Resistance and the Practice of Rationality

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By

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London, November 2012

AN INTRODUCTORY NOTE

In a series of workshops at the London School of Economics, sponsored by the Centre for the Philosophy of Natural and Social Science (CPNSS) and the Institute for Social psychology (ISP) we aimed at tackling one of the longstanding problems of our age. What are we to understand by the concepts of ‘rationality’ and ‘irrationality’ as they are used in our time? They figure prominently in critical discourses in which the follies of all kinds of people are offered in explanation of social disasters. After the examination of a wide range of material in which these concepts figured it became clear that there is no such thing as a context free concept either of rationality or of irrationality. Nor do they form a neatly opposed pair of antithetical partners. These concepts appear in a variety of discourses some of which have been much in evidence recently in what one might call the era of accusations. The claims by those who believed that extra-terrestrials had visited earth recently have been popular, and popularly derided as ridiculous, that is irrational. The same sort of rhetoric has surrounded discussions of global warming–is the earth actually warming–those who deny are the irrationalists, but only to the scientific establishment. But is that warming once conceded the result of human behaviour? Those who resist this uncomfortable conclusion join the ranks of the irrationalists. Those who deny the reliability of thermometers are very different from those who emphasise the possibility of natural processes of warming of the planet.

What would we say about those who fail to be convinced of the idea that it is human folly that is responsible for the changes in the climate? We might well say that they *resist* these ideas. So the discussion of rational and irrational responses to many situations and claims is tied in with the idea of resistance. But that too is a polysemic concept. Just as one person’s incompetent bank manager is another person’s cautious investor, so one person’s resistance is another person’s stubbornness, and, in another context and with respect to another contrast, wisdom! This insight suggested the project of a wider study of the concept of ‘resistance’ and its uses in contemporary discourses from physics and engineering to the phenomena of non-compliance to military, legal and political imperatives or to failure to adjust one’s beliefs to the available evidence or even to common sense.

This present collection of essays was a development of the Beyond Rationality program set up in the Centre for the Philosophy of Natural and Social Science (CPNSS) at the London School of Economics. This project involved many and diverse studies of the how the concepts of rationality and irrationality are and have been used in many contexts. For many philosophers the ‘gold standard’ of rationality has been conformity to the laws of logic. However, assessments of discourses and practices with respect to their rationality or irrationality turn on matters far removed from the strict rules of logic. Even such archetypal rational practices as scientific research and theorizing and the practice of the law do not conform to these rules.

The research topics that form the content of the first volume of the Beyond Rationality studies (2012) took up the challenge of sketching the domain relative meanings of categorizing practices and discourses as rational or irrational. How if at all are these meanings related and upon what are they based? The project involved the description and discussion of such assessments in an array of studies, including climate change debates, business models, and many others. There was no attempt to pull out a definition of what ‘rationality and ‘irrationality’ really mean. The work was simply aimed at mapping patterns of use with different degrees of similarity and dissimilarity in the criteria for their acceptable application.

Missing from the volume was the question ‘When is it rational to resist social pressures, fait accompli, authoritarian diktats, emotional blackmail, invading forces, and so on?’ And that raises the question of what might be meant by ‘resistance’ in this and other contexts. This led to the attempts to unravel the question of the context relative meanings of the word ‘resistance’ as it appears in all sorts of contexts as are presented in this volume. Is there a core meaning of ‘resistance’, and if not, what are the significant uses of the world and how are they related? What roles do they play in the management of our lives? Though we offer no solutions to these vexing questions there may be valuable insights to be reached on a case-by-case basis.

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PART I:

RESISTANCE IN THE NATURAL-BIOLOGICAL SCIENCES

Chapter One

Resistance as A Concept in Physics

Rom Harré

We can make a beginning in the study of the concept of ‘resistance’ prior to detailed studies of the many kinds of resistance we encounter in modern life, by setting out some of the ways the word is used in a variety of contexts. A casual survey of the uses of the word ‘resistance’ in English yields a diverse list of linked but different senses. The word appears in medical discourse, ‘resistance to disease’; in political/military discourse, ‘resistance to occupation’; in scientific discourse, ‘electrical resistance’ and ‘frictional resistance’; in engineering, ‘air resistance’; in psychological discourse, ‘resistance to reason’, and no doubt there are many more. Is there a core of meaning common to the use of the word in these contexts, and if so, are there any significant cross-fertilizations among the various domains?

Some Preliminary Lexicography

In this chapter the task will be examine the way the concept of ‘resistance’ is used in physical sciences. Laying out a field of family resemblances for the uses of the word ‘resistance’, the default position as our working assumption will be that in these contexts ‘resistance’ is morally neutral. There are no implications of valuations with respect to resistance as a natural phenomenon. However, in some material contexts the use of ‘resistance’ is linked by metaphor and simile to psychological and moral concepts, such as ‘laziness’. Nevertheless, as metaphor, it hardly needs remarking that the use of the word for the tardiness of the response of a magnetic field to changes in the current that animates a magnetizing coil, is shorn of any implications of blame.

This has some importance however, for our studies, because the question of which contexts are the basis of the meanings we assign to ‘resistance’ is important. If the psychological and moral contexts are the source of the meanings of resistance in mechanics, electromagnetism and so on we must assume that resistance in these contexts is a clear enough notion to determine meanings in material contexts by metaphor or simile. Fields of family resemblances have structure–historical, analogical and no doubt other inter-relations. Where do the core meanings lie, if there are any?

In this paper I propose to confine myself to the uses of the word ‘resistance’ in scientific and engineering discourses. In the course of this volume, the links between these uses and the concept of ‘resistance’ in moral, political, psychological, psychiatric and social contexts will no doubt emerge. In the end we may be able to see how far these uses of the word (concept) are derivative from the way it is used in the sciences and engineering. Medicine may straddle the seeming differentiation between material and moral meanings of ‘resistance’.

The Program of Study

We can begin with a glance at the dictionary.[1]
Three main uses are recorded.

1. Resistance as the action of withstanding an assault of whatever sort. ‘This crop resists drought very well’, ‘Straw offers hardly any resistance to combustion’.
2. Power or capacity of resistance. ‘Concrete has little resistance to shearing forces’; ‘Porcelain offers a great deal of resistance to the passage of a current.’
3. Opposition to pressure or movement of another body. ‘The wall resisted the force of the wind’; ‘Water resists the movement of one’s hands.

An obvious working assumption in the uses of ‘resistance’ in these contexts is that the concept is morally indifferent. It makes no sense to praise the wall for resisting the flood waters or to condemn the river for resisting the free movement of one’s limbs. However, in some physical contexts the etymology of the use the word discloses a metaphorical link to psychological and moral concepts such as ‘laziness’. In the context of the natural sciences this aspect of the root meaning is, I suggest, completely lost.

[1] A good place to begin: ‘Freely fair and fairly free, divinest Etymologie’, as J.L. Austin once put it.

Method of Analysis

I will be drawing on Wittgenstein's concept of resemblances and differences in the uses of a certain word, symbol or sign, uses that are not linked by neat synonymies but by similarities and differences in the conventions that express contextually but relative meanings. Discussions of this sort can be shaped by thinking in terms of a 'field of family resemblances'. By that Wittgenstein meant an array of uses of a word or phrase that are linked by similarities and differences in rules of correct application in their semantics (Wittgenstein, 1953). He made use of this idea to illustrate a common error in thinking–that of presuming that because a certain word is used across many contexts, there must be a common something in all of these contexts to which it refers. We use the word 'guide' in many ways. Is there a common meaning to 'being guided'–along a path, by a text or a score and so on? In this series of studies we are unlikely to fall into what is now a familiar philosophical trap. Instead we can use the idea of the field of family resemblances positively to track uses the concept of 'resistance' in contexts in the material world and the sciences that are devoted to material phenomena; to the medical concepts of 'resistance to disease' and 'resistant to infectious agents'; to psychological concepts around conversion and rational and irrational thinking; to social and historical contexts in which we encounter uses such as 'resistance to tyranny' and the like.

Shaping a Family Resemblance Study

The overall project of the work presented in this volume could be described as an attempt to locate the concept of 'resistance' in a great many contexts, including those of importance in everyday life in our time. We have many uses for the idea of 'resistance', in psychology, political and intelligence studies and so on. However, the ranges of uses of an important word like 'resistance' is very large and diverse. We can use the way a specific vocabulary is used in a technical context in order to sharpen our appreciation of the multiplicity of meanings in the wider scope of meanings, technical and vernacular. The discussion to follow in this chapter is aimed at laying out a field of family resemblances of uses in contexts in which the discourse is about the material world and expresses the knowledge we have of material phenomena in mechanics and electromagnetism.

Physics and engineering have given the concept of 'resistance' a small range of sharply defined uses which we can use as scaffolding with which to begin the wider study of resistances bringing in political, psychological, theological, military, medical and everyday uses.

Resistance as a Concept in Physics

The study of resistance to motion in physical systems, the root idea in the physical sciences, is '*Tribology*' (Kragelskiĭ and Alisin, 2001).

Resistance is a force preventing a process from starting, or once started from intensifying beyond a certain threshold. The main example in elementary physics is 'friction'. This concept is tied to the idea of 'opposition' or 'opposing'.

Active Opposition

This meaning is illustrated in the examples to follow:

Dry friction: This is the resistance opposing a force that would otherwise have set a body in motion or opposing those forces that tend to maintain it in motion while a moving or potentially moving body is in contact with its surroundings. We can imagine a rock sitting on a sloping surface, immobile until struck by an avalanche.

There are two cases of dry friction.

i. Static friction: the force equal and opposite to the force exerted on one body in contact with a surface before the body starts to move. We shove at the rock but at first it does not slide across the road.
ii. Kinetic friction: the force equal and opposite to the force acting on the moving body when there is relative motion between body and surface. Once we have got the rock to move we must keep on pushing to keep it sliding.

Once motion has begun and resistance is overcome by a greater impressed force, the residual force opposing motion, the kinetic friction, is less than the static friction.

A glance at elementary textbooks shows that the word 'resistance' is used in mechanics as part of the definition of the concept expressed by the technical definition of 'friction' in terms of forces. A common understanding of 'resistance' is presumed in the foundations of elementary physics. We do not learn what 'resistance' means by making use of a prior understanding of 'resistance'. Rather we learn what concepts such as 'viscosity' mean by drawing on the common meaning of 'resistance'.

Amontons' Laws

The laws relevant to dry friction as resistance to motion were anticipated by Galileo and Newton but first fully formulated by Guillame Amontons (1663–1705).

First Law: The force of friction opposing motion is directly proportional to the applied force. The greater the force exerted the greater the frictional force that opposes it.

Second Law: The force of friction is independent of the apparent area of contact.

Fluid Friction: or viscosity: the resistance of a fluid to the free movement of an immersed material body, the force we call 'drag'. This is illustrated by the energy required from the motor to maintain the speed of a car when it is being propelled through the air, of a boat as it goes moving through water, or a drill boring through a wooden block. Turn off the ignition and the car comes to rest thanks to 'air resistance'. In physics and engineering this concept refers to a species of *force*.

Stokes' Law

As is usual in physics a law is enunciated in a simple case, with refinements in different contexts of application. Stokes' Law links 'drag' or fluid resistance to attributes of the medium in which a body moves and relevant properties of one kind of moving body. The law links the force needed to move a small sphere at a certain velocity through a fluid of a certain viscosity against the resistance to motion exerted by the fluid.

We have then an understanding of resistance to motion of a solid in contact with another solid, and when immersed in a fluid. There are also analyses of the motion of one lamina of a fluid with respect to another horizontal slice of that same fluid or at surfaces of contact between two different fluids, such as oil and water. *In all cases motion meets with resistance.*

Electrical Resistance

Electrical resistance is a property of conductors. It appears in a simple form in Ohm's Law–that the voltage in a circuit is the product of the current by the 'resistance'–'V=IR'. We have the well-defined metrical concepts of 'volt', 'amp' and 'ohm', respectively.

The form of this law is explained in terms of the hindrance to motion of current bearing electrons driven through a conducting medium by a potential difference across the terminals of the conductor, anode and cathode.

There are conditions when it has been found that electrical resistance in a conductor to the flow of a current is zero. This is the phenomenon of *superconduction.* These conditions can be realized only when the conductor is cold enough, so far as we know. Engineers and material scientists work towards finding materials in which superconduction occurs at higher and higher temperatures.

Theoretical analysis of each of these examples–mechanical and electrical resistances–makes use of the concept of ‘force’. However these ‘forces’ are not fundamental but depend on electromagnetic interactions between molecules of the interacting bodies. For example, there are bumps and hollows in the surfaces of solid bodies that explain dry friction at a first level, but these are effective as resistance to motion because there are more fundamental electromagnetic forces shaping the surfaces of solid bodies. Similarly, the resistance to the motion of electrons through a conductor can be explained in terms of forces of attraction and repulsion between unlike and like charges. Negatively charged electrons interact with the electric charges of the molecular and atomic constituents of the solids through which they flow (Coey, 2010).

Inertia

Inertia is an attribute of material things, a tendency to resist an accelerating force. This is an intrinsic property of material things that is not due to any interaction with the surroundings. Even in a vacuum a force acting on a material body produces only a finite and proportional acceleration according to Newton’s Second Law–‘F = MA’–where F is the impressed force and M is the mass of the body acted upon. No explanations of inertia are or could be forthcoming in Newton’s Mechanics–it is a fundamental and unanalyzable basic feature of the material world.

However, in the late nineteenth century an attempt was made to account for inertia in terms of something else. According to Mach’s Principle the inertia of a single material body is the result of its relationship with all the other bodies in the universe. Contrary to what Newton presumed in his famous thought experiment of the pair of globes rotating in an immense vacuum a body in a universe devoid of any other material stuff would have a vanishingly small inertia. Newton concluded that if the globes were connected by a string in which a spring balance had been inserted, the balance would register a force of mv^2/rg where m is the mass of the globes, v is the tangential velocity of their rotary motion, r is radius of the circle of rotation and g is a constant. Since the force is proportional to the square of the velocity of rotation, it should vary with that velocity–regardless of the absence of all other matter in this stripped down universe. In this way Newton thought he had established the meaningfulness of absolute rotational motion. Mach pointed out that this thought experiment depended on the assumption that the globes would retain their inertia in the absence of all other material things. This assumption could be queried. There was no necessity that inertia should be an intrinsic property of all material bodies.

Hysteresis

The word derives from the Greek *'hustersis'* meaning a shortcoming or deficiency, having nothing to do with '*hysteria*', the Greek word for 'uterus', and thus nothing to do with gynaecology or the much later context of psychopathology, in the treatment of which Sigmund Freud made his name. In physics and engineering the word refers to a situation or process in which changes in some property of a physical system lag behind changes in the process which is causing these changes. For example: the application of an increasingly strong magnetic field induces increasing magnetization of the body to which it is applied, say an iron rod. But as the applied magnetic field decreases the magnetic flux in the magnetized body declines more slowly, so that when the applied field is zero the body retains some residual magnetization. This tardiness of response is 'hysteresis'. It can also occur in stretching elastic bodies, such as springs and even motor tyres.

We can see hysteresis as a kind of resistance to change in an induced physical state, such as magnetization and elasticity. The metaphor of 'laziness', stripped of it moral connotations, seems apt.

In the various contexts I have described resistance is related to energy–generally energy lost in a process in which motion is inhibited and dissipated as heat. According to the Second Law of Thermodynamics that energy can never be completely recovered in a reversal of the cycle.

Complementary Concepts

We must also recognise 'anti-resistances'–the negative complements of the concepts we have been describing. For example the negative complement of friction would be something that facilitated motion. The negative complement of inertia would be something that overcame the tendency to resist mechanical force, while the negative complement of hysteresis would be something that dissipated the energy stored in the spring or magnet.

Lubrication

Fluid friction can be substituted physically for dry friction by inserting a liquid between the interacting solid surfaces. Laminas in fluids suffer less mutual frictional resistance than do solid surfaces in contact. Oiling the bearings does not eliminate friction but facilitates motion by introducing surface to surface contacts with lower frictional forces.

‘Polishing’

The explanation of why there are frictional forces between contacting surfaces refers to bumps in the surface of solids and intermolecular forces in the contact surfaces. Changes can be brought about in the state of interacting solid dry surfaces by polishing, washing and so on to remove unevennesses and contaminants in the surfaces in contact. Elbow Grease is the process by which our manual labour facilitates such change in the nature of the interacting bodies, using the energy of the impressed force to bring about a change in the configuration of molecules in the surface of the body being worked on. Rubbing two sticks together can help a traveller in the wilderness to make a fire, when production of heat is derived from the energy used to overcome friction.

Changes can be brought about in physical state of fluid friction for example by heating the fluid.

Summary

In the physical sciences ‘resistance’ appears in a field of family resemblances, with two subfields:

1. Where ‘resistance’ comes into being as a force in opposition to an impressed force whether the body acted on has or has not yet begun to move or where it is in motion. The laws of these kinds of resistances are well known, and scarcely more than tidied up common sense. Later, molecular theory provided an explanation in the nature of the contacting surfaces.
2. Where ‘resistance’ appears indirectly in limitations in the efficacy of an impressed force or forceful process as in ‘inertia’ and ‘hysteresis’. In these contexts energy considerations are relevant,

but on the cosmic scale the debate between Machians and Newtonians continues.
3. Sometimes ‘resistance’ can be reduced by altering the nature of the contact interaction, and in the case of electrical resistance in some circumstances it can be eliminated entirely.

We have now laid out some of the patterns of use that make up the field of family resemblances of the uses of the ‘word ‘resistance; and some if its technical synonyms. The next step will be carry out similar studies of the way the word is used in other contexts, to display other fields of family resemblances. In the end a grand overall semantic map may be able to be created as we link the various specialised fields with one another and with the map presented here.

Abstracting from these various concrete exemplars of the use of the concept of ‘resistance’ we can lay out a triad of cases which we would recognise as examples of resistance:

1. Strongest: doing the opposite of what was expected–when expected to attract the resistor repels.
2. Intermediate: doing what is required or expected but reluctantly or with delays.
3. Weakest: doing nothing at all in circumstances where some sort of response is called for.

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CHAPTER TWO

RESISTANCE AND RATIONALITY: SOME LESSONS FROM SCIENTIFIC REVOLUTIONS

DEAN PETERS

1. Resistance and Rationality

The theme of this book is "Resistance and the Practice of Rationality". "Resistance" brings to mind the extensive literature analysing scientific "revolutions". These are instances in the history of science where an apparently radically new theory is proposed and eventually overthrows its predecessor to become the consensus or near-consensus view of scientists working in the field. A new theory is not, of course, typically accepted immediately. Indeed, the majority of working scientists may refuse to accept the new theory. This is the form of "resistance" that I focus upon in this chapter. It is a matter of longstanding dispute whether or not the key players–both proponents and opponents of new theories–in these episodes are to be counted as "rational". In keeping with the themes of "resistance" and "rationality", in this paper I will attempt to shed some light on this issue.

The term "rational", of course, is used differently in different disciplines, and its precise content remains contested in each. I focus on the use of rationality as a word to describe the proper way of deciding between scientific theories on the basis of empirical evidence. Rationality in this sense is primarily a *normative* term, a means for picking out the correct way of doing things. Any ascription of rationality must therefore be generalisable. That is, we cannot say an agent behaves rationally simply on the grounds that she reaches the correct conclusion on some particular occasion. We must be able to say that that she follows a certain pattern of reasoning which can be replicated on multiple occasions. Moreover, we cannot simply *observe* that she regularly applies the same pattern of reasoning: we should be able to articulate a corresponding *rule* that other agents would in principle be able to follow in carrying out their own reasoning. Another way of putting this is that, if challenged on her decision, the agent could in principle state the rule that she followed as the *reason* for behaving as she did. Finally, to be described as "rational" an agent must not only be following *a* rule but a "correct" rule (I will, make this notion a little less vague later). I shall use "arational" to describe any factor that influences an actor's behaviour, but fails to be general-rule-governed. Preserving its connotation of disapproval, I shall use "irrational" to describe a factor that involves an incorrect way of reasoning.

Were the scientists involved in episodes of theory change rational in the sense I have described? In section 2, I examine four broad answers to this question that have been offered in the literature. I dismiss two of these, and focus on the two that I regard as most plausible: I term these "Kuhnian" history and "rationalist" history. I then discuss briefly the particular form of rationalism I regard as the most promising. In section 3, I apply this rationalist account to a well-known instance of theory change, the "Copernican revolution", and find that its depiction of the collective decision astronomical community as rational is convincing. In section 4, I examine another famous case study, the "chemical revolution". I find here that it is less plausible to regard the scientific community as rational, given the account I have adopted. In the conclusion (section 5), I spell out the implications of these case studies for the question motivating this paper, whether or not the key actors in episodes of theory change should be regarded as rational.

2. Four Kinds of Scientific History

The first approach to the history of science, termed "Whig history", is more a foil for further discussion than a viable position, since few or no historians deliberately endorse it. Butterfield's (1931/1965) aim in coining the term, in the context of political history, was to diagnose and criticise what he saw as a pernicious tendency among historians to project their own concerns and beliefs anachronistically on to actors in the past. This tendency results in historical actors being cast either as heroes or villains, depending on whether their actions tended either to bring about or avert the current state of affairs. In the history of science specifically (see Jardine, 2003), "whiggishness" results in the ascription of epistemic virtue to historical scientists who supported theories that are approximately correct from the perspective of our current theories. So, in instances of theory change, whichever scientists supported the theory closest to our own are automatically described as rational. And, since newly-proposed theories have typically been closer to ours than their pre-existing rivals, this usually amounts to a judgement in favour of the proponents of novel theories. Their opponents, in contrast, are usually viewed either as irrational–mistaken about some factual matter, or in the grip of some cognitive illusion–or arational, perhaps acting to preserve their positions of power and social influence.

This asymmetric treatment of proponents versus opponents of novel scientific theories is extremely difficult to justify as an a priori attitude. While we are certainly entitled to judge that past actors were *incorrect* in their scientific judgements, it seems entirely unwarranted to judge that they were *irrational* simply on that basis. The task of any criterion of rationality is to warrant certain inferences against a background of beliefs and observations already accepted by the actor concerned. A Whiggish criterion of rationality fails in this task, as it takes as its starting point beliefs and observations available to the later historian, but not to the historical actor being judged. We may, of course, legitimately conclude that one or other party is less rational than another, but this can only be done *after* examination of the information available to each of them.

The “asymmetry” of Whig history is tackled directly by a second approach to the history of science, namely the “Strong Programme”, most famously associated with Barnes and Bloor (Bloor, 1976; Barnes and Bloor, 1982; 1996). For our purposes, the primary doctrine of the Strong Programme is the so-called “equivalence postulate” which states:

> “that all beliefs are on par with another with respect to the causes of the credibility… This means that, regardless of whether the sociologist evaluates a belief as true or rational, or as false and irrational, he must search for the causes of its credibility.” (*op cit* 1982, p. 23).

In light of the criticisms of Whig history, it seems that few could object to this view, as stated. In fact, however, the Strong Programme is controversial because of the emphasis that its adherents have placed on arational factors in influencing the course of scientific history. For example, in one highly-regarded product of the movement, Shapin and Shaffner’s (1985) *Leviathan and the Air Pump*, the authors examine the struggle between the competing scientific approaches of Boyle and Hobbes in Restoration-era England. They argue that it was ultimately because the complex of ideas associated with Boyle was *politically* successful that his scientific ideas triumphed. This conclusion is stated explicitly in the closing chapter of the book:

> "We have attempted to show … that the contest among alternative forms of life and their characteristic forms of intellectual product depends upon the political success of the various candidates in insinuating themselves into the activities of other institutions and other interest groups. He who has the most, and the most powerful, allies wins." (*op cit*, p. 342)

So, whereas Whig history casts one side of a scientific dispute as rational, and its opponents as a- or irrational, the Strong Programme refuses to attribute rationality to *either* side. Political ideologies, personal interests and other "sociological" factors essentially decide the outcome of these disputes.

In my view, the Strong Programme's initial diagnosis is entirely correct–that the truth of some scientific theory (from the perspective of a later theory) is not by itself a sound explanation for the success of that theory at an earlier point in history. But an explanation by reference to truth is not the same as an explanation by reference to rationality. To say that the proponents of some theory were "rational" is simply to say that they had good arguments in their favour. And a theory having good arguments in its favour is a perfectly acceptable explanation for its success. Human beings do, at least some of the time, behave in certain ways because they were convinced by argument to behave in those ways. Moreover, given the large amount of time that scientists spend presenting arguments for and against theories, it is implausible to claim that all this activity is merely a sideshow to the political manoeuvres which actually decide the issues. So considerations of rationality must play *some* role in episodes of theory change. The two remaining views I shall consider differ over exactly what this role is.

The third approach to the history of science emerges from the work of Thomas Kuhn (1962/1996; 1977). In his later work, Kuhn articulated a view about the rationality of scientific revolutions that is a hybrid of rationalist and anti-rationalist accounts. He argues that scientists apply "values" or "objective factors" in choosing between scientific theories. These include the *accuracy* with which the theory matches phenomena; the theory's *consistency*, both internal and with reference to other theories; its *scope*; its *simplicity*; and how *fruitful* it is in generating further research. These criteria may conflict in particular cases, and even the application of a single criterion can lead to conflicting judgements. One theory may, for instance, be highly accurate in accounting for a given class of phenomena, but less accurate than its rival in another domain. Kuhn holds that applying these criteria is simply *what it means* to count as rational, but also that there is no general means of ranking the demands of these values when they conflict. The demands of rationality are therefore indeterminate. Kuhn believes that it is arational factors which ultimately close the gap between rationality and theory choice. Individual scientists may prefer one or other epistemic value for aesthetic or otherwise idiosyncratic personal reasons. Each may prefer a theory that accounts adequately for the phenomena that they happen to be regard as important. Indeed, they may even be drawn to theories favouring their political ideologies or personal interests. And *all of this counts as rational* for Kuhn, so long as these other factors do no more than narrow down the range of possible answers that are compatible with the basic values of rationality.

The fourth approach to the history of science, finally, is what I call "rationalist". This view is somewhat aligned with Kuhn's account, in that it suggests that there are scientific values or "virtues" which theories might fulfil and that fulfilment of these virtues makes it rational to choose them over their competitors. However, where Kuhn argues forcefully against the notion of an "algorithm" that will uniquely choose the best theory amongst several contenders, rationalism claims that there is a hierarchy among the virtues, or some other general principle that will at least sometimes render accepting one theory, on balance, *more rational* than accepting its competitor. Along these lines, I follow a suggestion made by Worrall (1990, pp. 333-4):

> "[Kuhn's] argument against the objectivist nonetheless goes through *only* if we accept the initial assumption that the objectivist can do no better than supply a "laundry list" of objective factors, and is therefore left entirely without recourse when two factors from the list pull in opposite directions. But I know of no objectivist who would accept Kuhn's list as it stands and none who would be happy to leave *any* such list unstructured. For example, for Duhem, Poincaré, Lakatos, and many others, there is a *basic* criterion: that of predictive empirical success. When this criterion is properly understood, it informs most of those on Kuhn's list."

For Worrall, "predictive empirical success" does not necessarily require the prediction of a hitherto unknown phenomenon. The point is not literal temporal novelty, but "use-novelty" (Zahar, 1973; Worrall, 2002; 2006). That is, the theory must have empirical consequences other than those it was designed to explain. This concept is easily explained by use of a simple example. Imagine theory T with a single free parameter k. This need not be understood as a numerical parameter, but more generally as some aspect of the theory that can be modified to yield different empirical consequences. As it happens, T correctly predicts the outcome of two experimental measurements if and only if k is fixed to a particular value k_1. Starting with T and having made both measurements, we can now "accommodate" one of them by setting $k=k_1$. Whichever measurement we accommodate, the other is now predicted; even though we were aware of it, we did not use it in designing the theory.

So, under Worrall's usage, we can think of a theory with lots of predictive success as one with a large number of confirmed empirical consequences in excess of those required to fix all the free parameters. And, rather elegantly, predictive success described in these terms functions as a sort of composite epistemic virtue, incorporating various items on Kuhn's list. If a theory *accurately* matches phenomena and has wide *scope*, it has many confirmed empirical consequences. A *simple* theory is one with few free parameters. Moreover, Worrall denies that some of Kuhn's listed virtues are in fact virtues. Notably, he claims that consistency with already existing theories is not to be prized at all, as the conflict between the new and old theories "supplie[s] interesting and demanding problems for further research." (Worrall, 1990, p. 335). With Worrall's particular version of rationalism in hand, we can now see what assessment it gives to some concrete case studies. I shall outline the broad historical facts in each case, and provide some analysis, but leave for the conclusion the final analysis of how these cases fit the rationalist picture.

3. The Copernican Revolution

For the historical details of this section, I follow Kuhn's (1957) detailed study of the "Copernican revolution". Ptolemy's *Almagest*, produced around 150 AD in Hellenistic Egypt, proposed a detailed geocentric model of the universe. Despite some innovations accumulated during the Middle Ages, this was substantially the system to which Copernicus was introduced in the late 15th century. It envisages a universe contained between two concentric spheres. The surface of the earth is the inner sphere, and the much larger outer sphere holds "fixed stars". The outer sphere rotates around the inner, with the period of rotation defining a day. In between these two spheres move the planets, a term which applies to the sun, moon, Mercury, Venus, Mars, Jupiter and Saturn. The sun and moon appear as discs, whereas the other planets, like the fixed stars, appear as mere points of light. All the planets move with the outer sphere, circling around the earth each day, but also move slowly across it along a path called the ecliptic. The period of the sun's path once through the ecliptic defines a year, whereas that of the moon defines a lunar month.

The motion of the remaining planets is more complex, and accounting for this behaviour was the major task of astronomers in both the ancient and early modern periods. Like the sun and moon, they progress along the ecliptic, but are not strictly tied to it and may be found as much as 8° away from it on either side. Moreover, while each planet has a characteristic period of movement around the ecliptic, this is only an average; the speed of progression varies over time. In addition to varying in speed, the planets will occasionally reverse course entirely in a so-called "retrograde motion", before continuing in their usual direction along the ecliptic (see Figure 1). The two "inferior" planets, Mercury and Venus, are each to be found within a limited angular distance from the sun, progressing and then retrogressing back and forth across its position in the sky. The remaining "superior" planets may be any angular distance from the sun, but only retrogress when they are on the opposite side of the ecliptic to it ("in opposition").

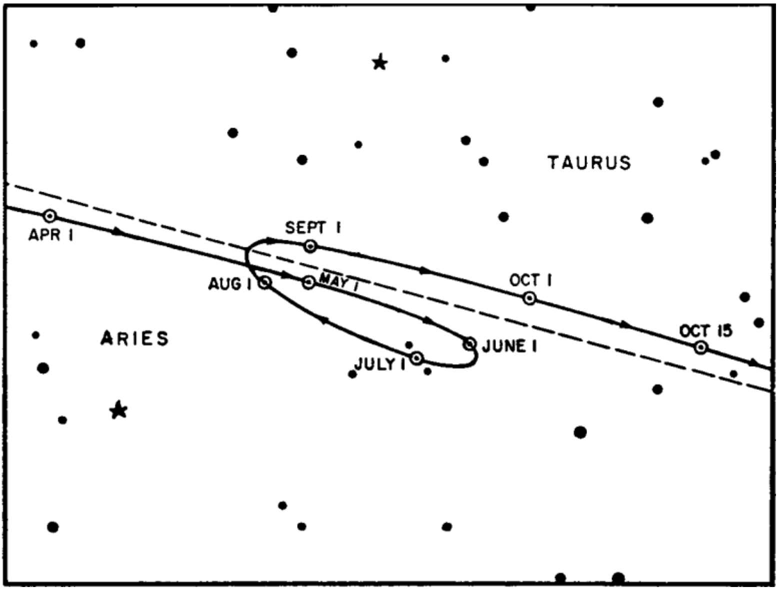

Figure 2.1. Retrograde motion of a planet relative to the fixed stars (Reproduced from Kuhn 1957, p. 48)

Ancient and medieval astronomers devised various mathematical devices to account for these complex observed motions. Probably the best-known of these is the deferent-epicycle system. This posits that each planet is carried not just on a great circle centred on the earth (the deferent), but on a smaller circle (the epicycle) carried on the larger circle. The combination of the motion of the two circles produces the motion of the planet. Importantly, the motion of the planet along the epicycle contrary to the overall direction of motion along the deferent gives rise to retrograde motion (see Figure 2). Fixing the speed of rotation of the epicycle fixes the frequency of retrograde motion.

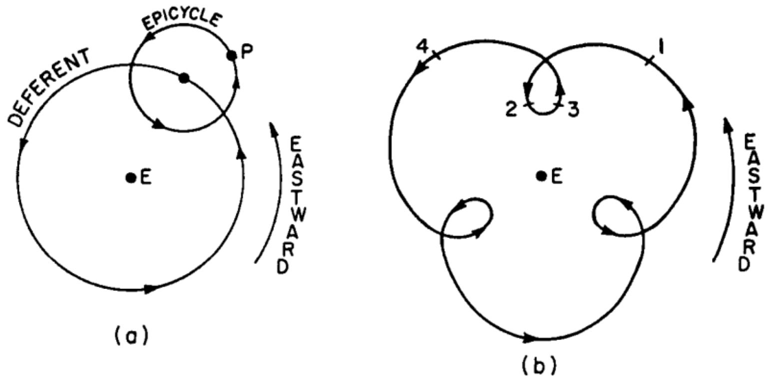

Figure 2.2. The deferent-epicycle system (Reproduced from *ibid,* p. 61)

The Copernican system, introduced with the publication of *De Revolutionibus* in 1543, remained substantially in the Ptolemaic tradition of astronomy in terms of its mathematical techniques and of the basic data set it took as evidence. Its key innovation is that it placed the sun at the centre of the universe, with the earth and other planets revolving in circles around this fixed point. It placed the known planets in the order we now accept today: Mercury innermost, followed by Venus, then the earth, Mars, Jupiter and finally Saturn. The motion of the moon remained centred on the earth. The key advantage of this system is that it accounts for many of the basic features of the observations very naturally, without the need for epicycles. The retrograde motion of the planets is explained very simply by the fact that the earth itself is a moving observation platform that will occasionally "overtake" the other planets, making them appear to reverse their direction of motion. The distinction between inferior and superior planets also emerges naturally–the former are simply within the orbit of the earth, whereas the latter are further out. It also explains why the superior planets should only undergo retrograde motion when in opposition to the sun, while the inferior planets pass back and forth regularly across its position.

However, while Copernicus easily accounts for these gross qualitative features of the data, his system does not yield precise quantitative prediction any more easily than does Ptolemy's. Indeed, Copernicus'