1-6

Committee I
The Limits of Science?

DRAFT--5/15/91
For Conference Distribution Only

SCIENCE AT AN END?
THREE LIMITS OF SCIENTIFIC KNOWLEDGE

by

Herbert Pietschmann
Institute of Theoretical Physics
University of Vienna
Vienna, AUSTRIA

The Eighteenth International Conference on the Unity of the Sciences
Seoul, Korea August 23-26, 1991

1. Border or Bound?

When we contemplate limits of anything – in particular such subtleties as limits of scientific knowledge – it is imperative not to confuse two different notions: limit in the sense of borderline and limit in the sense of bound.

As typical example for the first case we may choose the borderline between two different countries. Each country ends at its border, but on the other side is not nothing, rather the other country. Though the border separates two different things, there are also similarities between them. Contrary to the border, we may speak of a bound if something truly ends, like a measuring rod of a certain length. Nothing is beyond this end, it is a bound.

Like any "typical examples", we will hardly encounter them in true life. Rather, our limits shall be mixtures of both kind, but with preference to one of the typical examples. Still it will be necessary to keep the distinction if we want to transmit subtleties in the discussion.

Again, an example may serve a purpose: Think of the old days with still unknown areas on our maps. A country may join to such an area. Is this a bound or a border when we know there is another country beyond but we do not (yet) know at all how it looks like? We may call it a bound, since as long as we have no knowledge, we may call it a "blank" or even still "nothing (known)". We may also call it a border for we know there is something though we don't know the actual structure of it.

The first limit of scientific knowledge I want to discuss is of exactly this nature.

2. The Technological Limit

Scientific knowledge is based on the interplay between theory and experiment, i.e. rational explanation born out of empirical facts, born out of rational explanation ... As Nobel laureate T.D. Lee once put it[1]: "Without experimentalists, theorists tend to drift

... Without theorists, experimentalists tend to falter".

Successful experiments require refined equipment which, in turn, requires a certain technological standard. This defines – at each given point in time – a limit to scientific knowledge in an almost trivial manner. The largest telescope gives the limit in space we can resolve, the biggest accelerators give the limit of massive particles we can produce and study. It also defines the smallest scale we can separate. Anything below that scale is called "point-like". In 1960, this scale was about 10^{-13} cm, today it is three to four orders of magnitude smaller[2]. Hence we can call an electron point-like, but we can plot the charge structure of a proton which we now know as an extended structure.

The essential point is that the technological limit is of precisely the dual nature we have described at the end of the last section. We can be sure, that time and technological progress pushes the limit further and further but we do not know what will thereby be revealed. Nobody can tell for sure whether we will some day find out that the electron is also a particle with internal structure or how long it shall remain "point-like" (in this technical sense).

Whenever some adventurous thinker proposed an actual bound for technological progress, sooner or later it was transcended. "We shall never be able to fly with machines heavier than air" or "we shall never be able to actually see atoms" are only two of many examples. This tempted scientists in the first two centuries after the creation of the method around the middle of the 17th century to believe that the technological limit of scientific knowledge was the only possible limit. "What we do not know now, we shall surely know some day by means of science" was a general believe leading to mechanism and – consequently – to determinism and atheism.

The famous proclamation of Laplace is usually cited as illustration of this attitude. Laplace claimed, that if a very intelligent mind (called the Laplacian demon) would be able to know position and velocity of *all* particles in the universe at one point in time, it could compute from it everything that has ever happened in the past and that will ever happen in the future. Napoleon asked Laplace, where God had his place in this theory

and Laplace replied: "Your majesty, I do not need this hypothesis any longer".

3. The Methodological Limit

At the end of the last century some scientists actually believed that physics approached its final state. Very soon – so they claimed – everything about matter in space and time would be known and written down as "laws of nature" for eternity. No sooner was this superstition proclaimed, and the whole picture was torn to pieces. The electron was discovered; radioactivity, x-rays, and all the experiments showing that no motion of the earth in its surrounding ether could be measured, puzzled physicists in the deepest possible way. Eventually, it led to a total change of physics in a revolution which is sometimes called "change of paradigm"[3]. It also brought about a new kind of limit to scientific knowledge which was unthought of before.

The puzzles mentioned above (and some others, less pronounced ones) led to the formulation of new theories on a much deeper and broader level. The special theory of relativity was based on a change of the concept of time and Quantum Mechanics on that of locality. The essence of both theories can be formulated in a negative way: "There is no absolute time" is the basis of special relativity and "it is impossible to measure position and momentum of a particle simultaneously with arbitrary precision" is the basis of Quantum Mechanics. A simpler but less precise way of expressing it would be "there is no orbit in microcosm". (In passing we note that the basis of General Relativity can similarly be simplified into the statement "there is no absolute space").

Just as the acceptance of the fact, that "there is no perpetuum mobile" had once led to the invention of the steam engine (and subsequently to the internal combustion engines), these new insights by means of negative statements led to unforseen developments. Great as the new theories undoubtedly were, they incorporated by necessity a new kind of principal impossibility. The speed of light is the maximal velocity for particles as well as information and can never be transgressed. This was born out from the theoretical

description of special relativity. Whether a subatomic particle is discrete ("point-like") or continuous ("wave-like") can never be determined by experiment for both properties are corroborated empirically (collisions as well as interference phenomena exist at the *same* object, e.g. an electron or a photon).

It is very important to keep in mind that this limit is basically different from the technological limit. The theories themselves exclude the possibility of factual velocities greater than that of light in vacuum and the determination of orbits in an atom, say. It is *not* the experimental imperfection, but the principal impossibility which sets the limit. Nobel laureate P.A.M. Dirac puts it in beautiful words[4]: "... there is a limit to the fineness of our powers of observation and the smallness of the accompanying disturbance – a limit which is inherent in the nature of things and can never be surpassed by improved technique or increased skill on the part of the observer".

I chose to call this limit[5] "methodological" because it is born out of the method of physics itself and it became apparent as soon as the method was reflected in physical theories. Let us find out now whether this limit is of the border or the bound type, or a mixture in the sense of the technological limit.

The vacuum velocity of light as the limiting velocity certainly forms a bound. (Though the existence of "tachyons" was speculated in physics for a time, it does not give a counter-example because the velocity of light is a bound from below for them!) Although Albert Einstein was the first to recognize this bound, he remained reluctant to accept the same situation in Quantum Mechanics. His preference was towards existence of "hidden variables" which would extend physics into the domain beyond the present border given by Quantum Mechanics. However, the long and intensive study of such possibilities[6] has now settled the case and no such hidden variables seem to possibly exist.

4. A Profound Confusion

When it became apparent that the technological limit was not the only limit to

scientific knowledge, a profound confusion about the nature of science clouded even the best minds for quite some time. Since the new limit is born out of scientific method itself, it was claimed that this very method should henceforth be capable of dealing with the entirety of human problems, including mind and freedom.

Max Planck wrote an article about the free will[7] and in a talk on "Religion and Science" in May 1937 he said: "The exact method of science in its development since centuries, has proven so fruitful that scientific research today dares to tackle even less concrete problems; it successfully attacks problems of psychology, epistemology and even general world view, and from a scientific point of view deals with them thoroughly. One may say, that presently there is not any abstract question of human nature which is not somehow related to a scientifically formulable problem."

Discovery of its own limit which was not only a border but – at least in some sense – a true end, led to the deception that the totality of truth could now be unraveled. In a way, it is paradoxical that observation of a limit tends to induce these fantasies of omnipotency. In our days, the game seems to go through a new cycle of similar nature; the development of the theory of non-linear dynamical systems brought about the notion of "Chaos and Order" (and Fractals). Just as in the years after the development of Quantum Mechanics, this new concept is now carried into many domains of human interactions, even into economy and management.

Whenever a new question of human nature comes up, there are at least some groups of people who try to find an answer within science or at least with the application of scientific method. This may be understandable in view of the vast body of knowledge which science has provided and which is still ever increasing at a breathtaking rate. Many severe problems of mankind have been eradicated by scientific methods such as famine, illnesses (to mention just a recent one: small pox!) and lack of shelter; many dreams of mankind have come true, such as flying, telecommunications, "eternal" light and so on.

But cautious minds also saw the dangers of these fantasies. If it is claimed, that

scientific method is capable of describing "All-that-is", it follows necessarily that anything not included in the scientific picture of the world does not "really" exist; i.e. it is "just" imagination, wishful thinking or even mere lack of education.

In his quoted talk[7], Max Planck points to this when he says: "He who is serious in his faith and cannot tolerate if it contradicts his knowledge, has to decide before his conscience whether he can participate in a religion which includes miracles in its believe."

Of course, it is not only religion which is excluded from such a world-view. It is the totality of emotions, of free decisions, of qualities and thus even dignity. Therefore, it seems to me of utmost importance to distinguish yet another limit of scientific method; it is a border separating the realm of scientific world view from the abovementioned "rest", which is nevertheless an important part of humanity as a whole as well as for each individual life.

I chose to call this border the ontological limit of scientific knowledge[5]. To understand its nature, we must first dwell a bit upon the roots of scientific method itself.

5. The Method of Science

It is imperative to understand right away that one of the most crucial events in the discovery (or shall we say "invention") of scientific method was a particular differentiation made by Galilei; in order to evade the fate of Giordano Bruno, who was burned when Galilei was just 36 years of age, Galilei differentiated between the "Truth" of the Holy Spirit and "Knowledge" about Material Things. In a sense, he fulfilled by his actions the philosophical program of Descartes, who differentiated between "res cogitans" and "res extensa", mind and matter, sense and things. In his first conflict with the Holy Inquisition in 1616, Galilei is said to have made a famous statement, that the Holy Spirit tries to teach us how we approach heaven whereas he teaches us how the heavens approach each other.

This differentiation between Truth and Knowledge was not only able to prevent dis-

aster from the inquisition for Galilei, it also brought about all the powerful tools for mankind to restructure – if not to say recreate – the earth. (The famous trial of Galilei of 1633 was comparatively harmless since Galilei did not even have to go to jail. For details see for example reference[8]). For it requires a complete abstraction from such emotionally important qualities as beauty, meaning, hope and even love, in order to be able to concentrate on the quantities to be measured for the application of the scientific method. The sun, the moon, the planets and the stars had deep meanings for mankind since they first came into the focus of its visions. When we want to calculate the time of an eclipse or the conjunction of planets, all these qualities have to be superseded; the mass and geometric quantities, the coordinates of their center of gravity, are the only ingredients allowed in a scientific computation.

One might argue that is suffices to put qualities aside for the time and the sake of a quantitative argument. That is – unfortunately – not so! Since human beings are whole structures uniting emotions and rationality, a mere setting aside of these qualities would not prevent their interference with scientific rationality, thus they have to be less real! It is at least a historical fact that those scientists who more or less completely devoided themselves of these qualitative "sentiments" were the most successful in the battle for scientific recognition after Galilei and Newton.

Let us collect the main points of our argument: Science after Galilei and Newton is based on the imperative prerequisite to split All-that-is into an "objective" part (which is subject of the scientific method) and the "rest" (which started out to be as important but went through a fading process into "mere subjectivity" or the like). This splitting corresponds roughly to the distinction of res cogitans and res extensa, of mind and matter, of qualities and quantities. By this separation of the world (or All-that-is) mankind was able to establish laws of nature which are absolute in the sense that they "hold" independently of any human wish, believe, power or notion. By means of this knowledge, human technology could be developed to a degree which was completely unforseeable and which allowed mankind to restructure the world.

As I have tried to argue, the danger does not lie in a denial of the difference between the two parts of reality for this is almost a prerequisite for successful application of the scientific method. The danger lies in not accepting the equality in importance of the two parts for the whole. A scientist who works very hard in his field and by abstracting from all qualities finds a new law of nature is all too easily tempted to publicly declare the "other part" as irrelevant. To give but one example let me quote from the final paragraph of the otherwise excellent book "The first three minutes" by the Nobel laureate Steven Weinberg[9]:

"As I write this I happen to be in an airplane at 30,000 feet ... Below, the earth looks very soft and comfortable – fluffy clouds here and there, snow turning pink as the sun sets, roads stretching straight across the country from one town to another. It is very hard to realize that this all is just a tiny part of an overwhelmingly hostile universe. It is even harder to realize that this present universe has evolved from an unspeakably unfamiliar early condition, and faces a future extinction of endless cold or intolerable heat. The more the universe seems comprehensible, the more it also seems pointless".

The picture of the world which has been designed by scientific method is a description which can be characterized by the following axioms:

i) every notion is properly and uniquely defined

ii) there are no contradictions within this description

iii) there is a sufficient reason for everything to which this description applies.

Furthermore, no experimental result may contradict any of the predictions made from this description. If it so happens that such a contradiction occurs, the relevant part of the description is shown to be preliminary. Further work has to improve it until the contradiction is eliminated. This supposes however, that the experiment itself is shown to comply with the following three axioms:

i) it must be reproducible

ii) its results are given quantitatively

iii) it is a sufficiently simplified system so that so-called "systematic errors" can be controlled and corrected for.

Scientific progress is a process of unification by continuous elimination of contradictions. A theoretical description is said to be better than a previous one, if it predicts the result of more experiments by less assumptions. Thus the goal of science is a description of "reality" free from contradictions within itself and with all experimental results. This process itself *defines* what we call "reality" in science!

6. The Ontological Limit

From this discussion of scientific method it should now be clear what I mean by "ontological limit" of scientific knowledge. Within this border lies the scientific picture of the world. Everything within this view follows the six axioms listed at the end of section 5. We have also seen that this limit is all too frequently referred to as a true bound in the sense that everything beyond it is "less real".

Can we describe it in more positive terms?

From the six axioms it is obvious, that we are likely to find beyond this limit everything which is merely subjective, unique, not well definable and – above all – ambiguous and contradictory. This is also the reason why this field is often considered less real.

Let us contemplate for a moment on the meaning, the frightfulness and the chance within contradictions.

Suppose we have a closed system of statements, laws or rules, free from contradictions and well-defined (which we can call a "standard"). Within the field to which this standard applies, all decisions, all statements and all actions can be ordered into right or wrong according to whether they are in agreement with the standard or not. (A simple example is the standard which is called "traffic law" in all countries where traffic has to be ordered). In such a case, we are determined by the standard, we are not free to choose

for deviation from a right decision would be stupid or even self-destructive. It is the field of "Heteronomy" (according to Kant), where we are determined not by ourselves, but by the standard.

On the other hand, whenever an essential contradiction cannot be eliminated, we *have* to make our own choice in each concrete case according to our own free will. That is just the essence of a contradiction, that we cannot "derive" right or wrong, by mere definition of a contradiction. Therefore, contradictions are always simultaneously frightening and relaxing! They are frightening because we cannot delegate our decisions to a standard (directly or via an "expert"). They are relaxing because we do not have to project our own self onto a standard, because we are truly free to choose, even if we choose not to decide but to delegate the decision to somebody else, father, mother, big brother, coincidence, accident, inheritance or whatever possibilities mankind has thought up to evade and supersede freedom. This is the field of "Autonomy" (according to Kant), of truly autonomous or free decisions.

Insisting on free decisions in the field of Heteronomy is stupied!

Insisting on delegation to "experts" in the field of Autonomy is cowardice!

The problem, however, lies in finding the dividing line between the two fields in each concrete event! Is the decision, whether we are in the field of Heteronomy or Autonomy in a concrete event, itself a decision of Autonomy or of Heteronomy?

In some cases the answer is clear. Whenever we want to construct a technical equipment, say, we have to comply with technical standards derived from science. But are we still in the field of heteronomy when technical standards derived from science are applied to our own body in the case of illness?

Certainly, the answer cannot come from scientific investigations alone, for in that case it had to be unambiguous and it would always point to the field of heteronomy.

7. Constructive Realism as a Possible Answer

The 17th century brought about the method of science with all its consequences. The 18th century led to the fantasies of omnipotency, the claim that the technological limit is the only possible limit to scientific knowledge. At the turn of the 19th century the methodological limit dawned and it was taken seriously in the 20th century.

It may well be – and I personally claim it is – that the next century has to take the ontological limit very seriously. (It may even be a prerequisite for survival of the human species).

Suppose that this is the case. What is the consequence?

Nobody can tell for sure because it has to be an autonomous decision of *all* people concerned and thus *no* expert can (or should) forcast the result.

But we can contemplate possible first steps in the right direction.

At the end of section 5 we have said that scientific "reality" is *defined* by the six axioms given. It has been claimed throughout the history of science that this "reality" is an "approach to truth" or at least a faithful picture of what is called "objective reality". If we take into account that all results of scientific investigation are based on the splitting of "All-that-is" described above, thereby necessarily introducing the border called "ontological limit", it is better to abandon this notion altogether.

There is *no* direct way to "reality" itself. Once that negative statement is accepted with all its consequences, it may become basis for a totally new and fruitful approach (recall section 3!). What scientific investigations do achieve is the *construction* of a beautiful as well as useful picture of that part of "All-that-is" which falls into the domain of Heteronomy. This construction (which we may call "actuality" to distinguish it from "reality", following Nobel laureate Wolfgang Pauli[10]) is based on the axioms of section 5 but does *not* claim to be an image of "reality". However, contradictions to reality can be noted by experimental investigation and lead to an improvement of the construction[11].

The philosophical basis for this view is called "constructive realism" since it denies

neither the existence of a reality nor the fact that we always live in our own construction without *directly* reaching reality[12].

References:

1) T.D. Lee: CERN-Courier, Jan./Feb. 1987, p. 12

2) D. Haidt and H. Pietschmann: Electroweak Interactions - Experimental Results and Theoretical Foundation (Springer Verl. Berlin 1988)

3) Th. Kuhn: The structure of scientific revolutions (Univ. Chicago Press, 1970)

4) P.A.M. Dirac: The Principles of Quantum Mechanics, 4th edition (Clarendon Press, Oxford 1958) p. 3 f

5) H. Pietschmann: Die drei Grenzen physikalischer Erkenntnis, Philosophia Naturalis 17 (1978) p. 90

6) A. Einstein, B. Podolsky, N. Rosen: Physical Review 47 (1935) p. 777
J.F. Clauser and A. Shimony, Reports on Progress in Physics 41 (1978) p. 1891
A. Aspect, J. Dalibard, G. Roger: Physical Review Letters 49 (1982) p. 1804

7) M. Planck: Naturwissenschaften (1926) p. 249 and "Religion und Naturwissenschaft" (14th edition Leipzig, 1958)

8) J.M. Jauch: The Trial of Galileo Galilei, CERN yellow report 64-36 (Geneva, 1964)

9) S. Weinberg: The first three minutes (Andre Deutsch Ltd., London 1977)

10) W. Pauli: Phänomen und physikalische Realität, Dialectica, Vol. 11 No. 1/2 (1957)

11) H. Pietschmann: Die Wahrheit liegt nicht in der Mitte (Ed. Weitbrecht, Stuttgart 1990)

12) F. Wallner: Acht Vorlesungen über den konstruktiven Realismus (Cognitive Science 1) WUV Vienna (1990)