Karl Popper, "Unended Quest", pub. Fontana1976
P91. De Broglie and Schroedinger were far from happy with Bohr'S VIEWS (LATER CALLED "THE Copenhagen interpretation of Quantum Mechanics"
After second world war important dissenters were
P92 Schroedinger, who told me that he was deeply unhappy about quantum mechanics and thought that nobody really understood it.
P93 Yet I could not [understand] Bohr's "colmplementarity", and I began to doubt whether anybody else understood it .... This doubt was shared by Einstein, as he later told me, and by Schroedinger.

Now from Karl Popper, "Conjectures and Refutations", RKP 1963

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THREE VIEWS CONCERNING HUMAN KNOWLEDGE

1. THE SCIENCE OF GALILEO AND ITS NEW BETRAYAL

ONCE upon a time there was a famous scientist whose name was Galileo Galilei. He was tried by the Inquisition, and forced to recant his teaching This caused a great stir; and for well over two hundred and fifty years the case continued to arouse indignation and excitement—long after public opinion had won its victory, and the Church had become tolerant of science.

But this is by now a very old story, and I fear it has lost its interest. For Galilean science has no enemies left, it seems: its life hereafter is secure. The victory won long ago was final, and all is quiet on this front. So we take a detached view of the affair nowadays, having learned at last to think historically, and to understand both sides of a dispute. And nobody cares to listen to the bore who can't forget an old grievance.

What, after all, was this old case about? It was about the status of the Copernican 'System of the World' which, besides other things, explained the diurnal motion of the sun as only apparent, and as due to the rotation of our own earth.[1] The Church was very ready to admit that the new system was simpler than the old one: that it was a more convenient *instrument* for astronomical calculations, and for predictions. And Pope Gregory's reform of the calendar made full practical use of it. There was no objection to Galileo's teaching the mathematical theory, so long as he made it clear that its value was *instrumental* only; that it was nothing but a 'supposition', as Cardinal

[1] I emphasize here the diurnal as opposed to the annual motion of the sun because it was the theory of the diurnal motion which clashed with Joshua 10, 12 f., and because the explanation of the diurnal motion of the sun by the motion of the earth will be one of my main examples in what follows. (This explanation is, of course, much older than Copernicus—older even than Aristarchus—and it has been repeatedly re-discovered; for example by Oresme.)

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Bellarmino put it;[2] or a 'mathematical hypothesis'—a kind of mathematical trick, 'invented and assumed in order to abbreviate and ease the calculations'.[3] In other words there were no objections so long as Galileo was ready to fall into line with Andreas Osiander who had said in his preface to Copernicus' *De revolutionibus*: 'There is no need for these hypotheses to be true, or even to be at all like the truth; rather, one thing is sufficient for them—that they should yield calculations which agree with the observations.'

Galileo himself, of course, was very ready to stress the superiority of the Copernican system as an *instrument of calculation*. But at the same time he conjectured, and even believed, that it was *a true description of the world*; and for him (as for the Church) this was by far the most important aspect of the matter. He had indeed some good reasons for believing in the truth of the theory. He had seen in his telescope that Jupiter and his moons formed a miniature model of the Copernican solar system (according to which the planets were moons of the sun). Moreover, if Copernicus was right the inner planets (and they alone) should, when observed from the earth, show phases like the moon; and Galileo had seen in his telescope the phases of Venus.

The Church was unwilling to contemplate the truth of a New System of the World which seemed to contradict a passage in the Old Testament. But this was hardly its main reason. A deeper reason was clearly stated by Bishop Berkeley, about a hundred years later, in his criticism of Newton.

In Berkeley's time the Copernican System of the World had developed into Newton's Theory of gravity, and Berkeley saw in it a serious competitor to religion. He was convinced that a decline of religious faith and religious authority would result from the new science if its interpretation by the 'free-thinkers' was correct; for they saw in its success a proof of *the power of the human intellect, unaided by divine revelation, to uncover the secrets of our world*—the reality hidden behind its appearance.

This, Berkeley felt, was to misinterpret the new science. He analysed Newton's theory with complete candour and great philosophical acumen; and a critical survey of Newton's concepts convinced him that this theory could not

[2] '. . . Galileo will act prudently', wrote Cardinal Bellarmino (who had been one of the inquisitors in the case against Giordano Bruno) '. . . if he will speak hypothetically, *ex suppositione* . . .: to say that we give a better account of the appearances by supposing the earth to be moving, and the sun at rest, than we could if we used eccentrics and epicycles is to speak properly; there is no danger in that, and it is all that the mathematician requires.' Cf. H. Grisar, *Galileistudien*, 1882, Appendix ix. (Although this passage makes Bellarmino one of the founding fathers of the epistemology which Osiander had suggested some time before and which I am going to call 'instrumentalism', Bellarmino—unlike Berkeley—was by no means a convinced instrumentalist himself, as other passages in this letter show. He merely saw in instrumentalism one of the possible ways dealing with inconvenient scientific hypotheses. The same might well be true of Osiander. See also note 6 below.)

[3] The quotation is from Bacon's criticism of Copernicus in the *Novum Organum*, II, 36. In the next quotation (from *De revolutionibus*) I have translated the term '*verisimilis*' by 'like the truth'. It should certainly not be translated here by 'probable'; for the whole point here is the question whether Copernicus' system is, or is not, similar in structure to the world; that is, whether it is similar to the truth, or truthlike. The question of degrees of certainty or probability does not arise. For the important *problem of truthlikeness or verisimilitude*, see also ch. 10 below, especially sections iii, x, and xiv; and *Addendum 6*.

possibly be anything but a 'mathematical hypothesis', that is, a convenient *instrument* for the calculation and prediction of phenomena or appearances; that it could not possibly be taken as a true description of anything real.[4]

Berkeley's criticism was hardly noticed by the physicists; but it was taken up by philosophers, sceptical as well as religious. As a weapon it turned out to be a boomerang. In Hume's hands it became a threat to all belief—to all knowledge, whether human or revealed. In the hands of Kant, who firmly believed both in God and in the truth of Newtonian science, it developed into the doctrine that theoretical knowledge of God is impossible, and that Newtonian science must pay for the admission of its claim to truth by the renunciation of its claim to have discovered the real world behind the world of appearance: it was a true science of nature, but *nature* was precisely the world of mere phenomena, the world as it appeared to our assimilating minds. Later certain Pragmatists based their whole philosophy upon the view that the idea of 'pure' knowledge was a mistake; that there could be no knowledge in any other sense but in the sense of *instrumental* knowledge; that knowledge was power, and that truth was usefulness.

Physicists (with a few brilliant exceptions [5]) kept aloof from all these philosophical debates, which remained completely inconclusive. Faithful to the tradition created by Galileo they devoted themselves to the search for truth, as he had understood it.

Or so they did until very recently. For all this is now past history. Today the view of physical science founded by Osiander, Cardinal Bellarmino, and Bishop Berkeley,[6] has won the battle without another shot being fired. Without any further debate over the philosophical issue, without producing any

[4] See also ch. 6, below.

[5] The most important of them are Mach, Kirchhoff, Hertz, Duhem, Poincaré, Bridgman, and Eddington—all instrumentalists in various ways.

[6] Duhem, in his famous series of papers, *Sōzein ta phainómena*' (*Ann. de philos. chrétienne*, anneé 79, tom 6, 1908, nos. 2 to 6), claimed for instrumentalism a much older and much more illustrious ancestry than is justified by the evidence. For the postulate that, with their hypotheses, scientists ought to '*account for the observed facts*', rather than 'do violence to them by trying to squeeze or fit them into their theories' (Aristotle, *De Caelo*, 293a25; 296b6; 297a4, b24ff; *Met.* 1073b37, 1074a1) has little to do with the instrumentalist thesis (that our theories can do *nothing but this*). Yet this postulate is essentially the same as that we ought to '*preserve the phenomena*' or 'save' them ([*dia-*]*sōzein ta phainomena*). The phrase seems to be connected with the astronomical branch of the Platonic School tradition. (See especially the most interesting passage on Aristarchus in Plutarch's *De Facie in Orbe Lunae*, 923a; see also 933a for the 'confirmation of the cause' by the phenomena, and Cherniss' note *a* on p. 168 of his edition of this work of Plutarch's; furthermore, Simplicius' commentaries on *De Caelo* where the phrase occurs e.g. on pp. 497 l.21, 506 l.10, and 488 l.23 f, of Heiberg's edition, in commentaries on *De Caelo* 293a4 and 292b10.) We may well accept Simplicius' report that Eudoxus, under Plato's influence, in order to account for the observable phenomena of planetary motion, set himself the task of evolving an abstract geometrical system of rotating spheres *to which he did not attribute any physical reality*. (There seems to be some resemblance between this programme and that of the *Epinomis*, 990–1, where the study of abstract geometry—of the theory of the irrationals, 990d–991b—is described as a necessary preliminary to planetary theory; another such preliminary is the study of number —i.e. the odd and the even, 990c.) Yet even this would not mean that either Plato or Eudoxus accepted an instrumentalist epistemology: they may have consciously (and wisely) confined themselves to a preliminary problem.

new argument, the *instrumentalist view* (as I shall call it) has become an accepted dogma. It may well now be called the 'official view' of physical theory since it is accepted by most of our leading theorists of physics (although neither by Einstein nor by Schrödinger). And it has become part of the current teaching of physics.

2. THE ISSUE AT STAKE

All this looks like a great victory of philosophical critical thought over the 'naïve realism' of the physicists. But I doubt whether this interpretation is right.

Few if any of the physicists who have now accepted the instrumentalist view of Cardinal Bellarmino and Bishop Berkeley realize that they have accepted a philosophical theory. Nor do they realize that they have broken with the Galilean tradition. On the contrary, most of them think that they have kept clear of philosophy; and most of them no longer care anyway. What they now care about, as physicists, is (*a*) *mastery of the mathematical formalism*, i.e. of the instrument, and (*b*) *its applications*; and they care for nothing else. And they think that by thus excluding everything else they have finally got rid of all philosophical nonsense. This very attitude of being tough and not standing any nonsense prevents them from considering seriously the philosophical arguments for and against the Galilean view of science (though they will no doubt have heard of Mach[7]). Thus the victory of the instrumentalist philosophy is hardly due to the soundness of its arguments.

How then did it come about? As far as I can see, through the coincidence of two factors, (*a*) difficulties in the interpretation of the formalism of the Quantum Theory, and (*b*) the spectacular practical success of its applications.

(*a*) In 1927 Niels Bohr, one of the greatest thinkers in the field of atomic physics, introduced the so-called *principle of complementarity* into atomic physics, which amounted to a 'renunciation' of the attempt to interpret atomic theory as a description of anything. Bohr pointed out that we could avoid certain contradictions (which threatened to arise between the formalism and its various interpretations) only by reminding ourselves that the formalism as such was self-consistent, and that each single case of its application (or each kind of case) remained consistent with it. The contradictions only arose through the attempt to comprise within *one* interpretation the formalism together with more than one case, or kind of case, of its experimental application. But, as Bohr pointed out, any two of these conflicting applications were physically incapable of ever being combined in one experiment. Thus the result of *every single* experiment was consistent with the theory, and unambiguously laid down by it. This, he said, was all we could get. The claim to get more, and even the hope of ever getting more, we must renounce;

[7] But they seem to have forgotten that Mach was led by his instrumentalism to fight against atomic theory—a typical example of *the obscurantism of instrumentalism* which is the topic of section 5 below.

physics remains consistent only if we do not try to interpret, or to understand, its theories beyond (*a*) mastering the formalism, and (*b*) relating them to each of their actually realizable cases of application separately.[8]

Thus the instrumentalist philosophy was used here *ad hoc* in order to provide an escape for the theory from certain contradictions by which it was threatened. It was used in a defensive mood—to rescue the existing theory; and the principle of complementarity has (I believe for this reason) remained completely sterile within physics. In twenty-seven years it has produced nothing except some philosophical discussions, and some arguments for the confounding of critics (especially Einstein).

I do not believe that physicists would have accepted such an *ad hoc* principle had they understood that it was *ad hoc*, or that it was a philosophical principle—part of Bellarmino's and Berkeley's instrumentalist philosophy of physics. But they remembered Bohr's earlier and extremely fruitful 'principle of correspondence' and hoped (in vain) for similar results.

(*b*) Instead of results due to the principle of complementarity other and more practical results of atomic theory were obtained, some of them with a big bang. No doubt physicists were perfectly right in interpreting these successful applications as corroborating their theories. But strangely enough they took them as confirming the instrumentalist creed.

Now this was an obvious mistake. The instrumentalist view asserts that theories are *nothing but* instruments, while the Galilean view was that they are not only instruments but also—and mainly—descriptions of the world, or of certain aspects of the world. It is clear that in this disagreement even a proof showing that theories are instruments (assuming it possible to 'prove' such a thing) could not seriously be claimed to support either of the two parties to the debate, since both were agreed on this point.

If I am right, or even roughly right, in my account of the situation, then philosophers, even instrumentalist philosophers, have no reason to take pride in their victory. On the contrary, they should examine their arguments again. For at least in the eyes of those who like myself do not accept the instrumentalist view, there is much at stake in this issue.

The issue, as I see it, is this.

One of the most important ingredients of our western civilization is what I may call the 'rationalist tradition' which we have inherited from the Greeks. It is the tradition of critical discussion—not for its own sake, but in the interests of the search for truth. Greek science, like Greek philosophy, was one of the products of this tradition,[9] and of the urge to understand the world in which we live; and the tradition founded by Galileo was its renaissance.

[8] I have explained Bohr's 'Principle of Complementarity' as I understand it after many years of effort. No doubt I shall be told that my formulation of it is unsatisfactory. But if so I am in good company; for Einstein refers to it as 'Bohr's principle of complementarity, a sharp formulation of which . . . I have been unable to attain despite much effort which I have expended on it.' Cf. *Albert Einstein: Philosopher-Scientist*, ed. by P. A. Schilpp, 1949, p. 674.

[9] See ch. 4, below.