What is science? Lots of scientists and philosophers will try to tell you what it is. Many will get parts of it correct. Many won't. I don't want to spend much time criticising all the false theories here. Let's instead look at the best we have. We can turn to Popper. But didn't Popper just say it was about falsification? If you think this, you're onside with many prominent physicists and science communicators and philosophers who read a book where it said that's what Popper said. But actually there is more to it, to put it mildly. The capacity for science to be distinguished from things that are not is indeed drawn by the line we call "falsifiiability" but although that is a necessary condition, it is not a sufficient one.

David Deutsch has explained how we are after good explanations - in science, morality, philosophy, history - everywhere. And Deutsch picks up where Popper left off. But where was that? Well Popper did explain his broader view of science many times. And many times he was ignored or mangled or misunderstood or misrepresented. So it does take people like Deutsch to clarify and refine what he meant. Popper wrote whole books explaining his position. In terms of what science is or the Aim of Science he actually wrote directly on that topic. So that's my purpose here today to unpack one of his shorter essays. And the essay is called "The Aim of Science".

This is an essay that appears in multiple places. It first seems to have appeared in what is known as the "Postscript to the Logic of Scientific Discovery". This is Popper's first book and as many of us have observed - not our favourite one. His least best and so on. One reason for me that I regard it as being "not the best" is because he is writing for his peers in their language and conceding to them rather a lot that only later people were persuaded was wrong. Popper was sometimes generous in that way in going a long way - in his arguments and attempts at persuasion and his explanations - at meeting people with an entirely different world view part way. The Logic of Scientific Discovery is very dense. It's hard to read. I read it once and was not inspired. Later, after having read much more Popper and Deutsch and some other authors I went back to read logic and…it didn't stand up much better. The same ideas are better expressed in Popper's later work and, of course, they are further developed and refined by David Deutsch in his work. And we're going to see that today.

This essay appears in "Objective Knowledge" and also in "Realism and the Aim of Science" - both of which are books. The first is more a collection of essays. It's one of my favourite books of Popper's simply because it covers a lot of ground in epistemology in a simple way. He dispenses with induction, he covers arguments explaining realism and compares it to forms of philosophical nonsense and refines what might be meant by truth and various approaches to truth and he talks about knowledge without a subject which is deeply misunderstood by - well let's say it - anyone who has never understood Popper. And this is what makes Popper THE philosopher of objective knowledge. There is that other epistemology called - perversely - "objectivism" - but it never grapples with knowledge in actual objects and it still falls back in large part on subjective feelings. So it's actually subjective in both senses. Popper's epistemology is objective in both senses. The book objective knowledge also touches on Popper's theory of mind, some things about political philosophy and freedom or freewill and determinism and indeterminism; realism as applied to history and some other things and the amazing essay "The Bucket and the Searchlight" about how knowledge is created. And there's more.

Anyways among all this is the short essay “The Aim of Science”. That essay is incorporated then into an entire book of approximately the same name: Realism and the aim of science which is a 400 something page tome.

Now this essay on “The Aim of Science” was published in 1956. So it’s out of copyright. But I thought it very useful to go though as I was reading it again the other day because so much can be learnt directly from it, so much more can be learned by comparing the essay to improvements made since by Deutsch and as much again might be learned by questioning the state of the world in light of what Popper and Deutsch say about The Aim of Science or the purpose of science we might say compared to what people who claim to know what science is or what it’s about or what it can do or should do and so on.

And we will see almost immediately that Popper says “The Aim of Science “ - that framing could rightly be seen to be misleading.
So with all that in mind, let’s begin some reading. The essay itself is on my website right now at http://www.bretthall.org/the-aim-of-science.html and there you will find both a clean pdf copy of the essay and a separate document which breaks up the essay and includes my notes for this podcast. But of course what you’ll be missing there, as in the audio only version of this - the video accompanying this.

5. The Aim of Science

To speak of ‘the aim’ of scientific activity may perhaps sound a little naïve; for clearly, different scientists have different aims, and science itself (whatever that may mean) has no aims. I admit all this. And yet it seems that when we speak of science we do feel, more or less clearly, that there is something characteristic of scientific activity; and since scientific activity looks pretty much like a rational activity, and since a rational activity must have some aim, the attempt to describe the aim of science may not be entirely futile.

So already he has the caveat and this is due to the imprecision of language. Don’t take too literally the claim that science has an aim - as in it is aiming for a particular thing. For example, take particle physics. Is the aim to find ever smaller particles? You might think so. But that would be to presume too much. That assumes it can go on forever. Maybe you think the aim should be to find the smallest particles. Maybe the particles inside an electron so to speak? Similar error: who says there must be such a thing? The aim of science in modern speak is just to solve

scientific problem. That might be a little circular: but it's not entirely vacuous. You have to identify the problem first…which can also be a part of science.

> I suggest that it is the aim of science to find *satisfactory explanations*, of whatever strikes us as being in need of explanation. By

Well there we go. Isn't that nice? Now anyone who is listening to me will know that I, like many Popperians, complain that people who critique Popper almost never read Popper directly. Or at least don't read enough of him. Or perhaps read but do not understand him. Here is a perfect example. There it is in black and white. When prominent scientists and science communicators or philosophers or let's put podcasters into that mix - when they say "well Popper was naive. Popper thought that science was just about falsifiable theories" - we can see here now that is a complete misconception. Popper knew that science was about explaining the world. About explanations. Of anything you like.

Now here was can see he's invoked a term: satisfactory. That's not what David Deutsch says. Deutsch says "good explanations" and that is broader than just science. Science is of course that domain of inquiry that is about the physical world (and we can include there the chemical and geological and biological and astronomical and so on world as aspects of that physical world). So science is about good explanations - hard to vary explanations - of the world. Popper says satisfactory. Now he'll say something about that in a moment. But as we are about to read he gets into some jargon. This is a product of his time. Now I have always found these terms just too jargony. We can do without them. But for the moment I'll explain them and try to dispense with them as well. Let's go on:

> *tions*, of whatever strikes us as being in need of explanation. By an *explanation* (or a causal explanation) is meant a set of statements by which one describes the state of affairs to be explained (the *explicandum*) while the others, the explanatory statements, form the 'explanation' in the narrower sense of the word (the *explicans* of the *explicandum*).

Ok. So explanation is fine. But explicandum? Well that, to me, is like he basically says: the thing in need of an explanation. So at night small lights appear in the sky. That's your explicandum. You do not know what they are yet, perhaps. You might be a young child. You might have been living 10,000 years ago. You might have been growing up in a cave in Afghanistan for the last 20 years. Whatever. Those lights are the things you need to explain. I'd rather say "that's your problem". Or that's the question. The lights are real: you're not just imagining them. But what are they?

Well you might say: they are holes in a vast black glass dome that encircles the entire planet earth and beyond this is a a region of white light. So that through these holes comes that light. Now I have an explanation. It's not good. It's not testable for all practical purposes, so far as I know. But it makes claims: like there exists a glass dome over the whole earth. That's an "explicans" - a part of the explanation. An assertion about the world. "There are holes in that dome". Another part of the explanation. The explicans. I find this all a bit too clunky. But Popper is precise of course. The real explanation is of course that those lights are stars. The stars are bright. The stars are also far off so they appear dim. They are bright because they are hot. They are hot because they are vast in mass. With huge mass comes high gravity. With high gravity comes high pressure at the core of any such thing and if the pressure is high enough because the mass is high enough fusion can happen. Fusion happens because…well I won't go on. But you can see here more and more explicans are going into the overall explanation.

The explicandum is: "lights in the sky". And explican of this is "those lights are stars". Stars can then be seen as a new explicandum. And the explicans is "Stars are big spheres of plasma undergoing fusion". And the explicandum becomes fusion. And so it goes. And the conjunction in a sense of all this makes up the explanation.

> We may take it, as a rule, that the *explicandum* is more or less well known to be true, or assumed to be so known. For there is little point in asking for an explanation of a state of affairs which may turn out to be entirely imaginary. (Flying saucers may represent such a case: the explanation needed may not be of flying saucers, but of reports of flying saucers; yet should flying saucers exist, then no further explanation of the *reports* would be required.) The *explicans*, on the other hand, which is the object of our search, will as a rule not be known: it will have to be discovered. Thus, scientific explanation, whenever it is a discovery, will be *the explanation of the known by the unknown.*[1]

To unpack: when he says "true" he means - real. It's out there in the world. It's not part of your imagination. By the way it's interesting he uses flying saucers. If you want the David Deutsch take on such things see my podcast episode 72 titled "David Deutsch comments on recent UFO sighting" - a question for David 3.

So what Popper is saying there is that the problem with flying saucers are the reports. What are the reports about? Well it may be flying saucers - and we should be careful what we mean are alien spacecraft from lightyears away - not people throwing plates and dishes into the sky and others wondering "what was that?".

Not that flying saucer. But the thing is we have reports of flying saucers and that is it. We have to explain the reports. The explicandum is the reports. Not the saucers. The reports of flying saucers almost always turn out to be something that's not a flying saucer: namely the planet Venus. Or a hallucination. Or shooting star or name your mundane explanation. The flying saucer is a label for a problem: not the solution. But if an actual saucer crashed and it was clearly not of this world - ah. Then we have a new explicandum. Then it's not merely a report. It's an actual flying saucer. The problem then demands an explanation in terms of: where the heck did this come from, how and who and so on. Was it Venus or Mars? Or an Andromeda strain? Klingons? Etc.

And isn't that last bit there so nice: the explanation of the known by the unknown. Now David improves this. He speaks of the seen in terms of the unseen. And that is more precise. That is an improvement. And the reason I say that is because saying that the known is explained by the unknown implies that part of the explanation is unknown. But this is not quite right. It might not have a complete explanation - but we cannot have complete explanations. But this known in terms of unknown thing actually arises from a discussion of Berkely and Mach that Popper enters into. So it's all a bit esoteric (and that's coming from me, doing a podcast on an obscure essay by Popper) - but anyways a note in Popper's text leads one back to his other book "Conjectures and Refutations" and in that book if we look up what he refers to we get this and I'll quote it:

> So we can now admit, without becoming essentialist, that in science we always try *to explain the known by the unknown*, the observed (and observable) by the unobserved (and, perhaps, unobservable). At the same time we can now admit, without becoming instrumentalist, what Berkeley said of the nature of hypotheses in the following passage (*S*, 228), which shows both the weakness of his analysis--its failure to realize the conjectural character of all science, including what he calls the 'laws of nature'--and also its strength, its admirable understanding of the logical structure of hypothetical explanation.

"

So as we see there he actually does say the observed by the unobserved. Which is closer to the mark. I prefer David's which is simple language: seen in terms of the unseen. Lights in the sky at night (seen). In terms of fusion reactions in the core of stars hundreds of light years away (unseen and indeed in principle unseeable given how observation requires an observer and observers so far as we know cannot exist in the core of stars). But that is a side issue. We can see here how David clarifies Popper.

So back to the essay.

> The *explicans*, in order to be satisfactory (satisfactoriness may be a matter of degree), must fulfil a number of conditions. First, it must logically entail the *explicandum*. Secondly, the *explicans* ought to be true, although it will not, in general, be known to be true; in any case, it must not be known to be false even after the most critical examination. If it is not known to be true (as will usually be the case) there must be *independent* evidence in its favour. In other words, it must be *independently* testable; and we shall regard it as more satisfactory the greater the severity of the independent tests it has survived.

So Popper was heavily influenced by the philosopher and mathematician Tarski. Indeed his book objective knowledge is dedicated to Tarski and Tarski had a nice view of truth which was about correspondence. A thing is true if it corresponds to something in reality. But anyways - Popper used the word "true" liberally. More liberally than I do. The reason is that - following David - I would say that truth is a property of propositions. So we can never be in a position to say that some part of an explanation - the explicans - can ever be known to be true. Known means something like "have an explanation of" and given no explanation is final - as Popper will indeed come to say in this essay - "known to be true" is a paradox of a kind because "true" is final. If a thing is "known to be true" then we're saying "it could possibly be false that *it's not possibly false*". Logically. It's one of those cases where I'd love to be able to speak to Popper about exactly that. But we'll pass over this. The point in this paragraph is more about the fact that any given part of your explanation should itself be testable. That's the key point. I would not say "evidence in its favour" I think that has a smell of justiifcationism about it - the idea that evidence can accumulate and thereby make a theory more likely to be true or actually true or something like that. Again, I think Popper is actually trying to win over his opponents with phrases like this at times. And I think that's right to do if you want to have any readers at all left if you're absolutely tearing apart the hirtherto preexisting fabric of an entire discipline like philosophy, philosophy of science and epistemology.

But anyways - he said the actual thing there. The various parts of an explanation should be testable. Indeed the "severity" of the testability is important. So highly precise. You know if I make a testable claim like: the ball will fall to the ground. That's one thing. If I say it will fall at 9.8 ms^{-2} that's another. And if I say it will fall initially at 9.8 then 9.801 then 9.805 and so on increasing to a maximum of 9.81ms^{-2} that is something different again. I'm getting more precise. More "risky" so to speak. By the way - Popper will actually use an example like this shortly. I'll explain why that happens too.

I'm skipping a paragraph and going to an example he uses to illustrate the satisfactory vs unsatisfactory distinction. We will see here echoes of The Beginning of Infinity.

degree. Consider the following dialogue: 'Why is the sea so rough today?'—'Because Neptune is very angry'—'By what evidence can you support your statement that Neptune is very angry?'—'Oh, don't you *see* how *very* rough the sea is? And is it not always rough when Neptune is angry?' This explanation is found unsatisfactory because (just as in the case of the fully circular explanation) the only evidence for the *explicans* is the *explicandum* itself.[2] The feeling that this kind of almost circular or *ad hoc* explanation is highly unsatisfactory, and the corresponding requirement that explanations of this kind should be avoided are, I believe, among the main motive forces of the development of science: dissatisfaction is among the first fruits of the critical or rational approach.

So the thing to be explained is how rough the sea is. Why we ask why is it so very rough today? Well if we say: because Neptune is so very angry and it's always rough when Neptune is angry" - we've gotten nowhere. The bit of the explanation that is invoked: the sea is angry when Neptune is rough, is not testable. Because we will just say when it's more rough: Neptune is more angry. And when it's less rough, Neptune is less angry. This is what happens when people try to SUPPORT a theory with evidence. Each day, no matter the state of the sea, counts as evidence SUPPORTING the claim the anger of Neptune makes the sea rough. But that itself is never testable. Which is what we want.

In modern language - the way David explains this: we say that the Neptune theory is easy to vary. This takes the idea of satisfactory vs unsatisfactory explanations that Popper devised a big step forward. The hard to vary criterion for a good explanation is more precise than what Popper offered. Neptune after all could be swapped out for Poseidon. Or Ulmo (he's from Lord of the Rings). Or Aquaman. Take your pick. It's easy to vary. But the idea that the action of the Sun heating the oceans creating air currents that can cause high pressure in one place and low pressure in another and this causes wind and the wind causes waves and that makes the sea rough: well we can't just go swapping the sun, high pressure and wind out for anything else. But let's continue:

In order that the *explicans* should not be *ad hoc*, it must be rich in content: it must have a variety of testable consequences, and among them, especially, testable consequences which are different from the *explicandum*. It is these different testable conse-

Yes: so the explicans - the parts of the explanation - actually invoke the existence of things that previously were unseen or unobserved. Those things then form a part of the testable content of the explanation. This is why empiricism is false. A point we have made in this podcast many times. The explanation consists of a bunch of unseen things but we can test our explanation of those unseen things because those unseen things give rise to the things we do see and typically the only known explanation of those things we see and which we can measure and experiment on and so on - is the unseen things. To deny the unseen is to deny reality. But the only unseen things we say exist are the ones that actually appear in our best explanations. Not just any unseen things. This makes the difference between unseen Roman Gods and unseen fusion reactions in distant stars.

Now I'm skipping a part and Popper goes on to speak about the case of universal laws. He writes:

> Only if we require that explanations shall make use of universal statements or laws of nature (supplemented by initial conditions) can we make progress towards realizing the idea of independent, or non-*ad hoc*, explanations. For universal laws of nature *may* be statements with a rich content, so that *they may be independently tested* everywhere, and at all times. Thus if they are used as explanations, they *may* not be *ad hoc* because they *may* allow us to interpret the *explicandum* as an instance of a reproducible effect. All this is only true, however, if we confine ourselves to universal laws which are testable, that is to say, falsifiable.

Here ad hoc means something like made up for a specific purpose rather than being general - so general as to be universal. And universal applies everywhere. Universal ways in which knowledge is created. Universal wealth creation principles. Universal laws of chemistry, physics - the drift of continents or formation of rocks and so on. But broadly speaking physics: physical laws. They don't just apply in the laboratory. They apply everywhere in the universe and at all times. He goes on to say:

> The question 'What kind of explanation may be satisfactory?' thus leads to the reply: an explanation in terms of testable and falsifiable universal laws and initial conditions. And an explanation of this kind will be the more satisfactory the more highly testable these laws are and the better they have been tested. (This applies also to the initial conditions.)

Testable and falsifiable are, to me, the same thing. But maybe he is saying that for emphasis. As to the initial conditions thing: well as we know David Deutsch has invented constructor theory which goes deeper than this conception. Perhaps it's better not to specify what forms the laws must be or what kind of explanations can be developed. Better to just say what kind of explanation maybe said to be good? Well, in science testable - yes. But a good explanation is hard to vary. As to whether it needs to be about laws and initial conditions - well we know it does not. It can be about what is possible and impossible. Could there be more still? I imagine so. But there is no reason to close off the possibility of inventing still more modes of good explanation. Perhaps providence or intentions and so on can actually be brought into physics one day? Who knows? I guess Popper did not really imagine much that physics might begin to make its first tentative steps into epistemology. But it's happening.

> In this way, the conjecture that it is the aim of science to find satisfactory explanations leads us further to the idea of improving the degree of satisfactoriness of the explanations by improving their degree of testability, that is to say, by proceeding to better testable theories; which means proceeding to theories of ever richer content, of higher degrees of universality, and of higher degrees of precision.[3] This, no doubt, is fully in keeping with the actual practice of the theoretical sciences.

> We may arrive at fundamentally the same result also in another way. If it is the aim of science to explain, then it will also be its aim to explain what so far has been accepted as an *explicans*; for example, a law of nature. Thus the task of science constantly renews itself. We may go on for ever, proceeding to explanations of a higher and higher level of universality—unless, indeed, we were to arrive at an *ultimate explanation*; that is to say, at an explanation which is neither capable of any further explanation, nor in need of it.

So ultimate or final explanations or an end of infinity and an end of science and an end of progress. Now we know what David thinks about all this - it is possibly a prime motivation for his book The Beginning of Infinity. But what does Popper have to say about it?

But are there ultimate explanations? The doctrine which I have called 'essentialism' amounts to the view that science must seek ultimate explanations in terms of essences:[4] if we can explain the behaviour of a thing in terms of its essence—of its essential properties—then no further question can be raised, and none need be raised (except perhaps the theological question of the Creator of the essences). Thus Descartes believed that he had

So then Popper goes into a long discussion about Descartes vs Newton. Descartes thought one could get to final answers but Newton did not. The example Popper uses is in Newton's willingness to admit that although he did indeed have a law of gravity and made more progress on the nature of gravity than anyone else before him, he nonetheless never said and said he could not say what gravity actually was. What actually caused the force of gravity? He did not know. He accepted he had made some progress but not found the final answer. Which is odd given so many physicists who came after him did indeed make noises about how Newton was almost lucky in finding the once and for all final theory of gravity when Newton himself said he did not. There was more to do. There is always more to do.

Popper quotes Newton in the Principia:

Principia: 'So far I have explained the phenomena . . . by the force of gravity, but I have not yet ascertained *the cause of gravity itself* . . . and I do not arbitrarily [or *ad hoc*] invent hypotheses.'[5]

But Popper is criticising Newton for apparently not even trying. So for Newton - Newton thinks he is deriving rather than conjecturing of course. He is reading from a book of nature and that book does not tell him what the cause of gravity is. At least this is one way to understand what Popper eventually goes on to say. Whatever the case:
Essentialism is the misconception that in a physical thing - like gravity or an electron or even a bacterium or a person there is a final thing to be found which, when you find it - it's essence so to speak - then all the explaining has been done. But this never happens. Like gravity. We find that it obeys the inverse square law. Then we find: well not exactly. It's the curvature of spacetime. But what is spacetime made of? Is it truly continuously divisible? There are open questions with gravity even now. Must the gravitational constant truly be constant? A person is a universal explainer. But is that the essence of a person? No. It's more a precise statement of the problem that before could not even be articulated. Popper goes on:

I do not believe in the essentialist doctrine of ultimate explanation. In the past, critics of this doctrine have been, as a rule, instrumentalists: they interpreted scientific theories as *nothing but* instruments for prediction, without any explanatory power. I do not agree with them either. But there is a third possibility, a 'third view', as I have called it. It has been well described as a 'modified essentialism'—with emphasis upon the word 'modified'.[6]

Classic Popper, of course. He always finds a third way. He rejects a false dichotomy. Just because you've got X and Y before you and X and Y are all you know and form your spectrum of choices does not mean they are you only choices. You can actually use your mind and create something new.

This 'third view' which I uphold modifies essentialism in a radical manner. First of all, I reject the idea of an ultimate explanation: I maintain that every explanation may be further explained, by a theory or conjecture of a higher degree of universality. There can be no explanation which is not in need of a further explanation, for none can be a self-explanatory description of an essence (such as an essentialist definition of body, as suggested by Descartes). Secondly, I reject all *what-is*

Ok, so the first thing is he says all explanations will need a further explanation.

body, as suggested by Descartes). Secondly, I reject all *what-is* *questions*: questions asking what a thing is, what is its essence, or its true nature. For we must give up the view, characteristic of essentialism, that in every single thing there is an essence, an inherent nature or principle (such as the spirit of wine in wine), which necessarily causes it to be what it is, and thus to act as it does. This animistic view explains nothing; but it has led essentialists (like Newton) to shun relational properties, such as gravity, and to believe, on grounds felt to be *a priori* valid, that a satisfactory explanation must be in terms of inherent properties (as opposed to relational properties). The third and last

So there are no essences - no place where in science the buck stops here with the ultimate essence.

ties (as opposed to relational properties). The third and last modification of essentialism is this. We must give up the view, closely connected with animism (and characteristic of Aristotle as opposed to Plato), that it is the essential properties inherent *in each individual or singular thing* which may be appealed to as the explanation of this thing's behaviour. For this view completely fails to throw any light whatever on the question why different individual things should behave in like manner. If it is said, 'because their essences are alike', the new question arises: *why should there not be as many different essences as there are different things?*

Plato tried to solve precisely this problem by saying that like

Now all of that is more of the same kind of criticism. I'm skipping past a number of paragraphs now.

By choosing explanations in terms of universal laws of nature, we offer a solution to precisely this last (Platonic) problem. For we conceive all individual things, and all singular facts, to be subject to these laws. The laws (which in their turn *are* in need of further explanation) thus explain regularities or similarities of individual things or singular facts or events. And these laws are not inherent in the singular things. (Nor are they Platonic ideas outside the world.) Laws of nature are conceived, rather, as (conjectural) descriptions of the structural properties of nature —of our world itself.

Here there is some ambiguity. There are The Laws of Nature - the definite article and capitalised. The laws. Now those laws exist independently of what we think about them. Like particles do. Or cats or crayons. But our understanding of the laws of nature: they're conceived - they are conjectural. Popper understood this and language is imprecise and so on so we just have to be careful here with that.

> Here then is the similarity between my own view (the 'third view') and essentialism; although I do not think that we can ever describe, by our universal laws, an *ultimate* essence of the world, I do not doubt that we may seek to probe deeper and deeper into the structure of our world or, as we might say, into properties of the world that are more and more essential, or of greater and greater depth.

Possibly it's better if he just stuck with greater depth. More fundamental as we like to say. But "more essential" might be misleading. We can reject essences altogether and therefore not worry about being more or less essential because the essence doesn't even exist to begin with.

David likes to point out that he works on the foundations of physics…but he is not a foundationalist. When one says they are working on the foundations in physics what they mean is they are working on the deepest theories known. The most fundamental. What other people call the foundations. The deepest known.

But this is not to imply they are literal foundations. Actual foundations are where a structure stops.

But that too is ambiguous. If the foundations of physics are like the foundations of a building then of course there is something deeper there. Something that hitherto was not regarded as being a part of the structure. In physics - something that is outside physics. Like constructor theory. Or like computation.

Or in the case of an actual building are the foundations the bricks and steel columns on which the ground floor sits? Is it the existence of a basement? Or the concrete slab on which the basement rests? Or is it the bedrock beneath all this which, if it was less stable would not be a solid foundation? Or is it what is below the bedrock? Deeper geological structures not normally thought of as part of a building at all? Well it depends on how far you want to push the analogy.

But we can speak about the fundamentals: the deepest known theories that explain the most, encompass the most and have the greatest reach.

Now Popper really gets into the swing of things and I find passages like this brilliant because it really is unprecedented. So he goes on to say:

> Every time we proceed to explain some conjectural law or theory by a new conjectural theory of a higher degree of universality, we are discovering more about the world, trying to penetrate deeper into its secrets. And every time we succeed in falsifying a theory of this kind, we make a new important discovery. For these falsifications are most important. They teach us the unexpected; and they reassure us that, although our

> theories are made by ourselves, although they are our own inventions, they are none the less genuine assertions about the world; for they can *clash* with something we never made.

So I think it's just important to keep in mind that he was the first to say things like this. And he said it so well there. By this time of course he'd been engaged in years long discussions about it so he had refined his position. But it still reads as clearly as anyone today writing along similar lines could manage. Popper goes on to write extensively about depth. I'll just summarise. He says that depth has something to do with simplicity (and this is something like coherence or brevity) and something to do with richness of content. Which gets to the idea that David refines called: reach. Reach means that the content of the explanation has an effect on far reaching (hence reach) or distant subjects. So what happens in physics absolutely has consequences for chemistry but also aviation, computing, etc. Physics has maximal reach. Mathematics sometimes has reach. Sometimes it's just very narrow. Philosophy likewise. Sometimes it has reach (epistemology) and sometimes it's more parochial.

Anyways what Popper says about depth and it being about simplicity and richness is that he cannot define or restrict what he means here. He is appealing to intuition. Which is quite right. As David says: no language can be perfectly precise. But we can still have a reasonable understanding. We can get an idea of what depth is or degrees of depth by considering an actual example. And Popper turns to the history of physics for this. So let's go down that road with him:

> It is well known that Newton's dynamics achieved a unification of Galileo's terrestrial and Kepler's celestial physics. It is

often said that Newton's dynamics can be induced from Galileo's and Kepler's laws, and it has even been asserted that it can be strictly deduced from them.[8] But this is not so; from a logical point of view, Newton's theory, strictly speaking, contradicts both Galileo's and Kepler's (although these latter theories can of course be obtained as approximations, once we have Newton's theory to work with). For this reason it is impossible to derive Newton's theory from either Galileo's or Kepler's or both, whether by deduction or induction. For neither a deductive nor an inductive inference can ever proceed from consistent premises to a conclusion that formally contradicts the premises from which we started.

I regard this as a very strong argument against induction.

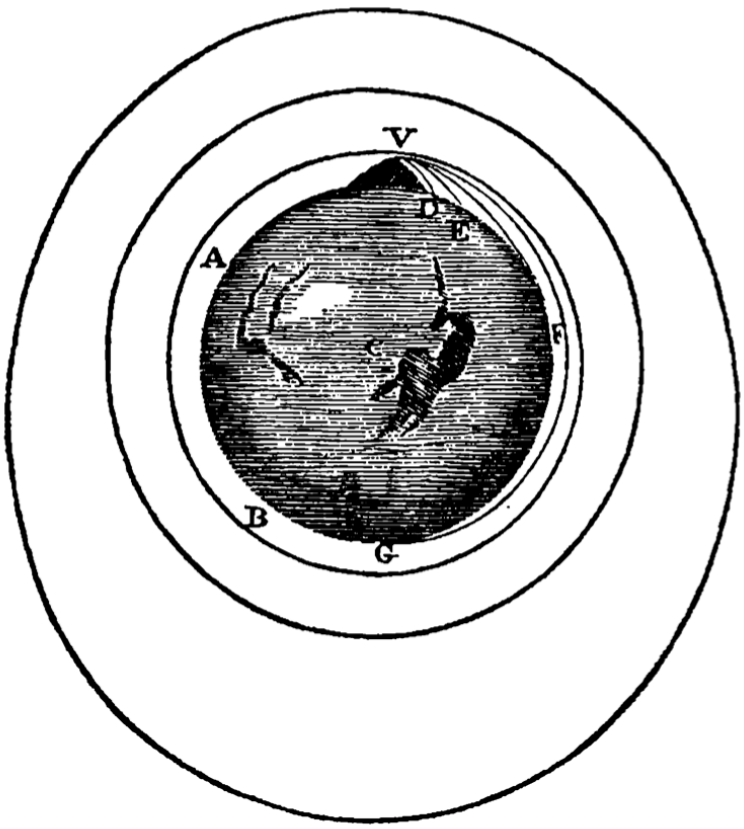
So I'm going to read quite a bit here and stop along the way to explain where needed:

I shall now briefly indicate the contradictions between Newton's theory and those of his predecessors. Galileo asserts that a thrown stone or a projectile moves in a parabola, except in the case of a free vertical fall when it moves, with constant acceleration, in a straight line. (We neglect air-resistance throughout this discussion.) From the point of view of Newton's theory, these assertions are both false, for two distinct reasons. The first is false because the path of a long-range projectile, such as an inter-continental missile (thrown in an upward or horizontal direction) will be not even approximately parabolic but elliptic. It becomes, approximately, a parabola only if the total distance of the flight of the projectile is negligible compared with the radius of the earth. This point was made by Newton himself, in his *Principia*, as well as in his popularized version, *The System of*

the World, where he illustrates it with the help of the figure reproduced on this page.

Newton's figure illustrates his statement that, if the velocity of the projectile increases, and with it the distance of its flight, it will 'at last, exceeding the limits of the earth, . . . pass into space without touching it'.[9]

Thus a projectile on earth moves along an ellipse rather than



a parabola. Of course, for sufficiently short throws, a parabola will be an excellent approximation; but the parabolic track is not strictly deducible from Newton's theory unless we add to the latter a factually *false* initial condition (and one which, incidentally, is unrealizable in Newton's theory since it leads to absurd consequences) to the effect that the radius of the earth is infinite. If we do not admit this assumption, even though it is *known to be false*, then we always get an ellipse, in contradiction to Galileo's law according to which we should obtain a parabola.

Next is a part I flagged earlier.

A precisely analogous logical situation arises in connection with the second part of Galileo's law which asserts the existence

[9] See Newton's *Principia*, the *Scholium* at the end of section ii of Book i; p. 55 of the 1934 edn. (Motte's translation revised by Cajori). The figure, from *The System of the World*, and the quotation here given, will be found on p. 551 of this edn.

of an acceleration *constant*. From the point of view of Newton's theory, the acceleration of free-falling bodies is never constant: it always increases during the fall, owing to the fact that the body approaches nearer and nearer to the centre of attraction. This effect is very considerable if the body falls from a great height, although of course negligible if the height is negligible as compared with the radius of the earth. In this case, we can obtain Galileo's theory from Newton's if we again introduce the *false* assumption that the radius of the earth is infinite (or the height of the fall zero).

The contradictions which I have pointed out are far from negligible for long-distance missiles. To these we may apply Newton's theory (with corrections for air resistance, of course) but not Galileo's: the latter leads simply to false results, as can easily be shown with the help of Newton's theory.

Then Popper compares Kepler to Newton in terms of planetary motion. And the same point is made. Newton's theory succeeds in a way Kepler's fails. He uses the example of Kepler's law for how a central body is orbited by smaller bodies. But in Kepler's view the period radius relationship which is basically that the cube of the radius of the orbit divided by the square of the period of the orbit is a constant. No matter the planet. But although this is approximately true it's not exactly true at all. Jupiter's mass affects how fast it orbits the Sun. But not on Kepler's theory. And this is measurable. You can reduce Newton's prediction to Kepler's by assuming that the orbiting planets (like Jupiter or Earth) have a mass of zero. But as Popper says:

> *planets*. This is quite a good approximation from the point of view of Newton's theory; but at the same time, putting $m_1 = 0$ is not only strictly speaking false, but unrealizable from the point of view of Newton's theory. (A body with zero mass would no longer obey Newton's laws of motion.) Thus, even if we forget all about the mutual attraction between the planets, Kepler's third law (2) contradicts Newton's theory which yields (1).

His whole point here is that Newton's theory cannot possibly be derived from Galileo's or Kepler's or any combination of them. Newton's theory is a conjecture: it is a created explanation that does not logically follow from the knowledge we had before. It was not deduced from Kepler and Galileo - it was not deduced from observation. - it was not deduced from anything. It is conjectural knowledge. As Popper says:

> It is important to note that from Galileo's or Kepler's theories we do not obtain even the slightest hint of how these theories would have to be adjusted—what false premisses would have to be adapted, or what conditions stipulated—should we try to proceed from these theories to another and more generally valid one such as Newton's. *Only after we are in possession of Newton's theory can we find out whether, and in what sense, the older theories can be said to be approximations to it.* We may express this fact briefly

So only in retrospect do we look back and go "Oh look from Newton you can say that Kepler and Galileo are approximations". Yes: if you make some assumptions.

But the reverse is never true. You cannot begin with Kepler and Galileo and with some minor corrections get Newton.

This is always the case and should be front of mind for any physicist working at the frontiers. Just incrementally fiddling with some bits of an existing theory will not lead you to the big breakthrough. You need to go to the foundations and rethink them. Popper goes on to say:

> *be said to be approximations to it.* We may express this fact briefly by saying that, although from the point of view of Newton's theory, Galileo's and Kepler's are excellent approximations to certain special Newtonian results, Newton's theory cannot be said, from the point of view of the other two theories, to be an approximation to their results. All this shows that logic, whether

> deductive or inductive, cannot possibly make the step from these theories to Newton's dynamics.[11] It is only ingenuity which can make this step. Once it has been made, Galileo's and Kepler's results may be said to corroborate the new theory.

Well…I've never much liked that way of saying it. Just say they can be seen to be approximations to that theory. Low mass approximations. Or Newton's theory with some substantial assumptions (like for example: the mass of Jupiter makes no difference to planetary orbits). Corroboration sounds justificaitonist. I think Popper was trying to concede again to his peers who objected to him. When he said confirmations are not possible he used corroboration. So it's like all those theories agree within a particular domain.

Popper goes on to write that Newton's theory is no mere conjunction of the theories that went before. Instead it can be thought of as a new way of explaining Kepler's results and Galileo's results. But also - as importantly - corrections to them. So this is how to view the system of knowledge here. A deeper theory explains the less deep theories and points out their errors and corrects them. That's what increasing depth does. He goes on later to say:

> I suggest that whenever in the empirical sciences a new theory of a higher level of universality successfully explains some older theory *by correcting it*, then this is a sure sign that the new theory has penetrated deeper than the older ones. The demand that a new theory should contain the old one approximately, for appropriate values of the parameters of the new theory, may be called (following Bohr) the '*principle of correspondence*'.

Then he also says there is more to depth still and I recommend the original article for more details on this - specifically page 13 of my pdf version. Depth is like the term "explanation" - we can always find new ways of explaining it. Of more deeply understanding depth and explain more about what explanations are.

Now let's read his concluding remarks

The task of science, which, I have suggested, is to find satisfactory explanations, can hardly be understood if we are not realists. For a satisfactory explanation is one which is not *ad hoc*; and this idea—the *idea of independent evidence*—can hardly be understood without the idea of discovery, of progressing to deeper layers of explanation: without the idea that there is something for us to discover, and something to discuss critically.

And yet it seems to me that within methodology we do not have to presuppose metaphysical realism; nor can we, I think, derive much help from it, except of an intuitive kind. For once we have been told that the aim of science is to explain, and that the most satisfactory explanation will be the one that is most severely testable and most severely tested, we know all that we need to know as methodologists. That the aim is realizable we cannot assert, neither with nor without the help of metaphysical realism which can give us only some intuitive encouragement, some hope, but no assurance of any kind. And although a rational treatment of methodology may be said to depend upon an assumed, or conjectured, aim of science, it certainly does not

that the true structural theory of the world (if any), is discoverable by man, or expressible in human language.

If the picture of the world which modern science draws comes anywhere near to the truth—in other words, if we have anything like 'scientific knowledge'—then the conditions obtaining almost everywhere in the universe make the discovery of structural laws of the kind we are seeking—and thus the attainment of 'scientific knowledge'—almost impossible. For almost all regions of the universe are filled by chaotic radiation, and almost all the rest by matter in a similar chaotic state. In spite of this, science has been miraculously successful in proceeding towards what I have suggested should be regarded as its aim. This strange fact cannot, I think, be explained without proving too much. But it can encourage us to pursue that aim, even though we may not get any further encouragement to believe that we can actually attain it; neither from metaphysical realism nor from any other source.

Now those last few remarks are odd and worthy of discussion. Popper seems to think that most of the universe would be hostile to knowledge production. Well absent people of course - that would be vacuous. But given people it's clearly false. The evidence is there for the taking and as David Deutsch observes if you really wanted to you could learn almost everything scientific by building a sufficiently large space station using the matter in otherwise empty space - it's not empty after all.

We could even learn about evolution by natural selection if it wasn't known already.

So this idea of chaotic radiation is not right - or at least the emphasis is not right. Popper seems to have actually underestimated the power of his own area of expertise: objective explanatory knowledge. It can make order out of that chaotic radiation - gather it with even modest telescopes, take measurements and guess at what it all means. Any region of space is almost favourable for this to be done.

Not that it's easy. Just that it's possible.

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