., x_n) \leftrightarrow x_1 = y_1 \wedge ... \wedge x_n = y_n) \rightarrow T(t_1, ..., t_n)$
- $\neg \exists \vec{x} T(\vec{x}) \rightarrow \neg \exists (x_1 = t_1) \wedge ... \wedge \neg \exists (x_n = t_n)$
- $\exists \vec{x} T(\vec{x}) \wedge \neg \exists y_1, ..., y_n \forall x_1, ..., x_n (T(x_1, .., x_n) \leftrightarrow x_1 = y_1 \wedge ... \wedge x_n = y_n) \rightarrow \neg \exists (x_1 = t_1) \wedge ... \wedge \neg \exists (x_n = t_n)$

Stating that if T is uniquely realised then it is so by $\vec{t}$, and that if it's not realised or multiply realised, then $\vec{t}$ don't name anything.

With this in place he can now define any T-term as a member of the unique realisation of T. For example, we can define t_1 as follows:

- $t_1 = y_1 \exists y_1, ..., y_n \forall x_1, ..., x_n (T(x_1, .., x_n) \leftrightarrow x_1 = y_1 \wedge ... \wedge x_n = y_n)$

This definition seems most natural, since the theorist who asserts $T(t_1, ..., t_n)$ probably is also implicitly conceding such definition for each t_i.

In conclusion, by requiring theories to be uniquely realised we gain a way to define theoretical terms as member of that unique realisation. However, we loose the ability to talk about multiple realisation and making our theories all the more rigid. Compared to Carnap, we can not so easily accommodate new data given the strength of the theory that we require, but it also important to bear in mind the different objectives of both authors when drawing upon the RS.

3 Chapter 3: RS and Model Theory

In this Chapter i will explore a concern raised against the use of RS from within the field of model theory, namely Newman's objection[7]. I elaborate on its significance and show the mathematical proofs leading to a troublesome result for the defendants of any form of realism that employs RS. Then, I will examine some of the answers to this problem provided by some authors as well as propose some of our own. Finally, we will take a stance regarding which of the positions using the RS can survive this objection and which would be better off with another tool.

However, before I start to explore the mathematical properties of the RS there is a distinction we should make. And that is between the extension and the expansion of a model, two things that *a priori* could be thought of as being the same. A model N extends M if there is an embedding $f : M \to N$. On the other hand, an L-expansion of an L_o-model M (where it is understood that $L_o \subseteq L$) is obtained by adding the non-L_o constants and predicate symbols to the model, without altering its structure[8]. If M is the L-expansion of an L_o-model N, we say that N is the L_o-reduct of M.

3.1 Newman's objections

In order to grasp the meaning of Newman's objection we must first understand where it comes from. Russell's *Analysis of Matter* states, besides the principle of acquaintance, that the only knowledge one can have of the external world is purely structural. That is, we can know how objects relate to each other and to our percepts (the only acceptably referable objects for Russell), but we know nothing about the nature of said external objects. In response, Newman

[7]It is important to note that through this chapter we refer to Maxwell H.A. Newman, 1897-1984, whereas in the previous chapter we cited Mark Newman, current physics professor at the University of Michigan

[8]for an explanatory example see section 3.4 of this chapter.

protested that if that was the case, then we could know nothing about it, since one can arrange any objects in the desired structure regardless of their nature.

The problem wasn't originally addressed against the RS procedure, but Demopoulos and Friedman [DF85] adapted it towards this end, while I take this version of it from Button and Walsh [BW18]. According to the latter account, and I agree, we can separate the objection into two separate problems, thus facilitating the analysis. Therefore I will speak of a conservation and a cardinality objection, and explain them separately. In what follows I provide a formalisation of said problems as well as the mathematical proofs behind them and possible answers to the philosophical challenges they pose.

3.1.1 Conservation objection

The first of the problems posed by Newman can be summarised as the claim that RS expresses nothing more than the observational consequences of T. In order to prove this I will need a few definitions.

Definition 3.1 Let T be a L^+-theory and S and L-theory[9], T is *consequence conservative* over S if and only if for all $\varphi \in L$, $T \vDash \varphi$ implies $S \vDash \varphi$.

Definition 3.2 Let T be a L^+-theory and S and L-theory, T is *expansion conservative* over S if and only if for every L-model $M \vDash S$ there is and L^+-model N such that N a signature expansion of M and $N \vDash T$.

With this in mind I can prove the following proposition:

Proposition 3.3 Let T be any finite L-theory and S be a L_o-theory, where $L_o \subseteq L$ [10]. The following are equivalent:

1. T is consequence conservative over S

2. T is expansion conservative over S

[9] Unless indicated otherwise, we assume that $L \subseteq L^+$

[10] And, assumed $L = L_t \cup L_o$ and $L_t \cap L_o = \emptyset$

3. $S \vDash Ramsey(T)$

Proof. ((3) $\rightarrow$ (2)) Suppose $S \vDash Ramsey(T)$ and take some L_o-model $M \vDash S$. Then $M \vDash Ramsey(T)$, so we have predicate witnesses that interpret the L_t vocabulary. Therefore we can get a signature expansion N of M that interprets the theoretical vocabulary of L in the desired way, therefore $N \vDash T$.

((2) $\rightarrow$ (1)) Let $T \vDash \varphi_o$ where $\varphi_o \in L_o$. take some L_o-model $M \vDash S$. By expansion conservative we have a signature expansion L_o-model $N \vDash T$. Since $N \vDash T$ we have $N \vDash \varphi_o$, and given that $N \equiv_o M$ we have that $M \vDash \varphi_o$. Since M was arbitrary we obtain $S \vDash \varphi_o$.

((1) $\rightarrow$ (3)) $T \vDash Ramsey(T)$ and $Ramsey(T) \in L_o$, so by consequence conservative $S \vDash Ramsey(T)$. $\square$

But now, what is the significance of this? Let S be the set of all true observational (L_o) sentences, we say that T is empirically accurate (L_o-sound) if and only if T is consequence conservative over S. But by proposition 3.3 that is equivalent to $S \vDash Ramsey(T)$. Therefore, I can conclude that RS says nothing more than the observational consequences of T.

This can be an issue for the RSR in so far as they believe the RS has some additional non-empirical content. A possible response to this is offered by Button and Walsh is to argue that a theory need not be L_o-sound. Imagine that T implies $\phi_o \in L_o$ stating that there is an unobservable object. An instrumentalist shouldn't be committed to this, just to 'properly' observable sentences. Therefore I define recursively from L_o a set of L_o^o-formulas that do not imply the existence of unobservables.

Definition 3.4 Let O be the predicate of observability. Take $\varphi \in L_o$, we recursively define the set of L_o^o as follows:

- $\varphi^o := \varphi$ if φ atomic

- $(\varphi \wedge \psi)^o := \varphi^o \wedge \psi^o$
- $(\neg\varphi^o) := \neg\varphi^o$
- $(\exists x\varphi)^o := \exists x(O(x) \wedge \varphi^o)$
- $(\exists X^n\varphi)^o := \exists X^n(\forall k_1, .., k_n(X(k_1, .., k_n) \rightarrow \bigwedge_{i\leq n} O(k_i)) \wedge \varphi^o)$

Thus I force every object to be observable and every predicate to refer exclusively to observable entities. Now we have only to claim that our theory T must be only L_o^o-sound in order to be empirically accurate, a much weaker requirement than L_o-soundness.

This is the solution proposed by the authors, but now I should evaluate whether this works. To begin with, the whole argument rests on the possibility of having an observable sentence *implying* the existence of an unobservable object. In modern science there is plenty of evidence supporting that position, but one can wonder if it is possible for a piece of evidence to imply the existence of atoms, for example. For all I know the world could be behaving as if there were unobservables, while there are none[11].

But even if there was no empirical instance of such a sentence, one could say that it is model theoretically feasible and that therefore our objection misses the target. Even if granted that there are another two issues with the argument. The first is that Button and Walsh argue that an instrumentalist should not require L_o-soundness, while the conservation objection is aimed against the realist! From an instrumentalist point of view, RS works just fine if it only tells us the empirical consequences of T; theories are mere instruments for prediction and explanation and therefore RS does a great job without having to deal with unobservable entities. By contrast, a realist should require theories

[11] See, for example, Malabranche's theory of causation, according to which there is no actual causality between objects. Instead, God makes it seem like there is while he is actually moving every object[Sch19].

to be L_o-sound, even when concerning the existence of unobservables. If there is an observable sentence that implies the existence of an unobservable object, a Ramsey sentence realist should require RS to imply it in so far as she wants the RS to have as much 'non-empirical' content as possible.

The third problem with the argument is that the conservation objection is not dependent on L_o-soundness. The same argument can be reconstructed for L_o^o-soundness, since $L_o^o \subseteq L_o \subseteq L$. Let S be the set of all true observational-non-unobservable-implying (L_o^o) sentences, we say that T is empirically-non-unobservable-implying accurate (L_o^o-sound) if and only if T is consequence conservative over S. But by proposition 3.3 that is equivalent to $S \vDash Ramsey(T)$. We have the same problem. Now Ramsey(T) expresses the observational (yet not unobservable implying) consequences of T, nothing else.

It is because of these three problems that I consider Button and Walsh's solution insufficient as a response to the conservation objection. I have yet to explore whether there could be another, but that can be a daunting prospect. Alas, in pursuit of an exit, we can sketch a few options. The first would be to notice how the conservation objection assumes the existence of a set of all true observational sentences, and that said set is consistent. This is ontologically not entirely trivial, but then again the same assumption is made by the defendants of RSR[12], so no advance is made here.

An alternative would be to question the scientific feasibility of $S \vDash Ramsey(T)$. How can this happen outside of model theory? Notice that $S \in L_o$, so we have our observational evidence implying the existence of certain predicates $\notin L_o$, that is, implying the existence of certain unobservables. As pointed out above, our evidence can very well suggest or support there being theoretical entities, it is more polemical whether they can *imply* so.

[12]If our theories are to be approximately accurate, there must be something as the consistent set of all (not just L_o) sentences, over which our theories are consequence conservative

Lastly, a more concrete rebuke would be to notice that the proof of proposition 3.3 relies crucially on the use of second order logic. As a matter of fact, the equivalence (1) $\leftrightarrow$ (2) does not hold for first order theories[13]. In this sense I will explore ways to treat the RS differently, with other logics, in order to avoid Newman's objection.

3.1.2 Cardinality objection

Let us concede that the conservation objection can be surmounted in the way depicted above, or at all. There is still a second side of Newman's work able to cause concerns amidst the defendants of any form of realism involving RS. The cardinality objection states, roughly speaking, that we can arrange any objects to have the structure depicted by Ramsey(T), so long as we have enough of them. Nonetheless, in order to prove this we need some further formalisation. In what follows I will refer to the L_o-reduct of a model M as Ob(M). Now I define:

Definition 3.5 Let C be the correct model of L_o. We say that an L-theory T is C-alright if and only if there is an L-model $M \vDash T$ such that $Ob(M) = C$

Now I can prove the following proposition:

Proposition 3.6: Let T be an L-theory $O \in L_o$ and A and L-model such that $A \vDash \forall x Ox$. The following are equivalent:

1. There is an L-model $M \vDash T$ such that Ob(M)=A
2. There is a cardinal κ such that: If $\|U\| = \kappa$ and $A \cap U = \emptyset$ then there is a L_o-model P with domain $A \cup U$ such that Ob(P)=A and $P \vDash Ramsey(T)$

[13]For a counterexample check appendix 3.B of Button & Walsh, 2018

Proof ((1) $\rightarrow$ (2)) Let M be an L-model as in (1). Take $\kappa = \|M \setminus A\|$. Let U be any set such that $\|U\| = \kappa$ and $A \cap U = \emptyset$ There is a bijection $g : (M \setminus A) \rightarrow U$. Now I define a bijection $h : M \rightarrow P = (A \cup U)$ such that:

- h(x)=g(x) if $x \notin A$
- h(x)=x if $x \in A$

Now I just define the L-relations over P such that $P \vDash R(h(x_1), ..., h(x_n) \leftrightarrow M \vDash R(x_1, ..x_n)$[14]. Naturally, $Ob(P) = A$ and $A \vDash Ramsey(T)$

((2) $\rightarrow$ (1)) Let P be as in (2). Since T is expansion conservative over Ramsey(T) there is an L-model $M \vDash T$ such that M is a signature expansion of P, so Ob(P)=Ob(M)=A. $\square$

The moral of the proposition is that we can take any model of T, substitute all the non-observable objects in it by new ones, arrange these in the desired manner and still have an observable reduct satisfying RS. Therefore we can arrange any theoretical objects in the desired structure provided we have enough of them. Put in plain terms, this result implies that I can take the atomic theory (T'), replace all the atomic particles with different species of (very small) ducks and still obtain a realisation to the Ramsey(T') if I have enough ducks and they behave to each other in the way described by Ramsey (T').

The problem arrives when we combine these results with the definition of theoretical terms that stems from RS. To recall, in section 2.4 we defined every t_i as a member of the unique realisation of T. However, the result above implies that we can have a realisation given *any* objects whatsoever, given that we have enough and we arrange them correctly.

Nonetheless, it can be argued that, while mathematically we could have a realisation given any objects, there must be, given any T, a unique tuple that as

[14]What I am doing here is take the necessary steps to force h to be an elementary embedding

a matter of fact does realise RS. We can immediately notice how this argument is circular, since it draws upon the single realisation in order to defend it. If it is (mathematically) possible to have multiple realisations, on what grounds can we guarantee that our theories are uniquely realised? The answer is none.

Furthermore, the cardinality problem also poses an indirect problem for the defendants of any kind of structural realism involving RS. For both of them endorse RS to avoid direct reference to the theoretical objects they have in mind, it is clearly not ideal that RS could be realised (in principle) by any large enough domain. The upwards SR believes in the existence of certain objects and uses RS to indirectly refer to them faces the same issue as the realist who eliminates the t_i of his favourite theory in favour of an existential quantification: we can't guarantee that the reference of the $\vec{x}$ is the desired one.

Finally, the cardinality problem is thought of by many as a stronger version of the conservation objection. Broadly speaking, if one can swap all the unobservables and still get the same observable consequences then that must mean that the RS says nothing about the nature of the unobservables. Therefore, the Ramsey sentence must only talk about the observable consequences and the arrangement of the $\vec{t_i}$. The opposite is less evident, from the fact that RS is true whenever the observational consequences are met it does not immediately follow that all the unobservables can be replaced. However dependent these two objections might be, they pose distinct philosophical challenges and thus we treat them separately. It shall be noted, nonetheless, that many authors refer only to the cardinality objection when they talk about Newman's problem. I will bear this in mind and clarify when needed.

In conclusion, Newman's objection against the uses of RS is twofold. On the one hand the conservation objection prevents the RS from having any content besides the observable consequences of T. This will be a problem for the realist

that endorses RS, since she will defend that scientific theories have content besides the observable. On the other hand, the cardinality objection threatens the possibility of defining theoretical terms as members of a unique realisation, since it implies the possibility of a realisation given any theoretical objects. Additionally, it poses an indirect problem for structural realism in so far as it makes indeterminate the reference of the variables in RS, contrary to the desire of indirect reference present in upwards SR.

3.2 Hintikka's IF-logic

It is precisely with these objections in mind that Hintikka publishes *Ramsey sentences and the meaning of quantifiers*[Hin98]. The objective is to shed some hope over the perspectives of the RS and thus this the paper aims to show that the model-theoretical content of unobservable entities can be preserved in the quantification of RS. However, it will also serve us to the purpose of introducing a tool for the study of RS, independence friendly (IF) first order logic.

The main idea here is that the t_i impose a constraint on the models of the observational consequences of T. Suppose I have a scientific theory T. Now we can take all the observational consequences of T, call it $T_o \subseteq T$, and pick a random $M'(O_1, ..) \vDash T_o$. It can be shown that then there must be a model $M(O_1, ..., T_1, ...) \vDash T$ such that M' is embeddable in M (hereinafter $M' \subseteq M$). This is attained by the theoretical terms, which force any observable prediction (model) to be embeddable into some model of T. In scientific terms, this just means that our predictions must fit into some model of the whole theory. This seems all but trivial until Hintikka claims that an analogous result follows if we take RS instead of T, if $N \vDash T_o$ then there must be some $M \vDash RS$ such that $N \subseteq M$. Thus, he takes this to mean that RS says as much about the observables as T does, since it restricts the class $Mod(T_o)$ in the same way.

Therefore, Hintikka concludes that the observational content of T is preserved in the second order quantification of RS. Importantly, the t_i are not eliminated semantically or ontologically since RS presupposes their existence. He can take this further by introducing independence friendly logic.

IF-logic is an extension of first order logic with equality in which we allow quantifiers to be independent from each other. Formally speaking, a quantifier Q_1 is linearly dependent on a quantifier Q_2 if the value of the variable quantified by Q_1 is dependent on the value of the variable quantified by Q_2. In ordinary first order logic the dependence is expressed via the scope of quantifiers: Q_1 is dependent on Q_2 if it lies within the scope of Q_2. In independence friendly logic we will fix this via the notation (Q_2/Q_1), meaning that Q_1 is independent of Q_2, even if it falls within its scope. Let us examine as an example the following sentence:

$$\forall x \forall z S(x, f(x), z, g(z))$$

Its Ramsey sentence would be:

$$\exists f \exists g \forall x \forall z S(x, f(x), z, g(z))$$

And the IF translation of the latter is:

$$\forall x \forall z (\exists y / \forall z)(\exists u / \forall x) S(x, y, z, u)$$

Here we can see how the expressive power of IF is much bigger than that of standard first order logic [15]. It interests us since Ramsey sentences belong

[15] By way of an example consider the definition of Dedekind infinity in Σ_1^1 form $\exists f \exists g \exists t \forall x \forall y((x = y \leftrightarrow f(x) = g(y)) \wedge f(x) \neq t)$ and its equivalent IF translation $\exists t \forall x \exists z \forall y (\exists u / \forall x)((x = y \leftrightarrow z = v) \wedge z \neq t)$. This property is not expressible in ordinary first order logic.

to the Σ^1_1-fragment of second order logic, where a string of existential second order quantifiers is followed by a first order formula, and said fragment is always translatable into IF-logic [Wal70][End70]. The opposite is also possible via Skolemisation[16][San91], so IF and the Σ^1_1-fragment are equally expressive. Moreover, the IF-dependencies on the translation of RS also preserve the constraints on observable reducts that the t_i imposed, so the structural content of the unobservables can be also captured this way.

Why does this interests us? Recall that the proof of the conservation objection (section 3.1, proposition 3.3) relied heavily on the second order character of our logic. Some would think that perhaps in using a new logic to address RS we can bypass the objection by avoiding the higher order quantification. It might be also the case that the cardinality objection can't be posed in a lesser order setting. However, this strategy fails. Since IF and Σ^1_1-fragment are equally expressive the conservation and cardinality objections can be reconstructed in IF logic, so the problems persist. It is not a problem of the logic at hand, but of the underlying model theory.

However, that doesn't put an end to our interest in IF-logic's properties. The objections might persist, but now RS is translatable into a more manageable logic with relatively more approachable game-theoretic semantics[MSS11]. Moreover, RS and its translation are proven to constrain the set of models of T_o (that is, $Mod(T_o)$) as we have seen above, which constitutes a very desirable property for our theories. So seems like there is, at last, a model-theoretical argument for endorsing the Ramsey sentence.

Nonetheless, our hopes are dashed soon. Ketland proves precisely that Ramsey sentences don't constrain the number of models in which empirical substructures can be embedded[Ket04][17]. Yet, Hintikka's result was not wrong at all.

[16] We understand this here as the opposite process by which we can transform, for example $\forall x \exists y \varphi(x, y)$ into the equivalent $\exists f \forall x \varphi(x, f(x))$. Here f is the so called Skolem function

[17] I will delve deeper into this in section 4.1

Let me explain. It is true that for every $N \vDash T_o$ there must be some $M \vDash RS$ such that $N \subseteq M$. However, if we reason about the significance of Newman's cardinality objection we realise that we can have a model of RS with any unobservable domain. It is possible to take such N model and add any unobservable objects in the desired structure to obtain a model of RS. According to the cardinality objection, I could take any model $N \vDash T_o$ and extend it with any unobservables I want (in the desired structure) and get a model for the Ramsey sentence. Therefore, RS is not imposing any significant constraint. There are far too many models of Ramsey(T) for it to be an actually impose any noteworthy limitation, at least philosophically speaking.

3.3 The significance of the RS

However, this does not mean that the RS is completely useless or that it only reflects the observational consequences of T. There is still room for hope, for the Ramsey sentence can distinguish between the models of T_o that can be *expanded* to a model of T and those that can't. Formally put, a model $M \vDash T_o$ satisfies Ramsey(T) if and only if it can be expanded to a model of T. To see how this works let us examine the following example from Demopoulos, 2011[Dem11].

Let $L_o = \{R\}$, $L_t = \{A\}$ and $L = L_o \cup L_t$. Now let T_o be the L_o-theory axiomatising the complete theory of the natural numbers with $<$[18]. T will be equal to T_o plus sentences expressing that A is non-empty, that the first element is not in A and that the complement of A is closed under immediate successors. It is clear that T_o holds in the standard model $(\mathbb{N}, <)$, but T holds only in non-standard models, and the same is true of Ramsey(T), which is the L_o-sentence $\exists X T(R, X)$. Consider the standard second-order model $(\mathbb{N}, \wp(N_i)_{i \in I}, <)$. For Ramsey(T) to be true we would need a set in $\wp(\mathbb{N})$ which contains zero, is closed under successors and does not contain every element in $\mathbb{N}$. But this is impossible

[18] Where the intended interpretation of R is $<$

in a standard model, we need transfinite ordinals.

In other words, the RS of T can fail in a model where all its observable consequences hold. That is because there is more to the RS than he observable consequences of T, the RS characterises among the models of T_o those that can be expanded to a model of T.

3.4 Conclusions

In conclusion, I can safely say, as it is widely accepted, that both of Newman's objections persist. The RS-employing structural realist must face the conservation objection meaning that RS truth implies nothing else than the observational consequences of T. On the other hand, the cardinality objection hinders the attempt at indirect reference made by the defendants of upwards SR. I can not indirectly refer to a certain entity by means of description if my description can be satisfied by a potentially infinite number of different theoretical entities. By a similar argumentation, the cardinality objection also undermines the defense of theoretical terms as members of a unique realisation. Additionally, any constraint made by a theory over the models of its observational part is analogously preserved by the RS, but immediately lost in the vastness of the possible models of a Ramsey sentence. Lastly, the Σ^1_1-fragment can be translated into IF-logic. However, while the mathematical importance of this should not be ignored, it is of little help to the realist in defense of her objectives. Lastly, we showed how the RS forces a model of the observable consequences of T to be expandable into a model of the whole theory.

4 Understanding the Mathematics

To recall, so far we have laid out the main uses of RS in the philosophy of science. These could be summarised as the defense of some form of structural realism, reached upwards or downwards (see Table 1), and the definition of the theoretical terms of a theory as members of its unique realisation. Chapter 3 focused on the model theory behind the Ramsey sentence, detailing the proofs of the conservation and cardinality objections, as well as outlining the philosophical consequences of both. However, we are set to provide a more detailed account of the objections and defences of the RS, so now that we have seen the raw math it's time to discuss in depth the philosophical implications of these results. Additionally, this chapter delves into other philosophical objections raised against certain uses of RS, among which we can count the problem of theory change and multiple realisabilty. However, before we are able to address the philosophical discussion we must first examine another technical result that synthesises what we have seen until now.

At the end of this chapter we will have an understanding of the philosophical debate around the uses of RS, including the discussion about the repercussions of both Newman's problems. In light of these result I will draw some conclusions based on my views on the matter.

4.1 Defense of SR

Now that we have seen the mathematical intricacies of the RS, it is time for us to explore the philosophical interpretations of these results. There is no better place to begin than with Newman's objections, the main concern raised in chapter 3. As said before, we treat both objections separately in relation to the challenges they pose against the uses of RS. Therefore we divide the discussion in three parts: the philosophical problems of the conservation objection, those

of the cardinality objection, and the problem for the definition of the theoretical terms that arise from the cardinality objection. We have decided to give the latter a separate treatment because the use of RS they call into question falls into a very different use in our initial categorisation. Since many reduce the debate to the cardinality problem we have deemed it appropriate to begin the exposition here. Once we have examined the arguments about the main debate we will be better equipped to understand the reasoning about the subsidiary ones.

The discussion of Newman's cardinality objection begins with the recovery if Newman's arguments against Russell's *analysis of Matter* by Demopoulos and Friedman [DF85]. In this article, besides going over the arguments we have seen in the previous chapter, the authors arrive at what will be called the DF thesis:

(DF) If a theory T is consistent and all its purely observational consequences are true then the truth of the Ramsey sentence *follows* as a theorem of set theory or second-order logic ([DF85], p. 635)

This thesis is justified on the basis of the results above. To recall, according to the conservation objection RS is true ($S \vDash RS$) -Recall that S is the correct L_o model- whenever the L_o-consequences of T are true, which is another way of saying that T is consequence conservative over S. Thus, put in philosophical terms, if T is empirically adequate then Ramsey(T) will be true. The consistency requirement there only to ensure non-triviality. However, if T was inconsistent then it would imply all sentences in L_o, so one wonders whether the requirement was strictly necessary.

The DF thesis will be central to the discussion over the philosophical significance of the RS, but it will not be the final word on the matter. Authors like Ketland[Ket04] and Melia and Saatsi[MS06] will have their saying on the matter, to which Demopoulos will in turn reply. At the end of the exposition

we formulate our own opinion on the basis of what we have seen. Let us then proceed.

4.1.1 Ketland's synthesis

First of, after the paper by Demopoulos and Friedman many philosophers contended that the objections could only be raised under the assumption of a sharp o/t distinction [CP02][Ket04]. This was at the very least contentious. On the one hand depending on where one drew the line some entities would be observational or theoretical, but there is nothing one could do about that. On the other hand, authors complained that there were some predicates that could apply to both observational and unobservable entities. Consider for example 'x is larger than y'. Here the variables could be instantiated by O-terms or T-terms indistinctly, even by one of each. In sight of this Ketland decides to separate any such predicates in three: 'x is observably larger than y', 'x is unobservably larger than y' and 'x is miscellaneously larger than y'. The first predicate belongs to L_o and the second to L_t, but what about the third? Ketland's approach will be to create a third class of predicates, *mixed* predicates, in which one of the positions is occupied by an O-term and the other by a T-term.

More formally put, Ketland writes his formalisation based on a second-order language $L_2((O_i)_{i\leq n}, (M_i)_{i\leq m}, (T_i)_{i\leq k})$ (hereinafter $L_2(O, M, T)$ for simplicity) in which he considers first order variables to range over observable and unobservable objects. O-predicates take the former as arguments, T-predicates the latter and M-predicates take one of each. If we delete the theoretical and mixde predicates we obtain $L_2(O)$, if additionally we eliminate second order variables we obtain the firs order 'empirical' language $L(O)$. A model for $L_2(O, M, T)$ is

a Henkin structure:

$$M = ((D_1, D_2), Rel, R_O, R_M, R_T)$$

Where D_1 is the primary domain containing observational variables and D_2 is the secondary theoretical domain. *Rel* is the 'relation domain', containing a collection of relations over $D_1 \cup D_2$. If all relations are included in *Rel* then the structure is called *full*. Lastly, R_O, R_M, R_T are the specific relations in M interpreting the primitive predicates of $L_2(O, M, T)$. The Henkin structure $W = ((D_O), (D_T), O, M, T)$ is the intended model, which stands for the 'real world'. D_O is interpreted as the union of the fields of the observational relations (i.e. the class of observable objects) and D_T is interpreted as the union of the fields of the theoretical relations. By assumption W is full. Now we define:

Definition 4.1: ψ is a true sentence in $L_2(O, M, T)$ if and only if $W \vDash \psi$. Similarly, ψ_o is a true sentence in L(O) if and only if $W_o = (D_O, O) \vDash \psi_o$.

Definition 4.2: A full $L_2(O, M, T)$-structure $((D_1, D_2), Rel, R_O, R_M, R_T)$ is *ontologically correct* if and only if $((D_1, D_2), Rel, R_O, R_M, R_T) \cong W$.

Proposition 4.3: $T(O, M, T)$ is a true $L_2(O, M, T)$-theory if and only if it has an ontologically correct model.[19]

In light of this we define the Ramsey sentence of a given theory as follows: $Ramsey(T) = \exists Y \exists Z T(O, Y, Z)$. We existentially quantify over both theoretical and mixed predicates, and this assumption is made explicit. Now we can obtain the following results:

Proposition 4.4: $((D_1, D_2), Rel, R_O) \vDash Ramsey(T)$ if and only id there is a sequence R_M of mixed relations and a sequence R_T of theoretical relations in *Rel* such that $((D_1, D_2), Rel, R_O, R_M, R_T) \vDash T$.

Proposition 4.5: Ramsey(T) is true if and only if there exist a sequence of

[19]The proof is trivial in light of the above, but it can be consulted in [Ket04].

theoretical relations (on D_T) and a sequence of mixed predicates (on $D_O \times D_T$) such that $((D_O), (D_T), O, R_M, R_T) \vDash T$

In other words, Ramsey(T) is true if we can expand the observable fragment of the world to satisfy T. So far there are no interesting results, but this formalisation interest us in so far as it will be the dominant one in the discussion about Ramsification once the mixed predicates are taken into account. We now proceed to take the empirical adequacy and cardinality requirements into account.

Definition 4.6: An $L_2(O, M, T)$-theory T is *weakly* empirically adequate just in case for any L(O)-sentence ψ, if $T \vDash \psi$ then ψ is true.

Definition 4.7: A full $L_2(O, M, T)$-structure $((D_1, D_2), Rel, R_O, R_M, R_T)$ is *empirically correct* just in case $(D_1, R_O) \cong (D_O, O)$

Definition 4.8: An $L_2(O, M, T)$-theory T is *empirically adequate* just in case it has an empirically correct full model.

Needless to say, if a theory is empirically adequate then its weakly empirically adequate too. *Proof.* Take T empirically adequate, then there is $M = ((D_1, D_2), Rel, R_O, R_M, R_T) \vDash T$ such that $(D_1, R_O) \cong (D_O, O)$. Take ψ an L(O)-sentence. Since $M \vDash T$ and $T \vDash \psi$ we have $M \vDash \psi$. Given that ψ has no theoretical vocabulary it follows that $(D_1, R_O) \vDash \psi$. Since $(D_1, R_O) \cong (D_O, O)$ we have that ψ is true. □

Definiton 4.9: A full $L_2(O, M, T)$-structure $((D_1, D_2), Rel, R_O, R_M, R_T)$ is *T-cardinality correct* just in case $\|D_2\| = \|D_T\|$

Now we are in a position to prove the main theorem of the article, to which we will refer to as Ketland's theorem (KT).

Theorem 4.10 (Ketland's Theorem): Ramsey(T) is true if and only if T has a full model M that is T-cardinality correct and empirically correct.

*Proof.*Left to right is easy. Suppose Ramsey(T) is true. Then there is an ex-

pansion $((D_O),(D_T),O,R_M,R_T)$ of the reduct $((D_O),(D_T),O)$ of the intended structure such that $((D_O),(D_T),O,R_M,R_T) \vDash T$. This full model is obviously empirically correct and T-cardinality correct

For right to left suppose there is said $M = ((D_1),(D_2),R_O,R_M,R_T) \vDash T$ that is T-cardinality correct and empirically correct. Since $(D_1,R_O) \cong (D_O,O)$ there is a bijection $f : D_1 \to D_O$ and since $\|D_2\| = \|D_T\|$ there is another bijection $g : D_2 \to D_T$. We use this bijections to define a full structure $N = ((D_O,D_T),O,R_M^*,R_T^*)$ that satisfies T. Thus we define:

- $(R_M)_i^* =_{def} \{(f(x),g(y))\|(x,y) \in (R_M)_i\}$
- $(R_T)_i^* =_{def} \{g(y)\|y \in (R_T)_i\}$

Thus we can now combine f and g in a two sorted isomorphism:

$$(f,g) : ((D_1),(D_2),R_O,R_M,R_T) \to ((D_O,D_T),O,R_M^*,R_T^*)$$

Therefore it follows that $((D_O,D_T),O,R_M^*,R_T^*) \vDash T$. Hence $((D_O,D_T),O) \vDash Ramsey(T)$, so Ramsey(T) is true. □

But what is the relevance of this result? Compared to the DF thesis, Ketland's Theorem (KT) is marginally, but importantly, different. Put in this terms the DF thesis says that if T is satisfiable and *weakly* empirically correct then Ramsey(T) is true. By contrast, KT requires T to be satisfiable in an empirically correct model, besides a Newman-like cardinality constraint. This thesis raises at least two important problems.

The first one is considered by Ketland [Ket04] as well as by Demopoulos and Friedman [DF85] and talks about RS treating contingent physical truths as mathematical necessities. For example, consider the theory T' of electron orbitals. This theory contains a lot of mathematical equations describing tra-

jectories with, in principle, contingent values for the parameters[20]. In asserting T' we are asserting something that could have been otherwise. By contrast, the defendants of Ramsey(T') are only claiming, according to KT, that T' has an empirically correct full model with enough elements. That is, instead of a contingent fact, we are asserting a satisfiability claim. Of course there is going to be a mathematical model where the parameters precisely as described in T', but that is mathematically necessary, not empirically contingent. What Ketland and Demopoulos notice here is that we transform contingent claims into necessary truths. As they put it, we are doing *physics without physics*.

There is one reply, however , that we could raise against this concern. The objection that Ketland is raising depends on the fact that we can have multiple empirically correct models, more concretely on the fact that we can alter the values of the parameters and still obtain a empirically adequate T'. Otherwise, the objection can't be formulated since the values are in fact necessary. Nonetheless, it is feasible that there is a case of a parameter whose value is not empirically determinant while remaining contingent. On this grounds that I consider Ketland's objection as legitimate, although pending a better example.

The second problem is that multiple theories can have the same RS. As a matter of fact, this was an assumption made by defendants of RSR in the interest of defending SR against the PMI argument [New05]. Therefore, when we assert Ramsey(T) we also assert Ramsey(T'), thus saying that both theories have an empirically correct, T(or T')-cardinality correct full model. This does not help in our choice between theories. If the observable consequences and the cardinality are captured by RS, then how does the sharing of a Ramsey sentence justify our change from an old, abandoned theory, to a new, better one?

[20] We say in principle because the necessitist about natural laws believes that natural laws could not have been otherwise. Therefore the values of the parameters in the equations would be necessarily those

4.1.2 Melia and Saatsi's response

The consequences of this argument are quite dire for the structural realist. We have just explained two of the concerns KT could raise: trivialisation of empirical result and lack of distinction between crucially different theories. Moreover, since in Ketland's formalisation the proof of KT is a logical consequence, very few would dare question the validity of the result. Nonetheless, Melia and Saatsi[MS06] challenge the result in three ways. The first is to question the supposition that we should Ramsify away all mixed predicates (see also Cruse 2005[Cru05]). The second is restricting the scope of the second order quantifiers in order to block Ketland's Theorem. The third is applying intensional notions to the Ramsey sentence to make it resistant to model theoretic objections. We now explore both answers and the possible replies to them.

The intuition behind the idea that not all mixed predicates should be Ramsified away is captured by two examples. First, consider the predicate 'x is a part of y'. The authors reason that this predicate is mixed and has instantiations that should be Ramsified, but some that should not. When it applies to two observable entities or to an unobservable and an observable (respectively, of course), it should remain unRamsified, but it should be quantified when it ranges over two unobservables. They motivate this arguing that the structural realist believes that the structure of reality can be known, and that the predicate 'x is a part of y' says nothing about the nature of either of them.

The way they see it, if we Ramsify all instances of such predicate we are barring the structural realist from saying that, atoms, whatever their nature may be, make up gasses. Therefore, they argue that some mixed predicates should be left untouched, and that in doing so KT does not go through. The idea is that a model of the RS will not necessarily be one in which what is claimed of the mixed relations holds. Therefore, by showing discretion in the

predicates for unobservables that she chooses to eliminate the structural realist can avoid the trivialisation objections posed by Ketland.

There are several points to be made with respect to this reasoning. First and foremost, the predicate 'x is a part of y' is imprecise rather than mixed. Ketland specifically define mixed predicates over $D_T \times D_O$ [Ket04], so a predicate with such a varied instantiation does not fit the category. It would be more precise in this case to 'separate' the predicate as we did with 'x is larger than y'. This way we would have 'x is an observable part of y' in $D_O \times D_O$, 'x is an unobservable part of y' in $D_T \times D_T$ and 'x is a miscellaneous part of y' in $D_T \times D_O$. Needless to say, only the latter is a proper mixed predicate.

Once applied the distinction we realise that the example they give is in fact legitimate, atoms are a miscellaneous part of gases. However, the way they put it is not entirely equivalent. They say 'atoms make up gases' ([MS06], p.571), which is different from 'atoms are part of gases' in at least one crucial way. The statement 'x makes up y' implies that there is nothing else to y than x, that x *constitutes* y. On the contrary, 'x is a part of y' does not. For example, my chairs are part of my furniture but it is not true that they make up my furniture. This distinction, which might seem picky, comes into relevance when we consider the justification of leaving some mixed predicates unRamsified (like 'x is a part of y) on the basis that they don't say anything about the nature of the entities at play. Claiming that the sentence 'atoms are part of gases' does not say anything about the nature of gases is already contentious, but saying the same of 'atoms make up gases' makes no sense whatsoever.

All of this would not be so important if the whole argument of Melia and Saatsi didn't rest on their examples. Their claim that some mixed predicates should be left unRamsified misunderstands the definition of mixed predicate and gives no good examples to defend their cause. Furthermore, the authors

themselves draw a counterexample to their thesis.

Consider a theory T of observable rays. When this rays are passed through a Grue device they turn either blue or green. For formalisation purposes, we assume that all rays are passed through a Grue device. We can formalise this observable theory with he following axioms.

- $\exists x Rx$
- $\forall x(Rx \rightarrow (Gx \leftrightarrow \neg Bx))$

Now suppose that some physicists come up with the idea that the rays that turn green contain P-particles, and the ones that turn blue contain N-particles. No rays contain both types of particles. Let's call this theory T', we axiomatise it with the previous axioms plus the following, where '$x < y$' means 'x is a part of y' and 'Mx' stands for 'x is a microscopic particle'.

- $\forall x((Px \vee Nx) \leftrightarrow Mx)$
- $\forall x(Rx \rightarrow (\exists y(Py \wedge y < x) \vee \exists y(Ny \wedge y < x)))$
- $\forall x(Rx \rightarrow \neg(\exists y \exists z(Py \wedge Nz \wedge y < x \wedge z < x)))$
- $\forall x((Rx \wedge \exists y(Py \wedge y < x)) \rightarrow Gx)$
- $\forall x((Rx \wedge \exists y(Ny \wedge y < x)) \rightarrow Bx)$

In this theory it is easy to see which predicates are observable, unobservable and mixed, being the only mixed one '$x < y$'. If we Ramsify according to Melia and Saatsi the only predicates we do away with are M, P and N. It is easy to see how Ramsey(T') has some additional physical content, it entails that rays have parts, about which T said nothing. Nonetheless, it does not matter what those parts are like, what relations this parts have to any observable properties or if they are causally responsible for to the color of the rays. Provided that rays have parts, Ramsey(T') is true.

What is the meaning of this example? It still matters not which objects instantiate the parts of the rays, so long as there are any and enough. Intuitively speaking, Ketland's objection should still come through. The mistake that Melia and Saatsi are making when they claim that KT is overruled when we leave mixed predicates unRamsified comes from their misunderstanding of a the notion of mixed predicate. For if we understand mixed as 'fuzzy', in the sense that it might apply to observables or unobservables then the predicate 'x is red' is mixed. In this case it is obvious that a model for a RS where we Ramsify 'x is red' might not be a model for the whole theory. However, if we take mixed predicates properly as ranging over $D_T \times D_O$, as my analysis above defended, then Ketland's Theorem is left unaltered.

It is in this line that Demopoulos points out that the Ramsey sentence of a theory with mixed predicates where the latter are not Ramsified will be true provided the original theory is satisfied[Dem11]. That is, Ketland's Theorem still applies even if we leave the mixed predicates untouched. This statement would be inconsistent with the previous authors' were it not for the latter being misled in the way we have explained. Let us reason about it.

Consider the proof of Theorem 4.10 (Ketland's Theorem) that I drew on section 4.1.1. It is not dependent on whether we Ramseyfy or not the mixed predicates. The proof would remain identical left to right and for the converse it would be enough to skip the stem where I defined:

- $(R_M)_i^* =_{def} \{(f(x), g(y)) \| (x, y) \in (R_M)_i\}$

In what respects to Newman's objection, it is also not affected if mixed predicates are taken into account. Whether we Ramseyfy them or not, the proof only requires of a partition of L between L_o and L_t.

However, if I take mixed predicate in the sense of Melia and Saatsi then both proofs are in trouble. For I would be leaving unRamsified certain predicates

applying to theoretical entities and therefore narrowing down the number of possible realisations, perhaps even attaining unique realisation. Nonetheless, I must insist I consider their treatment of mixed predicates as mistaken, since it leaves too much room to misinterpretation and vagueness. By sticking to mixed predicates as subsets of $D_O \times D_T$ we avoid ambiguity and preserve the validity of both theorems.

There is, nonetheless, another way in which Melia and Saatsi try to defend the Ramsey sentence approach from the objection posed by Ketland. Their hope is that in changing the logical framework the trivialisation results could be blocked. In this line of work they face the problem that if their system is too weak it will not block the trivialisation results, but if it is too strong it will not be consistent with the principles of structural realism.

Their approach to modifying the logical framework will be to restrict the second order quantifiers. The argument is that both normal speakers and scientists use restricted quantification when they make their statements. They claim that if a scientist says that everything carries energy she's not thinking of the number 2. The same occurs with properties, the range of our second order quantifiers may vary depending on the context. Thus, Ketland's assumption that the relation domain *Rel* is full goes precisely against this intuition. The idea is that under the assumption that our Henkin structures are not full KT fails.

While this restriction is enough to block the model-theoretic arguments we have not yet arrived at a restriction that is also consistent with the goals of structural realism. In the authors words, 'too strong a restriction and RS might not be preserved across successful theories, too weak a restriction and the theory runs the risk of being true too easily'([MS06],p.575)

The first candidate for this restriction are is the distinction between natural

and disjunctive properties. Plainly put, natural properties are the ones that cut nature at its joints, that unify their instances in some objective way. The properties 'being identical to A or B','being a triangle','being natural numbers x,y,z such that $x + y = z$' are natural. Any property that is not natural is disjunctive. Melia and Saatsi first proposal is to restrict the range of quantifiers to natural properties, and since is is not true that there is a natural property to any set of objects, this is a genuine restriction able to undermine KT. However, there are two problems with this line of thought. The first is that the distinction natural disjunctive is thought by some as ill motivated or theory-relative[Tay93], the second is that this treatment prevents Ramsified theories from avoiding the PMI. A way in which new theories gain on past ones is by showing that what was thought as a natural property is not in fact one. This way 'being hot' or 'being green' have been shown not to be natural properties. Our authors choose to discard this alternative in sight of these objections, and I agree.

The second distinction that they consider is intrinsic/extrinsic. Intrinsic properties are the ones that belong to something in virtue of what it is, extrinsic are the rest. However, to every set of objects there is an intrinsic property characteristic of them. For example, to the set $\{a, b\}$ there is the property 'being identical to a or b'. Clearly this is not enough to block the model-theoretic arguments, since it doesn't constrain *Rel* in any way. Thus, this alternative is also abandoned.

The third distinction that comes to mind is qualitative/non-qualitative. The idea is that if *Rel* is full then to every set of objects in D_T there is a property that all and only its elements share. However, the authors reason that properties in science should be about what objects are *like*, not mere mathematical assumptions. Since it is not true that every set shares a qualitative property this does block the formal arguments. The example the authors give is that of

a symmetrical world containing three perfect spheres, each of one unit mass, each at precisely 1m from the others. Call them a,b and c. There is no qualitative property that distinguishes any of them from the other two. However, in scenarios where the world is not that symmetric it is true that any object has an identifying qualitative property, so any set of objects has an identifying qualitative (disjunctive) property. Therefore this also fails to block the model theoretic arguments.

The last alternative for a distinction that our authors consider is causal/contingent. However, they also consider that the restriction will not work due to similar reasons as the qualitative/non-qualitative, although their explanation is not very clear. Therefore, we can conclude that their idea of restricting the second order of quantifiers is equally unproductive

However, Melia and Saatsi explore a third way, perhaps the most interesting, consisting of allowing intensional operators into our formalisation to block the formal objections. The idea is that some properties are related to other by other than mere chance. Some properties counterfactually depend on others or are correlated in a law like manner, and this should be reflected in our formalisation. For example, it is not mere coincidence that 'being water' and 'being H_2O' are related, they are *strictly necessarily* correlated ([MS06],p.581).

The model theoretic framework employed so far is not able to express relationships between properties, so Melia and Saatsi propose we add intensional operators in order to capture them. Their hope is that appealing to such notions the model theoretic arguments might be blocked. To illustrate, let us return to the example of the rays passing through a Grue device. We saw that for the RS of T' to be true we needed nothing else than for the rays to have proper parts. What this approach proposes is that we require those proper parts to have a law-like connection with the behaviour of the rays, the existential quantifiers in

the Ramsey sentence would need to be instantiated by some entities that can explain the observable phenomena.

One attempt at a formalisation of this kind is posed by the authors themselves. Recall how we said that water was necessarily H_2O. We can formalise it with the intensional operator L_p for physical necessity. We write $L_p\forall x(Hx \leftrightarrow Wx)$ for the sentence stating that the properties 'being water' and 'being H_2O' are necessarily coextensive. The authors believe that in this way one can solve the problems of multiple realisation posed by the model theorists. The sentence $\exists X L_p\forall x(Xx \leftrightarrow Wx)$ can only be instantiated by the property H, since H_2O is the only necessarily coextensive thing with water. Therefore, they believe this would block Newman's and Ketland's argument.

It looks like the formalisation will be able to resist KT, but we still need to talk about the philosophical aspect of the approach. In principle, the idea that properties are lawfully related is consistent with structural realism Melia and Saatsi argue that law-like connections between properties did play a significant role in Worrall's original formulation of structural realism. In his examples, electromagnetic properties associated with observable phenomena could be related in a law-like manner with vibrations in a mechanical aether or variations in a primitive field. Law-like associations also allow for multiple realisations, but require more from the real world than mere associations. The idea is that one could plug in any theoretical object in a Newmanesque way and keep the relationships intact, but to do so and preserve a lawful relation does not allow for just any kind of theoretical entity.

While for the authors this might seem like a perfectly valid answer, we can not shake the suspicion of certain circularity to the argument. When we say that the sentence $\exists X L_p\forall x(Xx \leftrightarrow Wx)$ can only be instantiated by the property H, are we not already assuming that water is H_2O? It is possible to imagine a

world in which water is not H_2O, but XYZ instead[Put70], so in principle it is not *necessary* that the predicates 'being water' and 'being H_2O' are coextensive.

The authors could argue that they still admit for cases of multiple realisation, so the complaint we raise against them is baseless. For example, they allow both the EM-field and the aether to be lawfully related to the observable properties of electromagnetic properties. However, one could ask on what grounds do they choose what if lawful and what is not. Why is there no other theoretical alternative they consider lawful? The cardinality problem tells us that for whichever $\vec{t_i}$ we choose there will be a model of RS, and conservation that any model of RS is empirically adequate. Therefore we wonder on what grounds do the authors separate the EM-field and the aether from other equally viable theoretical entities. This seems in our opinion like a very *ad hoc* way to save the ship, if not a complete begging of the question altogether.

4.1.3 The skeptical answer

The success of the the type of defense we have seen so far is controversial. Calling into question the different assumptions did not prove successful, while the addition of intensional notions runs the risk of circularity. Objecting the arguments posed by Newman and Ketland seems ill fated, but there is another alternative to the defense of structural realism, namely the one argued for by Worrall[Wor07].

In his 2007 paper, he defends SR from multiple critiques raised against it. Among other issues, he addresses the significance of Newman's objection for structural realism. Worrall's approach, in sort, consist of questioning the existence of a problem. In his view, the cardinality objection poses no problem whatsoever for a philosophically mature structural realism.

He argues that the Ramsey sentence of a theory asserts the existence of certain properties and entities, as a realist would want it. The problem arises when

we try to determine what preciesely those properties are besides what satisfies the RS. For Worrall an electron is whatever satisfies the Ramsey sentence of the theory of electrons. Instead of departing from an idea of the entities that we then can not recover, he proposes that we accept the limits of our knowledge and be content with it. Trying to determine the nature of our $\vec{t_i}$ beyond the structural constraints they pose would require an access to reality independent from our theories, and he argues, there is nothing more foolish than that.

There is however, one note to be made to Worrall's skeptical solution, and it is that it does not apply to every kind of Ramsey sentence employing structural realism. If one uses RS in order to avoid PMI it is true that the precise reference of the $\vec{t_i}$ can be dispensed of, Newman's problem can just be ignored because the structural content is unaltered. If there is something satisfying the RS, it does not matter too much what is it. However, if one comes to SR through the upwards path the problem persists. If we recall, Maxwell's structural realism employed Ramseyfication exclusively to the end of avoiding direct reference to *certain* theoretical entities. If that is not guaranteed then this form of realism is doomed.

4.2 The definition of theoretical terms

Structural realism aside, we still have to talk about the consequences of the Newman problem for the other contemporary use of the RS, namely the definition of the theoretical terms (see section 2.4). At first glance the answer would be clear: defining the $\vec{t_i}$ assumed that there was a unique realisation and Newman has shown that there are potentially infinitely many. Therefore this way of defining theoretical terms just does not work.

However, this is not the last word to this respect. For the one of the very rediscoverers of Newman's objection argues that it poses no problem for Carnap's

original definition of theoretical terms. In effect, Friedman argues that since Carnap assigns mathematical structures to be the extension of the theoretical terms, it does not matter which (multiple realisable) intension these take. To recall, Carnap defined a series of domains $D_0, D_1, ...$ by power set application over the basis of the naturals (modulo isomorphism) so that there would always a structure available to be the extension of theoretical terms. Thus Friedman argues that this is the *unique* extension of the theoretical terms, not any other physicists could think of. The intensions of the other hand are precisely this multiple realisable Newman-susceptible entities, and it is correct for them to have this ambiguous character. After all, they are whatever the scientist is thinking of when she asserts the theory. This way the problem of multiple realisation is avoided and the t_i are rightfully defined.

However, how does this response help any other posture? In what respects to Carnap's original position it might be true that the problem is solved, but there are many forms of realism that do not endorse mathematical entities to be the extension of theoretical terms. For most realists, when they existentially quantify via the Ramsey sentence they mean its variables to range over unobservable *physical* objects. If we take the extensions to be physical then the problem of multiple realisability persists.

4.3 Equivalence problem

There is yet another result worth discussing about the mathematical nature of the Ramsey sentence, and it is the one owed to J. English[Eng73]. She proved, as we show bellow, that any two incompatible Ramsey sentences must be observationally non-equivalent. That is, there must be an L_o-sentence about which they disagree.

Proof. Let $\exists \vec{X} T_1(\vec{X}, \vec{O})$ and $\exists \vec{Y} T_2(\vec{Y}, \vec{O})$ be two incompatible Ramsey sen-

tences. Since the existential claims are incompatible, any two instantiations of them will be too. So take two disjoint sequences of theoretical predicates $\vec{P}$ and $\vec{Q}$, we know that $T_1(\vec{P}, \vec{O})$ and $T_2(\vec{Q}, \vec{O})$ are incompatible. By Craig interpolation, there must be a sentence ψ in the shared vocabulary (that is, in L_o) such that $T_1(\vec{P}, \vec{O}) \vDash \psi$ and $T_2(\vec{Q}, \vec{O}) \vDash \neg\psi$. Since the sequences are arbitrary, by universal generalisation the same holds for the Ramsey sentences. □

According to English this means that if one takes theories to be just their RS then the underdetermination thesis fails. One can not have to incompatible Ramsey sentences that are both empirically adequate, since they would disagree in at least one observational sentence.

This would be good news for the realist, at last a property of the Ramsey sentence is beneficial towards her goals. However, there are two concerns I would like to raise about this result. The first is that the proof does not seem correct. In particular, I am concerned about the step where we take disjoint sequences of predicates $\vec{P}$ and $\vec{Q}$. The rest of the proof is correct, until we reach the last step where we use UG to infer the same result for the Ramsey sentences. If the sequences of predicates are disjoint we can not really assume they are arbitrary, so the use of universal generalisation seems flawed. If the sequences were arbitrary there would be still a possibility that they are not disjoint, thus the ψ in the shared vocabulary could contain terms not in L_o, ruining the proof altogether.

Additionally, one only wonders if the same proof could be carried out when taking mixed predicates into account. Our suspicion is that if we add said predicates and leave them unRamsified (as many realists request) then the no-underdetermination argument can be blocked. For example, let us recall the example of Melia and Saatsi about the green and blue rays. Let T_1 be the complete theory with microscopic particles and let T_2 be just the observable

part -particularly that there are rays and that they turn green or blue when passed through a Grue device- plus an axiom stating that rays have no proper parts. Here there is an example of two Ramsey sentences that are observationally equivalent but yet are incompatible.

The second concern is simpler. Even if the proof was correct, there is still something to say about its premise. In an ordinary case of underdetermination the whole theories need to be incompatible, but here we require for the RS to do so, which is a much stronger request. It is assumed by the defendants of structural realism that two theories can share a Ramsey sentence, so many cases of ordinary underdetermination would no longer be Ramsey-underdetermined. A famous example would be in the Fresner-Maxwell case, two theories with the 'same' RS but that would have been ordinarily a (past) case of underdetermination. This is probably very much the intent of the author, but we might be over-correcting here. That is, there might be some cases that we would like to be under-determined that will not count as such with this set up. This is because Ramsey sentences are existential statements, which makes it very hard for two of them to actually refute each other. We would need an existential statement preventing the type of relations in *Rel* that would make the other Ramsey sentence true. This seems complicated, at least at first glance. In any case the message is that incompatibility between Ramsey sentences is a much stronger requirement than incompatibility among theories, and that should not be overlooked.

But where some see a convenient feature others see a great disadvantage. Ladyman argues that this means that RSR collapses theoretical equivalence into empirical equivalence ([Lad98],p.413), but I disagree. If two RS are observationally equivalent then, according to English's result, this means that they are compatible, but that does not necessarily mean that they are equivalent. As

we have said, two Ramsey sentences can very difficultly refute each other, so in principle this should not be too much of a concern.

4.4 Conclusions

After having reviewed the interpretation of the main mathematical results exposed until now we are in a position to draw some preliminary conclusions. First and foremost, Carnap's attempt at defining theoretical terms as members of a unique realisation is doomed the very moment we take the extensions of the $\vec{t_i}$ to be physical (see section 4.2). The methodology works on his own framework in virtue of his particular treatment of extensions as members of a series of a fixed structure. On any form of standard structural realism the problem of multiple realisability persists and therefore the definition of theoretical terms proposed by Carnap inevitably fails.

Secondly, in section 4.1.1 we have seen how Ketland synthesised the mathematical results by Newman into a comprised enunciation KT:

(KT) Ramsey(T) is true if and only if T has a full model M that is T-cardinality correct and empirically correct.

We have seen all the further problems this led to. The first of them, multiple realisability, is the thesis that for any theoretical objects we may choose, there will be a model for a given RS that employs exclusively them provided they are enough. This is what precludes us from the intended definition of the $\vec{t_i}$ or from knowing the reference of the variables we are employing, thus posing serious challenges for a use of the Ramseyfication like Maxwell's [Max70]. For a downwards use of RS we have seen that a Worrall-like skeptical answer can save the ship for now, but we have yet to examine this in depth.

On the other hand, the problem of trivial realisation is heavily underlined by both Ketland [Ket04] and Demopoulos and Friedman [DF85] as one of the

main issues pertaining the realist use of Ramseyfication. Both articles focus on the trivialisation of contingent physical results. As we have seen, since for Ramsey(T) to be true it suffices that T has an empirically correct, T-cardinality correct full model, asserting the Ramsified version instead of the whole theory trivialises contingent physical results. The contingent values of unobservable constants are trivially realised for some model of T of the given characteristics, thus the complaint voiced by these authors that we are doing physics without physics. This will be another of the issues we keep in mind going into chapter 5.

In third place, we saw how this very thesis can pose a problem for the structural realist pretension of justification of theory change. If asserting Ramsey(T) just means that the whole theory has a desirable full model then, how do we choose between theories with the same RS? This seems complicated at least. The problem of theory change, one of the main motivations to adopt structural realism in the first place, remains unsolved.

Lastly, we saw a more promising result for SR. The underdetermination problem can be blocked if we take RS, but, as we have seen, only under certain circumstances. Nonetheless, since our doubts about the validity of the result are nothing but that, we will take this into account in our final valuation at the end of this thesis.

5 Trivialisation, Theory change and Multiple realisability

In the last two chapters I have exposed the mathematical results around the Ramsey sentence and their philosophical discussion in recent literature. The result of this endeavor is that now the concerns around Ramseyfication can be boiled down to three: multiple realisability, trivialisation and theory change.

In this chapter I explore some answers given in the literature in response to these issues, providing a discussion of them and drawing my own conclusions. Since they are easier to address and explanatory to other sections, I begin by explaining the issues concerning theory change. Afterwards I address the problems around multiple realisabilty, summarising the answers given in last chapter and exploring a new one. The discussion about trivialisation goes last, where I showcase the answer given by Cruse [Cru05] and introduce one of my own.

5.1 Theory change

One of the main doubts concerning the use of Ramseyfication is whether this theoretical device actually represents an improvement with respect to traditional entity realism. After all, the objective of the downwards use of RS (recall Table 1) is precisely to resist the pessimistic meta-induction argument. Many authors, and I agree, have some doubts about whether this is the case based on different reasons. In this section I explore their argumentations and try to recap the answers given to them and draw my own conclusions. There are two kinds of objections here: the ones about the structure of the RS itself and the ones related to the generalise-ability of the examples.

Regarding the former kind we find very similar complaints in both Ladyman

[Lad98] and Newman [New05]. They both object that Ramseyfication assumes a sharp nature/structure distinction. In chapter two we say how RSR (Ramsey Sentence Realism, the RS-employing downwards SR) assumes the Ramsey sentence to be precisely the structural part of the theory, about which one is to be realist, whilst leaving the theoretical objects as the natures that one ought to be skeptical about. For Newman this is just a transposition of terms. Worrall's original formulation of structural realism was hindered by the structure/nature distinction. Since now what falls in or out of the RS (that is, the structure) is determined on the basis of an also controversial observational/theoretical distinction, Newman argues that this is no real advance. The same point is shared by Ladyman, although on different grounds. He criticises the assumed nature/structure distinction in its own right arguing with Psillos ([Psi95]) that the nature of something is no other than its structural properties and the equations governing them, or quoting McMullin:

> What are electrons? What the theory of electrons says they are. (1984,15)[McM84]

This pertains here insofar as the Ramsey sentence is taken to be the structure and this the theory change persistent part of the theory. If structure can not be separated from nature the whole basis for the Ramsey sentence procedure is compromised.

Let us make nonetheless the perhaps no so trivial assumption that structure and nature can actually be separated. Both authors share yet another concern about the capacity of RS to solve the PMI objection. While the applicability to the Fresner-Maxwell case seems pretty straightforward, there are some other instances with more dire prospects. In particular, the concept of 'mass' comes to mind in both cases. While in the predecessor theory (classical mechanics) it was a property of an object with a 'fixed' value, it becomes a function of

the speed of light in the special relativity setup. Thus the RS that mentions mass in classical mechanics looks nothing alike the homonym's from a relativity standpoint. This is in clear contention with the claim that past and new theories share a Ramsey sentence and thus an structure.

It is in this line that Worrall also interrogates whether the Fresner-Maxwell example can be extrapolated to a more general conception of theory change[Wor07]. In consideration of very similar arguments as the ones posed above, he opts for the correspondence principle, according to which the equations of the old theory appear as limiting cases of that of the new one. For example, the Newtonian equations can be recovered from Einstein's relativity when $\frac{v}{c}$ tends to 0. Although Redhead points out that this strategy might not always be effective [Red06], Worrall goes on to argue that in mature (that is, genuinely predictive[21]) theories the principle does hold. Thus, if our theories are replaced it will be by some in the light of which they will look approximately structurally correct.

But what does this mean in terms of our Ramsey sentence? Worrall agrees that the RS reflects the structural content of the theory, yet fails to provide an account of theory change that addresses the particular role of Ramsification. It is to this end that I propose the following. Let us say that for any two theories T_1 and T_2, the latter is a correspondent successor of the former if and only if the theory change from T_1 to T_2 can be explained in terms of the correspondence principle. Now I propose:

Definition 5.1 Let T_1 and T_2 be two theories. T_2 is a correspondent successor of T_1 if and only if for any model $M \vDash Ramsey(T_1)$ there is a model $N \vDash Ramsey(T_2)$ such that $M \subseteq N$.

For example, any model of the Ramsey sentence of Newtonian mechanics can be embedded into a model of the Ramsey sentence of general relativity. As

[21]This is an equivalence made by Worrall, I remain impartial towards it.

we said, the former is a constraint of the latter where $\frac{v}{c}$ tends to 0. This could be done by defining an ultraproduct $\Pi_{i\in[0,1]}$ over f where for every magnitude assigns the general relative value that it takes when $\frac{v}{c} = i$. Then we take Π_0 to be the classical model, which is clearly embeddable in the ultraproduct. I believe this way many theories could be shown to obey the definition I propose above, although I have no proof that the principle follows in general. Additionally, this formalisation helps with the problem we extracted from KT, the issue that if a theory and its successor share a RS, then the defendant of RSR has no grounds for switching from one to another. Since now the successor RS outweights the previous one there is a solid ground on which to cement theory change. Lastly, a disclaimer. In proposing this formalisation I am not endorsing nor denying the correspondence principle, I am simply pointing at a possible way of formalising it to take the Ramsey sentence into account.

Therefore I can conclude that the problem of theory change requires us to accept some sort of structure/nature or observable/theoretical distinction. Furthermore, faced with slightly more challenging cases of theory change (like the ones pertaining 'mass') we must endorse some kind of principle that accounts for the dissimilarity of the respective Ramsey sentences. We have seen how the correspondence principle might be an alternative, and I proposed a manner of formalisation for it that accounts for the Ramsey sentence. In conclusion, theory change is still a problem for RSR. Part of it can be bypassed with a not so trivial assumption, whereas there is another part that requires a bit more inventive. I have explored and expanded one of the possible solutions, . However, should my hope turn out to be baseless, I still contend that there is probably some principle and formalisation of the sort that can solve this aspect of the theory change problem. We are faced but by a technical problem, one I suspect has a solution.

5.2 Multiple realisability

The second of the three problems that concerns me has been already addressed in the last chapter. Multiple realisability threatens the concerns of the structural realist in several ways. One of them is by hindering her attempt at defining the $\vec{t_i}$ in terms of the unique realisation of RS. Newman's objection states that given any theoretical objects there is a model of the RS that employs just them. Furthermore, any pretensions of indirect reference to certain theoretical objects are shattered, contrary to the objectives of upwards structural realism. Ladyman also recovers and earlier version of KT in his 1998 paper [Lad98], and he too objects this type of structural realism its inability to talk about any particular objects.

Faced with this objection we have seen Worrall's skeptical response. In short, RSR is unable to narrow down the reference of its variables just because it is not meant to do so. Since we can not have a theory-independent access to reality it would be nonsensical to try to determine the nature of our $\vec{t_i}$ beyond the structural constraint they pose on the observable phenomena. I also weighted this answer against the different uses of RS and concluded that, while it can be an option for the downwards structural realist, it falls short for the upwards use of Ramsification in sight of its pretension of indirect reference to certain theoretical entities.

There is, however, another way to answer the concern of multiple realisability. It is explored by Cei and French [CF06] on the basis of Lewis work around the definition of theoretical terms. The idea is that they distinguish between two types of multiple realisability and treat them differently. On the one hand, it can be the case that the theory whose Ramsey sentence is multiply realised is a provisional theory. In this case the authors consider that the multiple realisability might be resolved in progressing to a better (successor) theory. However,

Newman's objection means that there will be multiple realisation in any theory, regardless of whether it is final or not. Thus, this answer does not seem valid.

On the other hand, it can be the case that there is multiple realisation on a final theory. In this case the authors conclude that if both $\vec{t}$ and $\vec{s}$ satisfy the Ramsey sentence of such theory, then it must mean that there is no theoretical difference between said sequences. If all the constraints they put on the observable are the same and the structures they satisfy are identical, then our theory should not distinguish between them. Put simply, an electron is whatever the theory of electrons claims it is, any further ontological refinement is unnecessary and not scientific. This is what the authors refer to as the Humility principle.

It is easy to see how this second case resembles Worrall's answer, in both cases one accepts the inability our inability to further determinate the theoretical entities besides the content of our theory and take that as a positive feature of the Ramseyfication process. Thus I am going to treat both answers as one in what follows, when I will be addressing the concerns that still raise from the adoption of this strategy. According to French and Cei the Ramsey sentence structural realism can either be structural or realist, but not both [CF06]. Faced with multiple realisability one can opt for forcing unique realisation using the method explained in chapter 2:

$$t_i = y_i; \exists y_1, ..., y_n \forall x_1, ..., x_n (T(x_1, .., x_n) \leftrightarrow x_1 = y_1 \wedge ... \wedge x_n = y_n)$$

Let us denote G the set of sentences defining every theoretical term in this way. This strategy suggests taking RS + G instead of RS as a substitute for the original theory. However, there are two difficulties within this approach. The first is stated by the authors and is that the characterisation of the $\vec{t_i}$ is entirely syntactical. Issues of ontological commitment only make sense from an internalist point of view, where G is defined. Outside RS + G the theoretical

terms are not defined, therefore all the mechanism to force unique realisation becomes externally syntactical, rendering the notion of structure (the analytical content, G) too thin for a realist understanding of structure. I also find that, even if this difficulty could be surmounted, it can be proven that RS + G is equivalent to RS + CS [22], which we saw to be equivalent to the original theory. Therefore this approach might save multiple realisability only to fall in the problem of theory change, resulting in no advance whatsoever.

If, however, one decides to adopt the Humility strategy and claim that the RS says enough then French and Cei claim that one is subject to the critique that then the laws of nature are contingent since the entities that instantiate them are undetermined. If I could have qelectrons (which is what I decided to call a fictional RS-equivalent substitute of electrons) instead of electrons without it making any significant difference then I could argue that the laws of nature are not necessary. They argue that this is in clear contrast with the structural realist thesis that our theories are accurate in what refers to the structural description of the world.

Nonetheless, I find this argumentation problematic. For once, they are equating the employ of different $\vec{t_i}$ to that of different laws of nature. Not only that, they then claim that the structural realist should be realist about the particular laws of nature in place. In my opinion it is possible that the same law is instantiated by different entities whilst remaining the same. Otherwise, the law would not be a purely structural element, and thus there would be no reason why the structural realist should be committed to it. The authors make here two mutually excluding assumptions in order to discard the Humility strategy as an invalid response.

Some could argue that there remains the option of exploring a third way.

[22] Where CS stands for Carnap sentence. Recall that in section 2.4 Lewis defined $CS := RS \rightarrow T$

While there is mathematical evidence that multiple entities could satisfy the same RS, it seems obvious that as a matter of *fact* only one string of entities can actually realise it. Following this line one could force unique realisation as in the first strategy making $\vec{t_i}$ refer to precisely these entities. If one does this there are two obvious difficulties. The first is that the reference, even if determinate, is unknown. From an internal point of view one can determine it, but from an external standpoint this is impossible, which is already a controversial feature for a theory. In contrast, I can take the theoretical term posed by any given theory and know what it would refer to if said theory was true. Second and foremost, I consider that the line of thought that takes factual unique realisation as a prerequisite is altogether circular. If mathematically it is possible for many different entities to satisfy the same RS, what tells me that it is not actually the case? I find myself with no feasible grounds to reject this alternative, so I can only reject this strategy.

In conclusion, I have explored three alternatives to answer the problem of multiple realisability. The first and the third I have opted to reject on some shared an particular grounds, but I see no reason to object the second one. This means I consider the Humility answer to be a feasible response to the problem of multiple realisability. It is true that we can not determine the character of our theoretical entities beside what our RS say of them, but that does not mean that we are at fault. I deem that the structural realist has just about enough with this and should not aim for more. Thus, I conclude with Worrall that the problem of multiple realisability poses no threat for the philosophically mature structural realist.

5.3 Trivialisation

Last but not least, it is time for me to address the problem of trivial realisation. In what respects to this section, let us assume that the other two problems are solved for the sake of the explanation. To begin with, let us recall Ketland's Theorem:

(KT): Ramsey(T) is true if and only if T has a full model M that is T-cardinality correct and empirically correct.

From this results stems the problem of trivial realisation that we have forwarded in the previous chapter. Shortly put, trivialisation implies that for any given theory T, the contingent values of the equations ranging over theoretical entities are a product of mathematical necessity in a Ramseyfied setting. Allow me to explain via an example.

Let T be a theory in a language L. there be two types of theoretical entities P and Q part of a broader theory T. As a part of T, our scientists claim that there is a attraction force between Q-entities at P-entities with value 2 units, [and that this relationship has no bearing in the observational realm][23]. Let us name a relationship R_2 where xR_2y means that there is a force of attraction of 2 units between x and y. I can formalise the statement as $\varphi := \forall xy(Px \wedge Qy \rightarrow xR_2y)$. We can all agree that the value 2 of this force could have been (in principle) anything else whilst the observable part of the theory remains the same. Additionally, all P, Q and R_2 are theoretical relationships so they will be Ramsified away.

Now let us assume that T does have an empirically correct, T-cardinality correct full model. This makes Ramsey(T) automatically true, regardless of whether the value of the R is actually true or not. It is a matter of mathematical

[23]This last condition is important and ignored by Ketland, for if the value could not be changed without affecting the predictions then the trivialisation result would not follow.

logic, and the same would follow if we gave any other value to R. It can still be the case that T has no model that is both empirically and ontologically correct and that it is therefore false. And even if the value is correct, the validity of RS does not stem from the contingent fact that T is true, but from the mathematical property of the Ramseyfication process. This is what we call the trivialisation of a result.

It is precisely to this that Ketland [Ket04] and Demopoulos and Friedman [DF85] are referring when they talk about doing *physics without physics*. In adopting the RS, one is taking for granted some contingent physical results as a product of mathematical necessity. This trivialisation of physical results feels unacceptable from a realist point of view, for if our theories are meant to accurately describe the structure of reality then we must be committed to a specific value for our theoretical relations. By contrast, the Ramseyfication process ensures the truth of a RS regardless the values we ascribe to certain type of relations. This is in clear contradiction with the goals of the structural realist.

Reached this point, how can one solve this conundrum? Interestingly enough I have found no literature addressing this phenomenon or trying to provide an answer. The discussion is centered instead in the debate around multiple realisability, which is also sometimes referred to as trivial realisation. This leaves the problem of trivialisation somewhat untreated and cast to the side, perhaps by terminological confusion. In any case, in what follows I draw an answer of my own and evaluate it.

The whole trivialisation argument rests on the supposed existence of some theoretical relations whose value bears no significance in the observational realm. Whether this relations actually exist is already a debatable point, but my focus is not on that. On the contrary, my approach is more epistemological here.

If the scientists claim that the value of some theoretical relation is 'x' then it either is the result of an experiment (in which case the value of the relation *does* have observational consequences), it can be tested experimentally (of which the same is true), or it is a non-falsable, theoretical hypothesis. Since we assume that the value of the relation has no observable consequences then it must be the third case.

Now the question is up to which point should one be concerned about the specific value of any such relation. For the instrumentalist it is clear, so long as the theory predicts and explains -and it is clear that said value does not matter to this end- she will be content. Thus I argue that for certain positions this result is not entirely problematic. But the trivialisation result was meant against the structural realist, and here I believe it can be much more harmful. For the defendant of SR believes that our best theories accurately describe the structure of reality, without specifying whether it plays a role in observation or not. Therefore I believe that she should be concerned about the value of any such relation, thus the trivialisation argument becomes greatly problematic towards her goals.

We find ourselves with the fact that the Ramseyfication process not only can not account for the nature of the theoretical entities in play, but is also unable to explain the contingent character of the values of the equations governing them. Even if the multiple realisability and the theory change problems were solved the structural realist would still have to face the daunting challenge of avoiding trivialisation. I think there are two ways of answering this predicament.

The first is simple, the structural realist can argue that her Ramsey sentence is no worse than the original theory in this aspect. Ramseyfication makes some values trivially true, but the original theory can not properly *prove* those values either. If it was a matter of mere speculation to begin with, there is no reason

why the RS should be any better than the original theory. The problem remains, this strategy just questions its relevance. Even if valid, I find this answer lazy and lacking in what refers to the problem itself. The trivialisation remains, and it is important to address it properly rather than casting it to the side. The second option is more controversial. Since these values are not involved in the empirical adequacy of the theory, one option as a realist would be to limit my commitment to the parts of the theory that are relevant to the correct prediction and explanation of phenomena. This strategy might not be embraced by the majority of structural realists, but it does block the problem in so far as the specific value of said relations become irrelevant.

In conclusion, I think that the severity of the trivialisation problem has been overstated by Ketland and Demopoulos and Friedman. They ignore the condition that the values of the theoretical relations should not affect to the phenomena in any way, thus they deem the trivialisation result much more harmful than it is. In their view the contingent value of the gravitational constant G can be trivialised in this way, but I disagree in so far as a different value for G would imply radically different observable predictions. By limiting the claim to the values of purely theoretical equations with no impact on the phenomena we can greatly cap the scope of the problem altogether. This said, I still consider that the trivialisation result constitutes a very serious concern to the structural realist since she will want her theories to be accurate descriptions of the structure of reality regardless of whether they are empirically relevant. This can be blocked by limiting the ontological commitments of SR, a solution that will not be to everyone's liking. All in all, I consider that the trivialisation problem still poses a very hard challenge to the structural realist, one that we can not simply ignore.

6 Conclusions

Now that I have finished the exposition of the content of this thesis, let me recapitulate the work done until now. This will serve as a re-exposition of the main theses at which I have arrived, but I will also be drawing my conclusions along the way.

To begin with, the explanation commenced with a formal definition of the RS, making explicit its limitation to finitely axiomatisable (first order) scientific theories. The second chapter then focuses on the first historical use of the RS by Carnap, as well as on the more contemporary uses of Ramsey sentences. I divided the latter in three: avoiding PMI (downwards SR), indirect reference to theoretical objects (upwards SR) and definition of theoretical terms as members of the realisation of RS. Chapter 3 went on to explain the mathematical intricacies of RS, making emphasis on both Newman's objection. According to the first of them, conservation, RS is true whenever T is consequence conservative over the correct observational model, that is, whenever the observable consequences of T are true. On the other hand, cardinality implies that all the theoretical terms in a model of RS can be replaced by new ones provided they are arranged in the desired structure.

Additionally, I explained how Hintikka's IF-logic offers an interesting alternative towards the analysis of RS, even if it fails to prevent Newman's objections. Furthermore, I explained the constraint that RS imposes on the models of the observable consequences of T (namely that for every $N \vDash T_o$ there must be some $M \vDash RS$ such that $N \subseteq M$) and clarified how it did not constitute a significant limitation in light of Newman's or Ketland's argumentations (see section 3.2). Lastly, I provided a positive characterisation of the RS as distinguishing, among the models of T_o, those that can be *expanded* to a model of T.

Chapter 4 details the philosophical discussion around these results, as well as

provides the proof of Ketland's Theorem, another pivotal point of the debate. From this theorem we can extract two of the most important philosophical objections raised against the Ramseyfication process. The first is multiple realisability, the fact that (following cardinality) the theoretical terms of any model of RS can be replaced *salva veritate*. As explained, it threatens the prospects of the definition of $\vec{t_i}$ as members of a unique realisation, as well as the idea of indirect reference proposed by the defendants of upwards structural realism. Secondly, trivialisation constitutes a concern to any form of realism involving Ramsey sentences in so far as it makes physical, contingent results seem the product of pure mathematical necessity.

I then exposed the three different ways in which Melia and Saatsi tried to block the model theoretic concerns: by allusion to mixed predicates, by restriction of the scope of the second order quantifiers, and via the introduction of intensional quantifiers. To the first alternative I showed a counterexample in which even if mixed predicates are not Ramseyfied the multiple realisability persists. The second strategy is rejected by the authors themselves, and I argued against the third on the grounds that it is circular (see section 4.1.2). Section 4.1 ends with the exposition of an skeptical answer to multiple realisability offered by Worrall, consisting roughly on the idea that multiple realisability poses no real concern to a philosophically mature (downwards) structural realism.

Thereafter I explained one of the possible defences of the definition of theoretical terms against the problem of multiple realisability. To recall, Friedman argues that following Carnap it is possible to bypass the problem if we commit our theories to use mathematical structures (defined as in Carnap) as reference instead of the traditional theoretical terms. Thus, in using the physical only as intension the problem of indeterminate realisation can be avoided. Nonetheless, this strategy fails if such an assumption is not made. I argue that most

philosophers of science would see such idea problematic, therefore I conclude:

(1) The definition of theoretical terms as members of the unique realisation of Ramsey(T) fails in sight of the problem of multiple realisability (unless extensions are taken to be mathematical in nature)

The chapter concludes with a discussion over English's result that underdetermination can't occur between Ramsey sentences. I think the proof is mistaken on the grounds explained above (section 4.3), and that even if it was correct it can be blocked by taking mixed predicates into account. I also argue about it's significance for the realist and explain why Ladyman's interpretation of the result is mistaken.

The last chapter focuses on the possible solutions to the problems of multiple realisability and trivialisation together with an account of whether the Ramseyfication process can account for theory change. Starting with the last one, I showed how the Ramseyfication process translates the terms of the structure/nature distinction into observable/theoretical. If the RS is the structure, then whatever is theoretical will determine the realm of 'nature'. Some authors like Ladyman [Lad98] and Newman [New05] argue against any such distinction.

Furthermore, even if a line could be drawn there would remain the problem of the generalisability of examples like the Fresner-Maxwell case. The downwards use of RS aims to solve the problem of PMI by arguing a continuity between the Ramsey sentences of the old and new theory. However, there are many cases in which such continuity is at the very least doubtful (such as with regard to the idea of mass) and therefore we are in need of a principle that accounts for the dissimilarity of the Ramsey sentences. Worrall proposes the correspondence principle to this end, but even if accepted there would still remain need to find a formalisation for it that prevents any ambiguity. Thus I conclude:

(2) The Ramseyfication process can account for the problem of theory change

provided that:

- We have principle that accounts for the dissimilarity between the Ramsey sentences of the predecessor and successor theories.
- We can find a non-ambiguous formalisation for such principle.
- We accept some sort of structure/nature or observable/theoretical distinction.

In what respects to multiple realisability I examined three strategies that defendants of downwards SR employed to bypass the problem. The first was to force unique realisation and take RS + G[24] instead of RS alone. This is equivalent to the original theory itself, so I argue that this might solve this problem only to fall in the pit of PMI. Therefore I consider this is no real alternative for the downwards use of RS. The second strategy was that defended by Worrall, the Humility strategy as French and Cei refer to it. The latter authors criticize it, but I have shown how their concerns are based on premises that together enter in conflict with the principles of structural realism (see section 5.2). There remained still a third way to defend SR on the basis that there must be *de facto* a unique realisation for the RS of our best theory, but I argued that this reasoning is circular (see section 5.2 or 3.1.2).

Focusing now on the upwards use of RS, I consider that multiple realisability makes it impossible to refer indirectly to certain theoretical entities. For reasons very similar to the ones that made impossible the definition of theoretical terms I consider that the prospects of upwards use of RS are also doomed. The defendant of upwards SR could still endorse the first strategy and force unique realisation, but then she would still be making direct reference to theoretical entities, so no advance would have been made. Therefore I conclude:

[24] Which was shown to be equivalent to RS+CS

(3A) Multiple realisability makes it impossible to refer indirectly to theoretical entities. Therefore the upwards use of Ramsey sentences is no longer viable.

(3B) The Humility strategy can make downwards SR immune to the problem of multiple realisability, therefore this use of Ramsey sentence remains valid.

Lastly, I addressed the problem of trivialisation. After an explanation of the manner in which it threatened the prospects of any kind of structural realism I made it clear that both Ketland and Demopoulos and Friedman were overstating the severity of the problem. By restricting the trivialisation concern to those values that have no bearing in the observational consequences of T (see section 5.3) I could hugely restrict the philosophical significance of this objection. Furthermore, I provided an answer to the problem consisting on limiting the ontological commitments to the structural realist to those parts of the theory that are involved in the prediction of observable phenomena. Therefore I conclude:

(4) The trivialisation objection can be blocked by restricting the ontological commitment of SR to those part of the theory that are involved in the prediction and explanation of phenomena.

I admit that this is a constriction that most structural realist would not be willing to adopt. However, I consider that if left unchecked the trivialisation problem does pose a severe threat to the structural realist if she wants her theories to be structurally accurate about values regardless of whether they play part in extracting predictions.

All in all, I consider the viability of RS as a philosophical tool to be very position-dependent. If one's aim is to define theoretical terms or to indirectly refer to them, then the Ramsey sentence will be of no help. The multiple

realisability concern makes it impossible to narrow reference enough to make it univocal. However, the debate is not so simple when it comes to the downwards use of RS. On the one hand I have shown multiple realisability to pose no threat towards its prospects, but on the other hand trivialisation and the theory change problem suggest that there is much room for improvement. The former requires us to adopt a watered-down version of SR while the latter asks for a principle and a formalisation that we have yet to find. We are faced by a technical problem and a problem of structure. Moreover, I can not judge the Ramsey sentence without taking into account its intrinsic limitations. It can only be applied over finitely axiomatisable theories and it forces us to adopt some kind of observable/theoretical distinction.

The PMI-avoiding use of Ramseyfication is viable, provided that the conditions above are met, but it leaves us with a version of SR that is significantly different than the one we started with. Some would argue that such a realism leans too much into empiricism, and I would agree, since it only cares about the empirically relevant parts of the theory. However, if only the technical problem is tackled and the commitments are unchanged I consider that the trivialisation concern together with the intrinsic limitations of RS constitute enough grounds to abandon the RS altogether. There is no use in endorsing a tool that (might) salvage *some* of our scientific theories from PMI only to trivialise their contingent values. We can either keep the realism in SR or defend RS from trivialising results. All in all, downwards Ramseyfication can remain viable at the cost of realism, or remain realist at the cost of viability.

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