PHILOSOPHICAL IMPLICATIONS: SPACE, TIME, MATTER, & MEASUREMENT

Mathematicians and some philosophers had been worrying about the exact nature of space ever since the axiomatic formulation of geometry by Euclid; but it was really Kant who brought space & time back into mainstream philosophy. However neither he nor anyone else anticipated the remarkable discovery of the mathematicians (Gauss, Bolyai, & Lobachevsky) of non-Euclidean geometry. This required a fundamental revision of our ideas of space & geometry, accomplished largely by Riemann.

Even more shocking was yet to come. First came special relativity, which unified space & time (an idea never suspected by anyone except CS Pierce). Even then it was still possible to maintain that spacetime was simply a relational concept, between material objects, defined by measuring rods & clocks. But then Einstein turned everything upside down by showing that spacetime was itself a dynamical object: in fact it was a field just like the electromagnetic field. Moreover the fundamental work of Riemann had shown how it was possible to define a geometry WITHOUT saying what 'higher space' it was embedded in – the existence of this higher space was superfluous.

All of this left philosophy trying to catch up with physics. The Kantian idea that space & time were *a priori* notion of human understanding was clearly wrong – spacetime complex entity, seemingly independent of human understanding. To define it by measuring operations seemed utterly inadequate, yet the first ½ of the 20th century was dominated by positivist discussions of experimental verification, which were mostly a throwback to old-style empiricism. All this was before quantum mechanics.

The REVOLUTION in GEOMETRY

At the beginning of the 19th century both Bolyai & Lobachevsky published the 1st mathematical theories of non-Euclidean geometry. In fact the great mathematician Gauss had already anticipated their discovery years before, but not published the work because he did not relish the public controversy he thought this would bring. Somewhat later the equally extraordinary mathematician Riemann gave a very general formulation of geometry, which was decisive in its impact on mathematics & the philosophy of mathematics.

CF Gauss (1777-1855)

B Riemann (1826-1866)

Riemann showed that any geometry could be defined purely by its local properties, in terms of a 'metric' which is a 'tensor' defining the distance between nearby points. This was the mathematical framework upon which Einstein built his general theory of relativity (in which the metric describes curved spacetime).

This way of defining geometry left it open for philosophers & mathematicians to discuss closed geometries, not embedded in anything, and to define space purely in terms of the distance measures between all pairs of points.

CS Pierce (1839-1914)

All this left everyone quite mystified about what was 'real' about geometry. There was no clear idea that somehow space & time might be connected (although some speculation by Riemann & by CS Peirce).

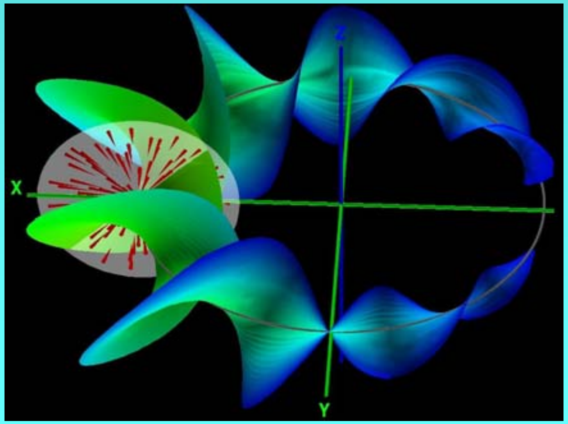
POINCARE & 'CONVENTIONALISM'

One of the greatest & most creative mathematicians of all time, H Poincare also set out a philosophy of physics, starting from his views on geometry. His view is called 'conventionalism': it argues that the laws of physics are, in a certain sense, decided by convention. Consider eg. Newton's 2nd Law. Poincare argues that this can be altered at will, provided all other laws are altered in the same way: we might, eg. make distance measures vary as we move around. This would make the laws of physics very complicated, but still valid, provided they consistently correlate different physical phenomena. The choice we make is a convention, usually made so that the laws will look as simple and elegant as possible.

JH Poincare (1854-1912)

It follows that all geometries are equivalent, & no particular set of geometric axioms describes the 'true' geometry. The choice of non-Euclidean geometry as a description of Nature is then purely a matter of choice of convention. In his book 'Science & Hypothese" he argued that science involved the formulation of hypotheses in which economy and generality were important, leading to predictions which were tested by experiment – falsification typically leading to new hypotheses.

POINCARE & TOPOLOGY



'Poincare sections' in dynamics

One can generalise the study of geometry to what mathematicians call 'topology'. This deals with the way in which sets of points can be assembled into different kinds of 'space', and how these spaces may (or may not) be transformed into each other. This field was largely invented by Poincare, and is now a central part of mathematics. From it grew the modern theory of dynamical systems – Poincare's work showed the enormously complex trajectories, mostly chaotic, of even simple dynamic systems (eg., 3 masses orbiting each other in space, the '3-body problem').

POSITIVISM, EMPIRICISM, & RELATIVITY

Ernst Mach
(1838-1916)

One of the great ironies of the history of positivism is that in his early work on relativity, Einstein was strongly inspired by some positivist ideas, notably the rather extreme ones of Mach. Yet later on, he completely rejected these, adopting instead a more Kantian point of view.

In his special theory of relativity, Einstein emphasized the importance of measurement operations using 'clocks and rods' (cf p. 3.26 of the slides) for the definition of quantities like space and time. This was seen as support for the positivist approach of Mach.

This support was confirmed when Einstein endorsed Mach's idea that the inertial properties of any mass derived from all the other masses in the universe. This idea, called 'Mach's principle' by Einstein, came directly from Mach's rejection of absolute space & time, and Mach's assertion that only other masses could determine the dynamics of a given mass. Mach's argument was that there was nothing else - ie., that space & time had no independent existence, but were merely relations between objects. This "relational" theory of spacetime was adopted by all the later logical positivists.

H Reichenbach
(1891-1953)

The idea was further developed by H Reichenbach, who although he had been associated with the Vienna circle, was not a logical positivist – in fact he started the 'Berlin circle' of logical empiricists, which emphasized, following Einstein, the physical operations involved in defining quantities like length & time, making the link between axiomatic geometry and physics. However Reichenbach also emphasized the conventionalist aspect of the theory, stressing the way in which the choice of a geometry depended on the convention used for comparing lengths & times at different points in spacetime. All of this was very much in line with the original formulation of special relativity by Einstein.

The PHYSICAL REALITY of SPACETIME

A Einstein
(1879-1955)

Einstein's views on spacetime changed completely with his General Theory, which made spacetime a dynamic field. Positivist doctrines were then clearly Inadequate – the coupled dynamics of matter and spacetime put them on the same ontological level, particularly given that matter could be converted to gravitational energy (and thence to spacetime curvature).

For similar reasons Einstein also abandoned Mach's principle, which conflicted with the General Theory. Thus, eg., the geometry around a fast rotating wheel had to change, (length contraction of the outer rim meant that its circumference had to decrease compared to a stationary wheel, and this was only possible with a change of local geometry). This effect happened independently of the matter distribution elsewhere in the universe, which clearly was then not determining the local geometry.

A Einstein with K Godel
in Princeton (c 1950)

Later work in General relativity has confirmed the idea that the spacetime field should be viewed as just as real as matter (or as the EM field). The richness of solutions to the GR equations has illustrated this. These include not only black holes, but also wormholes (the Einstein-Rosen bridges), the 'rotating universe' solutions found by the logician Godel, and rotating black holes (the Kerr solution); all these objects seem pretty real. The last two contained close time loops, although more recent work indicates that time travel is probably impossible in practise.

EINSTEIN: PHILOSOPHICAL BELIEFS

Einstein's philosophical ideas evolved a great deal in his lifetime, and one can see now that these ideas had a decisive impact on the development of many trends in 20th century philosophy of science. Einstein spent some time distinguishing his own 'epistemological credo' from the views of positivist and empirical philosophers of all stripes, & he largely rejected the ideas he had found useful when younger. His mature philosophy began to appear in the early 1920's, and he started to write extensively about it once he had finally left Germany (in 1933) and then moved definitively to the USA (to work at the new 'Institute of Advanced Study', in Princeton) in 1934.

The Einstein house on Mercer St., Princeton, NJ

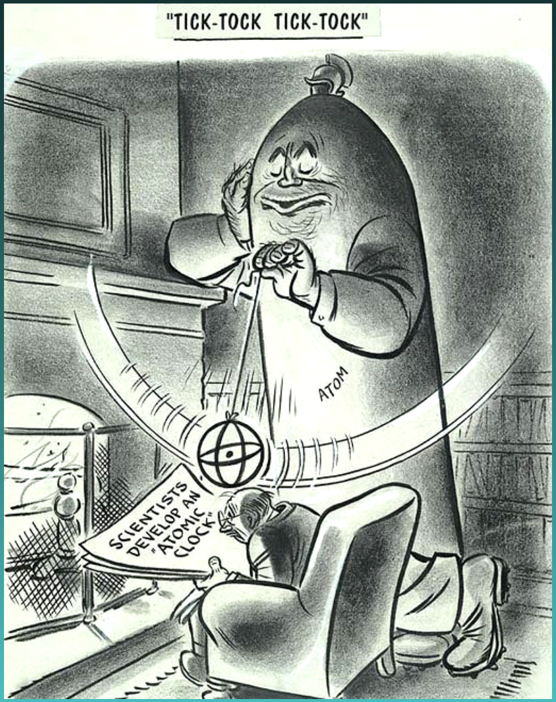
In his last 20 years Einstein found himself increasingly isolated from the community of physicists he had fostered: his views were so clearly at odds with the prevailing Quantum orthodoxy.

Einstein's later views combined an epistemology which had strong Kantian elements (in its emphasis on the amalgam of empirical and *a priori* components in our picture of physical reality) modified by 2 important extra ingredients:

(i) the remark that none of the 'categories' of our understanding involved in this amalgam were fixed *a priori* – in fact they were 'free creations of the mind', to be modified by the physicist where it seemed necessary to understand Nature.

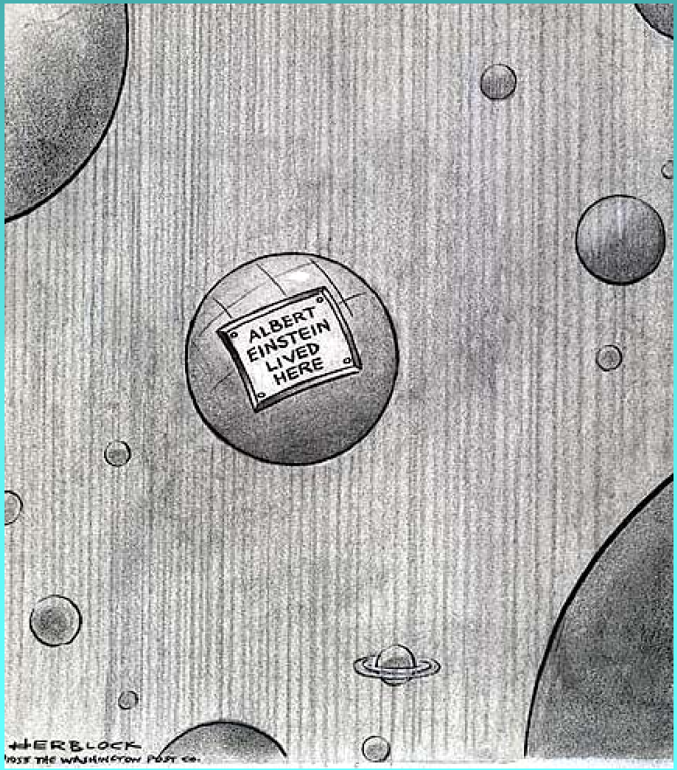
(ii) the clearly expressed faith that there was an *objective* reality of which humans partake (although it is independent of us & would exist in the same form without us); & that we can come to know truths about this reality, even if only approximate, & liable at any time to revision.

EINSTEIN: the LEGACY



Even before the General theory of Relativity in 1915, Einstein was widely regarded as the world's pre-eminent theoretical physicist. The confirmation of the General theory by the British Eclipse expedition in 1919 quickly gave him the aura of the greatest thinker since Newton, and perhaps of all time.

The public circumstances of the announcement of the eclipse results also rocketed Einstein to worldwide fame, which steadily increased thereafter – at this death, he was widely revered, more for his moral authority than his science. In the year 2000, the readers of 3 newspapers (the "Times' of London, 'Le Monde' in France, & the 'Globe & Mail' in Canada) voted Einstein to be the most important human to have lived during the previous 1000 yrs!



His scientific legacy is still being evaluated, as is his personal life. Physics has still to find any way of resolving the conflict between general relativity & quantum theory, a problem reinforced by the stunning successes of both theories.

The popular idea, that Einstein's special relativity (with the result $E = mc^2$) led to the atomic bomb, is basically false. But his work fundamentally modified the world we live in. Einstein himself, understanding the secondary role of applications of a theory compared to the theory itself, would have been unimpressed by this. But one suspects he would have been pleased by the continuing influence of his ideas on world peace, and of his faith in an impersonal guiding spirit in the universe, utterly uninterested in human affairs – what he called 'the Old One'.