Ulm talk, C W Misner, 19 September 1978:

The Immaterial Constituents of Physical Objects

Some of Einstein's ideas were so forceful and clear that it was quickly evident they would have a permanent cultural impact. For instance, special relativity reconstituted space and time. Minkowsky proclaimed its impact in elegant phrases, "Henceforth spaces by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality".

Einstein's influences as clear and dramatic as this I do not need to review. And I lack the historical skills to seriously assess the impact of Einstein's ideas on modern culture, even if that would fit the title of this conference nicely. But I would like to inquire about Einstein's impact by pointing out some nebulous but pervasive ingredients of our present culture in which I seem to see the spirit of Einstein.

In addition to overturning our ideas of space and time, special relativity also constituted an assault upon the mechanical view of the physical world and upon the materialistic view of nature. After special relativity was accepted, one no longer searched for insight into what really lies at the base of electromagnetic phenomena by conceptually building models full of gears and idler wheels, or by imaging an ether as a superpenetrable material with peculiar properties. Instead Einstein's concept of field as refined from the ideas of Faraday and Maxwell is frequently taken as fundamental. Today the search for insight into what really lies at the base of elementary particle phenomena often leads to building conceptual models of interacting fields. (Of course, the model builders of both Maxwell's generation and our own, although often motivated by a desire to know what things really are, proceed with a very large dose of skepticism as to whether the models they create actually seize much of that goal). The question I present then, as defining an area in which the impact of modern scientific ideas on society should be studied, runs "Is the world made up of material objects?"

An aspect of this question was forcefully presented by Sir Arthur Eddington (who, as we know, led the eclipse expedition in 1919 that seems to have triggered the elevation of Einstein to his unique status as a hero in popular culture). Writing the introduction to his popular book, The Nature of the Physical World [2] he says (and I condense):

> I have settled down to the task of writing these lectures and have drawn up my chairs to my two tables…
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> One table has been familiar to me from the earliest years. It is a commonplace object of that environment which I call the world… Table No. 2 is my scientific table… [It] is mostly emptiness sparsely scattered in that emptiness are numerous electric charges rushing about with great speed…. Modern physics has by delicate test and remorseless logic assured me that my second scientific table is the only one which is really there -- wherever 'there' may be.

Eddington does not say that his scientific table contains no material substance (although he questions it), nor can we now. The idea that everything is to be explained as a construct built from some replacement for Newton's "hard, massy" material atoms is a theme [3] still capable of motivating scientists. If elementary particles have failed to be elementary, no matter, a search for the 'ur-atom' still proceeds.

But it is not the 'ur-atom' but a contrary theme that I want to explore. Eddington's captivating review of modern science shows that the material substance of the universe is on the defensive in this century, reduced at most to scattered specks in the emptiness, its garrisons pulled together in isolated posts. Of course, it does not necessarily follow that by conceding ground in the spatial arena, matter has lost sovereignty in the sphere of understanding. But, in fact, matter's position is not good there either. For the scientist who can see Eddington's second table, the locus of understanding is not in matter, the particles, but in the interactions among them. We do not say, what an electron is, but we do write laws for how it interacts with photons and other electrons. Thus even for the action-at-a-distance atomic theorist, the locus of understanding is not in the specks of matter, but in the intervening space through which the particles communicate in order to interact, and in the patterns of higher symmetry in the laws describing their interactions.

Part of Einstein/s genius was his ability to see real if invisible things inhabiting the emptiness in Eddington's table, where so many others had seen nothing. Attempting to explain how we grasp external realities, Bronowsky tells a delightful tale [4] of a Sherpa mountaineering guide who had for a lifetime known two mountains seen from two different valleys, and called by their own proper names in the different local languages. The guide reacted with the pleasure of scientific insight when a European climber suggested that they were the same mountains, seen from different viewpoints. And the guide could then even verify this to his greater satisfaction by recognizing features visible in both views. In some such way an infant must correlate his varying retinal images as he turns a toy over in his hand and achieves the conception of independently existing objects that we all share in common discourse. This was Einstein's approach, also in special relativity. He had no need for the Michelson-Morley experiment. He instead played with a simple electromagnetic experiment in his mind. Viewing this experiment one scientist could see electric forces at work, another magnetic forces. The **E** and **B** forces were, to infant scientist Einstein, mere retinal images. But he soon saw, and taught others to see, the really existing thing, the invariable object in the external world (indeed in empty space) that gave rise to them, namely the electromagnetic fields F. Notice how different my emphasis is from the usual statement that Einstein unified the two vectors **E** and **B** in the tensor F. It is not the unification I stress, but the grounds he found for conviction in the existence of some external reality (here F). By this insight Einstein discovered fields in nature as surely as Galileo discovered the solar system by showing it to us (actually a model of it) from a new viewpoint in turning his telescope on the moons of Jupiter,

We must now skip rapidly on. Einstein showed us that immaterial entities are fundamental constituents of the universe. He discovered (in the sense described above) not only the electromagnetic field, but also the first conscious use of what is called ‘higher symmetries’, which is the use of the mathematical structures as co-authors in writing the laws of physics, and not merely as the pen and paper that communicate and embody the laws when written. (Perhaps in these higher symmetries we will find those further embodiments of geometry in physics for which Einstein had long searched, as Dirac has reminded us.) The extent to which these generative structures will be seen as fundamental constituents of ordinary matter is not yet known. Most theories of this type (general relativity, Yang-Mills, harmonic maps) are only beginning to be explored and we cannot have a sound philosophical reaction to vague hints of insights speculated for achievement in the future.

But beyond Einstein and modern physics we find many other examples in modern culture of the expanding conquest of immaterial entities while material objects decrease relatively in value, although apparently overwhelming us. Russell Baker in a humorous column for the NYT about a decade ago made the point. ‘What do you do all day, Daddy?’ asks a young school child studying his first books, which have stories of colonial villages filled with blacksmiths, carpenters, farmers, and other materialists. ‘I go to New York and sit at a desk.’ ‘Yes, but what do you do at your desk?’ ‘I read papers people give me, sometimes I write something on them, then the papers go on to other people, or into a box.’ ‘What do the other people do with the papers?’ ‘The same thing.’ ‘And is that how automobiles get made then, Daddy?’

To an increasing extent it appears that this, in fact, is the way automobiles do get made, and computers even more so. The computer field provides also the best language for succinctly summarizing the theme I am trying to explore. There it reads: ‘Hardware is software.’

We know that software in the form of labor, design, advertising, management, finance, insurance, etc, is a significant part of any product. For nuclear power, for instance, fuel is a relatively small part of the cost, with the major parts being developmental, design and labor costs, and interest on the invested capital. The theme ‘hardware is software’ suggests that in any object whatsoever there is nothing except design and environmental impact (or ecological participation) and other such ‘software’ constituents. While we are normally prepared to accept that material objects embody significant ‘software’ in the form of design and craftsmanship, we customarily assume that the coal and steel or other material used in the construction process are something entirely different. Eddington’s table reminds us, however, that all we have so far found by the scientific study of such materials is more design, more software. The theme ‘hardware is software’, whose origins (including the field concept as clarified by Einstein) I would like to see traced, proposes that ‘software’ is not only all that we will ever find, but even that in some sense it is all there actually is underlying the material world of everyday experience.

Chemistry, and particular biochemistry, is a field where the ‘hardware is software’ theme seems quite apt. Chemical theory discusses how some basic ‘materials’ unite, combine and interact to produce a variety of substances. The units may be atoms or molecules, or other groupings, but are rarely anything as small as an electron or a nucleus. Thus the chemical unit is not normally Eddington's 'speck of matter' but rather a conceptual or software unit corresponding to logical and geometrical relationships among other small units that include the 'speck of matter' that only gets resolved into software by the elementary particle physicist. The DNA molecule is an excellent example of this hierarchy, with its arrangement in terms of phosphates, sugars amd nucleic acid bases seldom resolved into atoms in any discussion. And above this level of organization it also shows more software, with bases grouped into triplets as characters in a twenty letter alphabet and these into longer messages coding complete proteins, and these again into still larger structures whose significance for the process of cell development are only beginning to be worked out. But even greater levels of software are required before a simple piece of biological 'material' such as a simple cell is explained. One is also curious why some DNA strings have come to exist, among all those physically possible, and other DNA strings not. This we find is governed largely by history, through the process of evolution.

I hope, I have now sketched enough, so that you can provide yourself with many more examples illustrating how the modern scientific viewpoint can be considered radically anti-materialistic, since all its explanatory power resides in the immaterial constituents – the design relationships – in the object it analyses. This 'hardware is software' theme is rarely explicitly stated (Einstein's hopes for a unified field theory and some successor in that tradition being exceptions), but it is so close to the surface in the work being done in many fields that I presume it must be having some quiet impact on society at large. I cannot imagine that one important and pervasive myth – Newtonian atomism – can be jettisoned in favor of another – Einstein field theory – at all levels of culture and society without consequences of great moment. The nature of these changing presuppositions can be stated in conclusion in the language of another myth:

> The world is made of earth
> water air and fire.
> Earth and water are, we see,
> just knots of air and fire –
> what then can air and fire be
> but skeins of hope and history?

REFERENCES

1. H. Minkowski, address delivered at Cologne, 21 September 1908, as translated in *The Principle of Relativity*, Lorentz et al. (New York: Dover reprint).
2. Arthur Eddington, *The Nature of the Physical World* (Cambridge University Press, 1929).
3. G. Holton, *Thematic Origins of Scientific Thought – Kepler to Einstein* (Harvard University Press, 1973).
4. J. Bronowski, *Science and Human Values* (New York: Harper, 1965), p. 30.