COMTE, MACH, PLANCK, AND EDDINGTON: A STUDY OF INFLUENCE ACROSS GENERATIONS

Alan H. Batten
2594 Sinclair Rd, Victoria, B.C., Canada, V8N 1B9.
Email: ahbatten@telus.net

Abstract: Auguste Comte is frequently ridiculed by astronomers for saying that human beings would never be able to know the physical nature and constitution of the stars. His philosophy, however, influenced scientists throughout his lifetime and for over a century after his death. That influence is traced here in the work of three outstanding scientists who spanned, roughly speaking, three successive generations after his own, namely, Ernst Mach, Max Planck and Arthur Stanley Eddington.

Keywords: Auguste Comte, philosophy, positivism, Ernst Mach, Max Planck, Arthur Stanley Eddington,

1 AUGUSTE COMTE

Although there are exceptions, astronomers in general are not noted either for their knowledge of, or interest in, philosophy. It is, therefore, somewhat ironical that so many of them should remember Auguste Comte (1798–1857; Figure 1) who, although he was influential in his lifetime and, indirectly so, well into the twentieth century, was scarcely in the first rank of philosophers. He ventured to state, however, that human beings would never be able to know the physical nature and chemical composition of the stars and many astronomers have recalled this statement to ridicule not only Comte himself, but sometimes philosophy in general.

Only a few years after Comte's death, Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) laid the foundations of spectroscopic analysis, which would eventually enable astronomers to do just what Comte supposed they could never do. I sometimes imagine that, in whatever portion of the Elysian Fields that is reserved for philosophers, the shade of Comte permits himself a wry smile every time a living astronomer quotes him on that subject: at least he is being remembered! We are too ready to make fun of him and to forget that he wrote his *Cours de Philosophie Positive* before astronomers had reliably determined the distance to a single fixed star.

Moreover, leading astronomers of the day would have agreed with him and, perhaps, would have argued that the study of the composition of the stars was not part of astronomy. For example, Friedrich Wilhelm Bessel (1784–1846) an older contemporary of Comte, wrote to Alexander von Humboldt (1769–1859) emphasizing that astronomy was restricted to what could be observed from the Earth and was a matter of precise measurements of the positions and orbits of celestial bodies, adding that

> Everything else that one may learn about the objects, for example their appearance and the constitution of their surfaces, is not unworthy of attention, but is not the proper concern of astronomy. (Kragh, 2004: 18).

Similarly, George Biddell Airy (1801–1892), who was born only three years after Comte, wrote of the importance of a national observatory having some distinctly useful task (such as the time service in Greenwich or the meridian survey in Pulkovo) to prevent "… astronomers from wasting their time in the mere fanciful abstractions of science." (Airy, 1848: 355). It is not entirely clear what Airy meant by that phrase but we may be fairly sure that he held much the same view of the proper concerns of astronomers as Bessel did.

Figure 1: Auguste Comte (en.wikipedia.org).

Comte was echoing quite accurately the opinions of leading scientists of his day, and he had a high opinion of astronomy as he knew it. He maintained that there were three stages in the development of a science, the theological, the metaphysical, and the positive, and he considered the science of astronomy to have been the first—except for pure mathematics—to reach the final stage (Martineau, 1853: 32, 56). Unlike terrestrial sciences, astronomy was limited by what could be deduced by the use of the sense of Sight (capitalization in the English version of his philosophy) and it is hardly surprising that he should, in the 1830s, have supposed that the internal constitution of the stars must be forever beyond our powers of discovery. Astronomers themselves have not always been very prescient about what can or cannot be known: Kragh (2004: 20) also reminds us that, as late as 1906, even Simon Newcomb thought that the human race would never be able to know whether or not there were other galaxies besides our own Milky Way

The best source in English for what Comte actually said is Harriet Martineau (1853). Her freely translated and condensed version of Comte's original work appeared in his lifetime and had his approval. She wrote:

> Whatever knowledge is obtainable by means of the sense of Sight, we may hope to attain with regard to the stars, whether we at present see the method or not; and whatever knowledge requires the aid of other senses, we must at once exclude from our expectation, in spite of any appearances to the contrary. As to questions about which we are uncertain whether they finally depend on Sight or not, -- we must patiently wait for an ascertainment of their character, before we can settle whether they are applicable to the stars or not. The only case in which this rule will be pronounced too severe is that of questions of temperatures. The mathematical thermology created by Fourier may tempt us to hope that, as he has estimated the temperature of the space in which we move, we may in time ascertain the mean temperature of the heavenly bodies: but I regard this order of facts as for ever excluded from our recognition. We can never learn their internal constitution, nor, in regard to some of them, how heat is absorbed by their atmosphere. Newton's attempt to estimate the temperature of the comet of 1680 at its perihelion could accomplish nothing more, even with the science of our day, than show what would be the temperature of our globe in the circumstances of that comet. We may therefore define Astronomy as the science by which we discover the laws of geometrical and mechanical phenomena presented by the heavenly bodies.
>
> It is desirable to add a limitation which is important, though not of primary necessity. The part of the science which we command from what we might call the Solar point of view is distinct, and evidently capable of being made complete and satisfactory; while that which is regarded from the Universal point of view is in its infancy to us now, and must ever be illimitable to our successors of the remotest generations. Men will never compass in their conceptions the whole of the stars. The difference is very striking now to us who find a perfect knowledge of the solar system at our command, while we have not obtained the first and most simple element in sidereal astronomy – the determination of the stellar intervals.[1] Whatever may be the ultimate progress of our knowledge in certain portions of the larger field, it will leave us always at an immeasurable distance from understanding the universe. (Martineau, 1853: 148–149).

However wrong Comte may have been about our inability to probe the internal constitution of the stars, that final sentence still rings true, despite all our advances in cosmology! Experience shows that solving today's problems in cosmology only brings to light new problems for us to tackle. Comte's later thinking developed his system almost into a substitute religion, causing T.H. Huxley (1889: 70) to remark that he desired "… to leave to the Comtists the entire monopoly of the manufacture of imitation ecclesiasticism." The underlying principles of Comte's positivism remained influential, however, even after his death and were very similar to many found in the philosophy of Ernst Mach. Through the latter, they were transmitted to the Vienna Circle and, as *logical positivism*, continued to influence both philosophers and scientists well into the twentieth century.

2 ERNST MACH

If it is ironic that Comte is remembered by scientists mainly for his false limitation on our knowledge of the stars, it is even more so that Ernst Mach (1838–1916; Figure 2) is remembered by non-scientists only because his work on shock waves led to the use of his name as the unit of speed in supersonic aeronautics, and by scientists primarily for 'Mach's Principle' (which he never enunciated) and his apparently-stubborn refusal to acknowledge the reality of atoms, even though he lived to see the work of Rutherford on the atomic nucleus and Bohr's model of the hydrogen atom with its explanation of the emission spectrum of hydrogen.

In fact, Mach made many contributions not only to physics, but also to the newly-emerging science of psychology, and to the history and philosophy of science—he may almost be said to have invented that latter discipline. A thorough biography and account of his work and philosophy has been published by Blackmore (1972).

Mach is often described as a positivist; he did not use that term of himself, but neither did he reject it when others used it of him. There are certainly similarities between Mach's ideas and Comte's, particularly their joint insistence on the priority of sense-data. Mach (1905: 72) also quoted with approval Comte's notion of the three stages of science, and seems to have agreed with him that astronomy and mathematics were the sciences that had advanced closest to the final stage.

For Mach, sensations, or 'elements' as he preferred to call them, *were* reality, and the business of science was to relate sensations to each other as economically as possible, and preferably by mathematical equations. From this point of view, atoms *could not* be real, although Mach was prepared to grant that it might be helpful to think in terms of atoms until the true relationship between various sensations could be found. This attitude to atomism may be the reason that Mach has been largely neglected. In his lifetime he was much respected and extremely influential, especially through his many books.

As a young man, in his twenties, he did, for a short time, accept the reality of atoms, as he admits in his book *Erkenntnis und Irrtum* (Mach, 1905: 329). As he developed his philosophy (although he was reluctant to call it that) he came to believe that he had been mistaken. Individual atoms could not be observed—at least in his lifetime—and therefore, he argued, could not be regarded as real. Already, when he wrote that book, Joseph John Thomson (1856–1940) had discovered the electron a decade previously, and Ernest Rutherford (1871–1937) had moved to Manchester, where, with his associates, he began his most important work on the atomic nucleus.

Mach's progress was against the trend set by most nineteenth-century scientists. Although John Dalton (1766–1844) had published a version of atomic theory in 1808, it was by no means immediately generally accepted. By the time of Thomson's discovery of the electron, however, the reality of atoms was increasingly being accepted by physicists and Einstein's (1905a) paper on Brownian motion convinced all but the most resolute sceptics that molecules, at least, were real. After Rutherford's results and Niels Bohr (1886–1962) developed his model of the atomic nucleus, Mach was almost alone in maintaining that, at best, atoms could be regarded as useful models until a better explanation of the phenomena was found. Yet he continued to exert an influence, as indicated by the following excerpt from a letter to him from Albert Einstein (1879–1955):

> You have had such an influence on the epistemological conceptions of the younger physical generation, that even your current opponents, such as Herr Planck for example, would be considered "Machists" by physicists holding the views of most physicists of some decades ago. (cited in Blackmore, 1972: 223).

During the nineteenth century, James Clerk Maxwell (1831–1879), Lord Kelvin (1824–1907), Hermann von Helmholtz (1821–1894) and Ludwig Boltzmann (1844–1906) were developing the kinetic theory of heat, which identified heat with the kinetic energy of atoms or molecules. Mach, who made contributions of his own to thermodynamics, continued to maintain that atoms were at best explanatory models that ultimately would be found unnecessary. It is understandable that Mach, with his belief that sensations were reality, should be sceptical of a theory that explained the sensation of heat as the result of the motions of a vast number of hypothetical particles, for which there was very little observational evidence at the time and which then certainly could not be observed directly.

We belong to a generation that was taught the kinetic theory of heat as established fact and, probably, few if any of us doubt it. Nevertheless, I suspect that if we were called upon to explain to a non-scientific friend how the vibrations of atoms in a solid body could convey to our own bodies the sensation of warmth, let alone in extreme cases, the burning of our flesh, most of us would be hard put to do so convincingly. All the same, it is harder to understand why Mach continued to resist the reality of atoms after the experiments of Rutherford, and Bohr's (1913) theoretical explanation of the hydrogen spectrum.

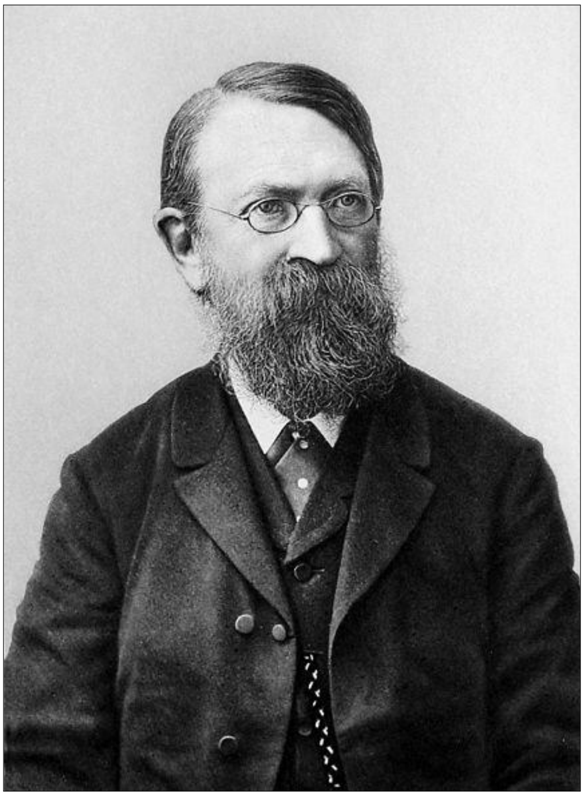

Figure 2: An photograph of Ernst Mach made prior to 1902 (after *Zeitschrift für Physikalische Chemie*, 1902).

There has been some speculation that Mach did indeed change his mind towards the end of his life, and this is discussed by Blackmore in an Appendix (pp. 319–323) to the work already cited. Apparently, Mach was shown scintillations caused by individual alpha particles (helium nuclei) and was reported to have said that he now believed in atoms. Blackmore concludes, however, that there was no conversion, and offers several quotations from Mach's later years to support his conclusion. The latest, written in 1915 a year before Mach's death, and two years after the publication of Bohr's paper, seems to me conclusive:

> I do not consider the Newtonian principles as completed and perfect; yet in my old age, I can accept the theory of relativity just as little as I can accept the existence of atoms and other such dogma.

Interestingly, Mach appears to have had no trouble accepting Clerk Maxwell's theory of electromagnetism, which also was controversial when first published until Hertz discovered radio waves. Mach (1905) was convinced of the wave theory of light, and in *Erkenntnis und Irrtum* presents it as the final word on the nature of light. He does not so much as mention Planck's quantum of action (discovered in 1900) or (even in the 1906 edition) Einstein's (1905b) famous paper on light quanta. Mach's openness to the wave

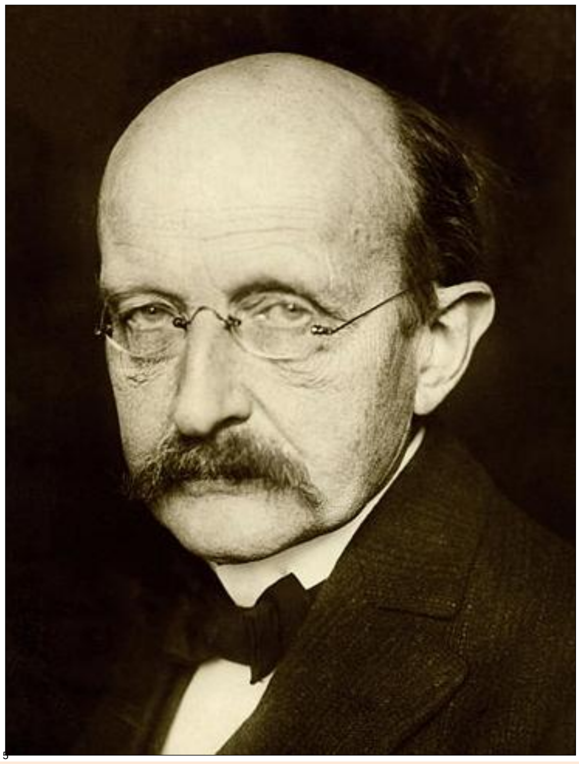

Figure 3: Max Planck in 1933 (en.wikipedia.org).

theory of light leaves one wondering if, had he lived to see Schrödinger's development of wave mechanics, he might have hailed that as a step towards a more realistic description of what we now regard as sub-atomic phenomena. Had he been granted another thirty years of life, Mach would have witnessed the explosions over Hiroshima and Nagasaki; in a sense, they exploded his philosophy of science too.

It would be a mistake, however, to discount that philosophy altogether. One does not have to share it to admire the thought and the erudition that went into its construction, and it was influential well beyond Mach's lifetime. The 'Vienna Circle', that flourished between the two world wars, originally called itself the *Ernst Mach Verein* and developed his ideas into logical positivism, introducing the notion that statements that could not be verified empirically were meaningless, and influencing the thinking of many scientists until well into the twentieth century. It was in reaction to this that Karl Popper (1959) placed emphasis on *falsifiability* as a criterion of a scientific theory, rather than *verifiability*, and this idea, too, is still influential today with many scientists.

3 MAX PLANCK

As a young man, Max Planck (1858–1947; Figure 3) was strongly influenced by Ernst Mach and, like him, was sceptical about the reality of atoms but came round to accepting their reality before his own discovery of what he later called 'the elementary quantum of action'. (Planck, 1949: 98). His early work was in thermodynamics and especially was concerned with the nature of entropy. It was at this stage of his life that he was most strongly influenced by Mach, and earned the disapproval of Boltzmann because of his disbelief in the reality of atoms—something that he regretted in later life, although he became reconciled with Boltzmann after his discovery.

B.R. Brown (2015: 115–124) gives the clearest account that I have read of Planck's reasoning and his own estimate of what he had achieved. The assumption that energy was quantized was 'purely formal', and he did not use the word "quantum" in 1900. Five years later, Einstein (1905b) developed Planck's thinking and postulated the light quantum, or photon. The well-known historian of science, Erwin Hiebert, as quoted by Blackmore (1972: 220), and Abraham Païs (1986: 193), however, point out that Planck was reluctant to accept that light could behave like a particle and only some years later fully accepted the physical reality of light quanta.

As Planck matured, however, and developed his own philosophy of science, he departed more and more from Mach's point of view, and became a realist, in the sense that he believed that scientists were investigating a real world that existed independently of human consciousness, but which we could never hope to understand completely. A referee has kindly drawn my attention to a quotation from a 1930 essay by Planck, reprinted in a book unavailable to me (Greenberg, 1990: 64), which makes this last point very clear:

> The physicist's ideal goal is knowledge of the real outside world; but his only research tool, his measurements, never tell him anything directly about the real world, but are always only a more or less uncertain message … a sign that the real world transmits to him and from which he then tries to draw conclusions, similar to a linguist who must decode a document

> which comes from a culture completely unknown to him.

Planck (1932: 82–83) returned to the theme in a collection of essays published in English under the title *Where is Science Going?* where he wrote:

> Now there are two theorems that form together the cardinal hinge on which the whole structure of physical science turns. These theorems are: (1) *There is a real outer world which exists independently of our act of knowing*, and, (2) *The real outer world is not directly knowable*. (Planck, 1932: 82–83; his italics).

This is followed at the bottom of page 83 by:

> But if physical science is never to come to an exhaustive knowledge of its object, then does not this seem like reducing all science to a meaningless activity? Not at all. For it is just this striving forward that brings us to the fruits that are always falling into our hands and which are the unfailing sign that we are on the right road and ever and ever drawing nearer to our journey's end. But that journey's end will never be reached, because it is always the still far thing that glimmers in the distance and is unattainable. It is not the possession of truth, but the success which attends the seeking after it, that enriches the seeker and brings happiness to him.

Planck, therefore, departed from positivism and from Mach, whom he regarded as the leading exponent of that philosophy in late nineteenth-century Germany and Austria. In 1908, he gave a lecture that ended with a personal attack on Mach, who soon replied. Planck returned to the fray in 1910 with a still more personal attack. Planck's strident tone, for which he has been criticized, may partly be explained by the fact that this was just the time when, according to Hiebert and Païs, Planck was wrestling with his own views on the reality of photons and, as Brown (2015) points out, it was also close to the death of his first wife. A fuller account of this episode, including some of the criticisms levelled against Planck and references to the original sources, is given by Blackmore (1972: 223–226). Planck's real target was positivism, of which Mach happened to be the representative. Einstein's letter about Mach's lasting influence on physicists, quoted above, was written in the context of this debate between Planck and Mach. Later, Einstein's own philosophical position moved much closer to Planck's than to Mach's, although he still retained his respect for the latter.

Brown (2015) makes the point that the development of the Copenhagen interpretation of the quantum theory seemed to Planck to be a return to Mach's positivism, as does Planck's other biographer, J.L. Heilbron (1986). Mach, at least as Planck understood him, denied the existence of a real external world, while Planck, for his part, developed the ideas in the first quotation above to distinguish three worlds, or perhaps better, a threefold division of the world into the world of the senses, the real world, and the world of the physicist. We shall encounter a theme very like that in the next section.

Planck was also much interested in the fundamental constants of nature. In a paper published in his *Scientific Autobiography* (Planck, 1949: 168*ff*.) Planck discusses the masses and charges of elementary particles, and, earlier in the book (on page 98) the velocity of light and his 'elementary quantum of action', which all the rest of us know as 'Planck's constant'. Positivists, he argues, do not like these universal constants since they are evidence for the real outer world which exists independently of our act of knowing. Indeed, one of Mach's objections to the theory of relativity was the postulate that the velocity of light is the same for all observers, whatever their relative motions may be. For Planck, the existence of fundamental constants of nature shows that the philosophy of positivism is false. His concern with these fundamental constants is one of many ideas that, as we shall see, he shared with A.S. Eddington.

It is, however, surely something of an oversimplification to say that Mach denied the existence of an external world. While, as mentioned above, 'Mach's principle' was not enunciated by Mach himself, he did discuss the possibility of relating motions to the fixed stars, which presumably confers some sort of reality behind the optical sensations that most of us interpret as arising from the external Universe

4 ARTHUR STANLEY EDDINGTON

Eddington (1882–1944; Figure 4) was a generation younger than Planck, as Planck was than Mach. There were many points of similarity between Eddington's thinking and Mach's, possibly indicating that the latter had considerable influence on Eddington, just as he had had on Planck. Kragh (2004) discusses the influence of positivism on the thinking of both Jeans and Eddington, although, somewhat surprisingly, Stanley (2007), in his important study of Eddington's life and work, does not refer either to positivism or to Mach, and his sole reference to Comte is to the dictum with which I opened this discussion.

Eddington's insistence that all we know directly are our sense impressions and internal thoughts could have been taken straight from Mach's *Erkenntnis und Irrtum*, although that work was not available in English during Eddington's lifetime. Several of Mach's works were available in translation, however, even during Eddington's student years, and he was certainly familiar with some aspects of Mach's thought. In one of his books, *Space, Time and Gravitation: An Outline* *of General Relativity Theory* (Eddington, 1920: Chapter 10), Mach is discussed in the context of what we now call 'Mach's Principle' but, apart from that, the names of Mach and Comte, or the term 'positivism', do not appear in the indices of any of Eddington's semi-philosophical works.

Eddington's (1928: 252) statement that all our knowledge of the physical world reduces to pointer readings was anticipated by Mach, who recognized that instruments both give our sensations more precise quantitative values and extend the range of sensation to, for example, infrared or ultraviolet radiations, that we cannot see directly. Nowadays, of course, we would substitute digital read-outs for pointer readings, but that implies no change of principle. Mach, who understood the necessary interaction between theory and observation, might even have agreed with Eddington's (1935: 211) statement that, while most physicists distrusted a theory that was not supported by observation, one should also be wary of accepting observations that were not supported by theory. There are even germs of Eddington's (1939: 16–27) 'selective subjectivism' in the final chapter of *Erkenntnis und Irrtum.* Finally, Eddington's (1928: 291) famous definition of the electron as "... something unknown is doing we don't know what ..." might well have been hailed by the older man, had he lived to read it, as justification for his scepticism about the physical reality of atoms.

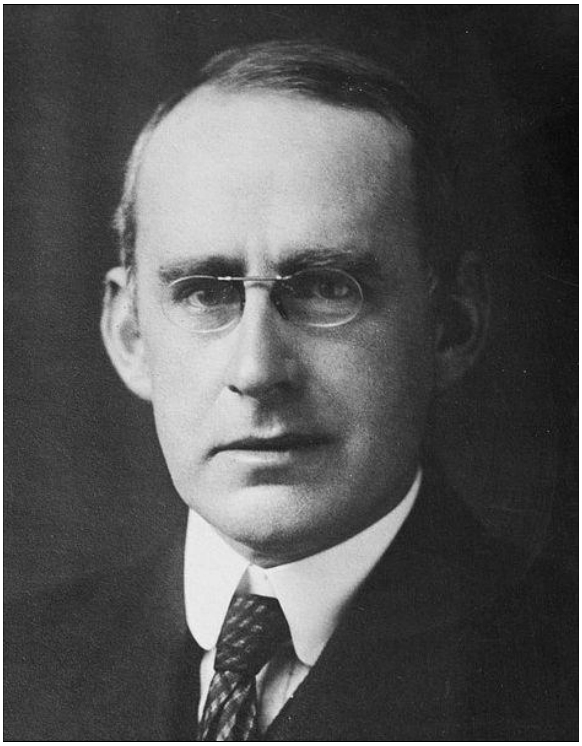

Figure 4: A.S. Eddington (en.wikipedia.org).

Undoubtedly positivism, the most popular philosophy of science in Eddington's lifetime, had its effects on his thinking, yet he was *not* a positivist; his Quaker mysticism did not accord well with the atheism of both Comte and Mach. Moreover, like Planck, Eddington was a realist in that he believed that the physical world was part of an objective reality, even though he thought there were very definite limitations to what we could know about it. Eddington held Planck in high regard, although it is unclear if they ever met, and there are also parallels between the thinking of those two, which perhaps are more important than those between Eddington and Mach.

For example, as just mentioned, like Planck, Eddington believed that scientists were investigating a real external world, but, also like Planck, he was aware of the difficulty of defining just what 'reality' is. This, it seems to me, is the real point of the introduction to *The Nature of the Physical World* (Eddington, 1928: xi) in which Eddington describes his two tables: the ordinary everyday table, with which we are all familiar, that provided a firm surface for his writing paper, and the 'scientific table' composed of atoms whose vibrations supported the paper rather as a swarm of bees might do. This illustration invited the criticism of the philosopher Susan Stebbing (1937: 54–60) who thought it quite misleading. Her criticism was based on the assumption that Eddington really believed that there were *two* tables. I do not read him so: rather, I think he was challenging his readers to question which one of these two descriptions of the table were closer to reality or, to use a Kantian phrase with which Mach dispensed, to the *ding an sich*. Planck (1932: 69) also adopted the imagery of a swarm of atoms supporting the paper on his desk and on pages 92 and 97 of the same book there are passages on the mutual dependence of theory and observation that are reminiscent of Eddington's statement cited above about not trusting an observation unless it is supported by theory.

Eddington fully agreed with Planck that we could not hope to know the external world completely, and he wrote:

> We seek the truth; but if some voice told us that a few years more would see the end of our journey, that the clouds of uncertainty would be dispersed, and that we should perceive the whole truth about the physical universe, the tidings would be by no means joyful. In science as in religion the truth shines ahead as a beacon showing us the path; we do not ask to attain it; it is better far that we be permitted to seek. (Eddington, 1929: 16).

The parallel between Eddington's "... beacon showing us the path ..." and Planck's "... still far thing that glimmers in the distance and is unattainable ..." is striking. Did these two men hit on similar metaphors, or did one copy the other? Since Eddington's book was published first it would have been Planck who copied, if copying there was; but it does not matter whether there was copying or independent choice of the metaphor. Either way, the two men, each of profound physical insight, were thinking in a similar fashion. Both men saw science as an endless quest: neither would have agreed with Horgan (1996) that all the best and most fundamental scientific discoveries have now been made. Planck (1932: 82), a mountaineer, used the metaphor of reaching a hilltop only to find still more hills ahead of us.

In addition, Planck, almost certainly, and Eddington, quite possibly, were influenced by the eighteenth-century German writer, Gotthold Ephraim Lessing (1729–1781), in their insistence that seeking the truth is more rewarding than possessing it. Lessing (1778) wrote:

> It is not in the possession of truth, which a person holds, or claims to hold, that the value of human beings lie, but rather in the sincere effort which they have applied to get behind it. It is not possession of the Truth, but rather the pursuit of Truth by which they extend their powers and in which their ever-growing perfection consists.

In an Eddington Memorial Lecture, the British physicist and philosopher Herbert Dingle (1890–1978) discussed Eddington's realism, which he regarded as a relic of Victorian thinking (Dingle, 1954). Eddington, he believed, could not break free from this 'Victorian' conception that scientists, and in particular physicists, were investigating a real external world. Dingle believed that the theory of relativity had made it impossible to believe that physicists were in fact investigating the external world. He wrote:

> In other words, the scientific problem, as seen by the Victorians, is reversed. Instead of starting with a given, unknown world and finding out its nature and character by observation, we start with observations and construct (or infer, if you prefer the word) a world to satisfy them. (Dingle, 1954: 12–13).

Dingle is in fact advocating here a point of view very similar to Mach's who, after all at least in point of time, was a 'Victorian', but his argument that the theory of relativity had made it impossible to believe that physicists were investigating a world that existed independently of human consciousness is questionable. Even Einstein himself believed he was investigating a real world and Planck (1932: 198), whom Dingle does not mention in his lecture, explicitly denied that the theory of relativity had got "... rid of the absolute." On pp. 17*f*, Dingle went on to summarize Eddington's position, reasonably fairly, as one in a belief in three worlds, or at least, as with Planck, a threefold division of the world. There is the real, or as Dingle termed it, the *external* world, which we wish to study, parts of which we can study by metric methods, and the results of these methods give us the world of the physicist which in some way symbolizes the *structure* of the external world. Meanwhile, non-metrical studies, such as art and religious experience, showed us a *spiritual* world comprising other aspects of the external world. Here again it seems that Planck and Eddington were thinking quite independently and yet reaching very similar conclusions (see the previous Section).

Dingle, however, saw Eddington's three-fold division as a rather tortured attempt to reconcile the developments in physics of the early twentieth century with the notion (which, as we have seen, Dingle believed to be untenable) that physicists were investigating a real external world. As already mentioned, Dingle's own philosophy of science appears to have been Machist: his statement (Dingle 1954: 12) that post-relativistic physics is "... a description of the relations existing between the results of certain operations ..." would have won Mach's full approval, as would the phrase on pages 37–38 defining science as "… the rational correlation of experience." Perhaps Dingle's own tendencies to Machism were a factor in his strenuous attacks, only a few years after this lecture, on the theory of relativity, which Mach had not accepted. If so, it is an inconsistency in his own thinking that he should turn on the very theory that seemed to him to lead directly to Mach's brand of positivism. It is also curious that Dingle sees the belief that physics is a description of a real external world as 'Victorian'. Perhaps it was in Britain, but in Germany Mach's positivism prevailed for much of the nineteenth century and Planck came to what Dingle called the 'Victorian' belief by rebelling against Mach.

Perhaps the most important agreement between Planck and Eddington, however, and where they each diverge from Mach, is in their interest in the fundamental constants of nature. Eddington is famous (or notorious—depending on your own views) for his belief that the values of these constants could be deduced by pure reasoning, without empirical input. Such a notion, of course, would have been anathema to Mach and would probably not have been accepted by Planck. In recent decades the study of these constants has become of great interest in the discussion of the so-called 'fine-tuning' of the Universe, to which I shall return in the next Section, even to those who do not subscribe to Eddington's beliefs.

There is another important matter, however, in which Planck and Eddington found themselves on opposite sides, and that is the question of whether or not the Universe is deterministic at the level of sub-atomic particles. Planck, like Einstein, believed that there must be deterministic laws underlying the apparent indeterminacy of quantum physics. As we have seen, Planck was troubled by Heisenberg's (1927) uncertainty principle. Eddington believed that the behaviour of sub-atomic particles was truly unpredictable. He even ventured to speculate that that indeterminacy provided an opening for human free-will. Planck (1932) devoted two whole chapters to the question of physical causation and free-will and came to the qualified conclusion that, if we knew all the influences acting on us, we could predict the behaviour of others, but that we do not yet have sufficient knowledge to do so. Moreover, since we could not analyze our own behaviour without interfering with it, we felt ourselves to have free will even though we do not. Here, he was closer to Mach (1905: 45), who believed that our will, as a "... special mental power ..." does not exist, and

> The will consists in subordinating less important or only temporarily important reflex actions to the processes that have a leading role in the functioning of life …

Eddington and Planck also shared an interest in the relations of science and religion and both wrote and lectured on the topic. Planck was active in the Lutheran Church throughout his life, although his beliefs were hardly orthodox. Like Einstein, he denied a belief in a personal God and yet he certainly believed in a creator of some kind. Eddington was an observant Quaker and explicitly endorsed the concept of a personal God (Eddington, 1929: 49–50) but, in practice, there may not have been all that much difference between Planck's deism and Eddington's mysticism.

5 THE COLLAPSE OF POSITIVISM?

The title of this section is inspired by a book by Michael Heller (1996), an English translation of a book originally published in Polish four years earlier. The biologist Peter Medawar (1984: 66) also referred to positivism as "dated". Heller seemed confident that positivism had begun to collapse early in the 1970s, although he conceded that its attitudes would linger on in the minds of many scientists. Also, commenting on the search for a so-called "... theory of everything ..." he showed considerable prescience with the following remark:

> I wish … to draw attention to the fact that, in my opinion, in the not too distant future this will be an attractive theme for various anti-religious ideologies. (Heller, 1996: 71–72).

It is of interest that Heller considers that the first signs of the collapse of positivism appeared in the early 1970s. This was when interest in the fundamental constants of nature was revived in the astronomical community and Brandon Carter's (1972) paper appeared, which promoted the 'anthropic principle'. As we have seen, positivists tended to resist the idea of universal constants, at least so Planck argued. Carter's contribution was to point out that the relationships these constants bear to one another created the conditions in which our kind of life could appear and flourish. Moreover, those ratios are very tightly constrained indeed if carbon-based intelligent life is to appear in the Universe.

There seem to be two possible explanations: either the Universe was deliberately created by some omnipotent power in order that intelligent and morally self-aware life should appear, or there is a vast number of Universes (composing a so-called 'Multiverse') so that by chance there would inevitably be at least one in which such life would appear. Neither solution would have been very palatable to Mach. His atheism would not have commended the first to him, and someone who throughout almost his whole life had opposed the idea that atoms had a real existence, despite the slowly-accumulating evidence for them that he witnessed, would hardly believe in the existence of many 'Universes' that were certainly unobservable in his lifetime and for which we still have no clear observational evidence. Nevertheless, had he come to accept the significance of universal constants, he would have had a way out of the dilemma: another aspect of his philosophy was monism. He believed that the Universe is One (Bradley 1971: 158). Since we are a part of the One, the Universe must necessarily have the properties that enable us to exist. As to *why* the One has those properties and includes us, that probably is a matter on which Mach would have declined to speculate.

There is an interesting strand running through the thought of all four of the men discussed in this paper: the limitations on human knowledge. Comte may have been wrong about what he thought we could never know, which included not only the physical nature of the stars but the whole of modern cosmology; at least he was modest enough to suppose that there *were* limits on what we could know. Mach did not express that idea quite so explicitly, but he limited reality and, therefore, what we could hope to know to our bodily sensations and the relations between them. Ideas like the Multiverse, and possibly even 'dark matter' and 'dark energy', he would have dismissed as hopelessly unscientific. Planck and Eddington, although they believed that they were investigating a real physical Universe, agreed that we would never be able fully to understand it.

Peter Medawar (1915–1987), a generation younger than Eddington and a generation older than my own contemporaries, also shared a belief in the limits of science, but he did not think that this any way derogated from science. Science, he argued (Medawar, 1984), was designed to answer questions of a certain sort and there are no limits to the number of questions of that sort or to the ability of science to answer them; Planck's metaphor of the hilltops would have won his full approval. On the other hand, Medawar believed that there were questions, the ultimate questions about the meaning of life and the Universe and the beginning of the Universe, which science *could not* answer.

There is a different spirit abroad amongst at least some scientists of our time. Krauss (2012), for example, believes that it is the business of science to find a naturalistic explanation for everything, including the origin of the Universe itself. Historically that belief was not shared by most of the people we look on as the founders of modern science, and there are still many scientists who would not subscribe to it, but Krauss is representative of a considerable number of modern scientists. He tackles the Big Question: why is there something rather than nothing? He favours the Multiverse solution to the dilemma outlined above, and argues that this ensures that there will be at least one Universe in which the laws of quantum physics will be such as to permit the emergence of beings like us. I, personally, do not find his argument convincing, but the main point I wish to make here is that those who argue like him are creating a new view of the nature and scope of science. That may not be wrong in itself; after all, Comte, Mach, and their successors the logical positivists created a new view of science that was certainly different from the views of Galileo, Newton and Boyle, to name a few. Heller may or may not be correct that positivism has collapsed in our own time; he was certainly prescient to see how the search for a "theory of everything" would affect the science-religion debate, for it is precisely that search that leads to the claims of those who think like Krauss.

Einstein, too, was correct when he wrote to Mach that his influence had been so pervasive, that even those who attacked him were in some sense 'Machists', but we seem to have reached a time in which even that influence has begun to wane. Of course Comte and Mach were right to insist on the importance of sense-data as both the starting point and the test of scientific theories: in that limited sense all scientists must be positivists. The positivist view of the nature of science may well have been incorrect, but it avoided Airy's "... mere fanciful abstractions of science ..." and acknowledged the limitations on our human ability to understand this Universe of which we are a very small part. Planck was perhaps thinking of a distinction similar to that made by Medawar when he argued, during a conversation with Einstein that

> Science cannot solve the ultimate mystery of nature. And that is because, in the last analysis, we ourselves are part of nature and therefore part of the mystery that we are trying to solve. (cited by Planck, 1932: 217).

That remark remains a useful warning against the *hubris* of supposing that the methods of science can lead to a final understanding of life, the Universe, and everything.

6 NOTES

1. I assume that what is meant here is *stellar distances*, which were indeed unknown when Comte first wrote.

7 ACKNOWLEDGMENTS

I am grateful to John Leslie for useful comments on an earlier draft of this paper, to Michael Hadley for drawing my attention to the probable influence of Lessing and providing the translation, and to two anonymous referees for helpful suggestions.

8 REFERENCES

Airy, G.B., 1848. Schreiben des Herrn Airy Königl. Astronomen in Greenwich, an den Herausgeber. *Astronomische Nachrichten*, 26, 353–360.

Blackmore, J.T., 1972. *Ernst Mach: His Work, Life, and Influence.* Berkeley, University of California Press.

Bohr, N., 1913. On the constitution of atoms and molecules Part I. *Philosophical Magazine*, 26, 172–198.

Bradley, J., 1971. *Mach's Philosophy of Science*. London, Athlone Press.

Brown, B.R., 2015. *Planck: Driven by Vision, Broken by War*. Oxford, Oxford University Press.

Carter, B.W., 1972. Large number coincidences and the anthropic principle in cosmology. In Longair, M.S. (ed.). *Confrontation of Cosmological Theories with Observational Data*. Dordrecht, Reidel. Pp. 291–298.

Dalton, J., 1808. *A New System of Chemical Philosophy*. Reprinted with an introduction by Alexander Joseph, Philosophical Library, New York (1964).

Dingle, H., 1954. *The Sources of Eddington's Philosophy*. Cambridge, Cambridge University Press.

Eddington, A.S., 1920. *Space, Time and Gravitation: An Outline of General Relativity Theory*. Cambridge, Cambridge University Press.

Eddington, A.S., 1928. *The Nature of the Physical World*. Cambridge, Cambridge University Press.

Eddington, A.S., 1929. *Science and the Unseen World*. London Allen and Unwin.

Eddington, A.S., 1935. *New Pathways in Science*. Cambridge, Cambridge University Press.

Eddington, A.S., 1939. *The Philosophy of Physical Science*. Cambridge, Cambridge University Press.

Einstein, A., 1905a. Ueber die von der molekularkinetischen Theorie der Warme gefordete Bewegung in ruhenden Flüssigkeiten suspendierten Teilchen. *Annalen der Physik*, 17, 549–560.

Einstein, A., 1905b. Ueber einen der Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Standpunkt. *Annalen der Physik*, 17, 132–140.

Greenberg, V., 1990. *Transgressive Readings: The Texts of Franz Kafka and Max Planck*. Milwaukee, University of Michigan Press.

Heilbron, J.L., 1986. *The Dilemmas of an Upright Man: Max Planck as a Spokesman for German Science*. Berkeley, University of California Press.

Heisenberg, W., 1927. Ueber den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. *Zeitschrift für Physik*, 43, 172–198.

Heller, M., 1996. *The New Physics and a New Theology*. Translation by G. Coyne, S. Giovannini, S., and T.M. Sierotowicz of a book published in Polish four years earlier. Vatican Observatory publications. (distributed by University of Notre Dame Press Notre Dame, Indiana).

Horgan, J., 1996. *The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age*. Reading (Mass.), Addison-Wesley (reprinted by Broadway Books, New York).

Huxley, T.H., 1889. *On Agnosticism*. Reprinted in Castell, A. (ed.), 1948. *Thomas Henry Huxley: Selections from the Essays*. Northbrook, AHM Publishing Corporation (Croft's Classics).

Kragh, H., 2004. *Matter and Spirit in the Universe: Scientific and Religious Preludes to Modern Cosmology*. London, Imperial College Press.

Krauss, L.M., 2012. *A Universe from Nothing: Why There is Something Rather than Nothing*. New York, Free Press.

Lessing, G.E., 1778. *Anti-Goetze: Eine Duplik*. Braunschweig. Reprinted in Göpfert, H.G. (ed.), 1979. *Werke*. *Bd. VIII*. München, Carl Hanser Verlag. Pp. 32–33.

Mach, E., 1905. *Erkenntnis und Irrtum*. Leipzig, Johann Ambrosius Barth. [Page references in the text are to the English translation by T.J. McCormack and P. Foulkes of the 5th (1926) edition, published in 1976 as *Knowledge and Error*. Dordrecht, Reidel.]

Martineau, H., 1853. *The Positive Philosophy of Auguste Comte Freely Translated and Condensed by Harriet Martineau*, London, J. Chapman. [A later edition published in 1896 by George Bell and Sons, London, and reprinted by Batoche Books in 2000, is available on line. Page numbers in the text refer to that edition.]

Medawar, P. B., 1984. *The Limits of Science*. Oxford, Oxford University Press.

Païs, A., 1986. *Inward Bound*. Oxford, Oxford University Press.

Planck, M. 1932. *Where is Science Going?*. English translation by James Murphy, W.W. Norton & Co. Inc., New York.

Planck, M., 1949. *Scientific Autobiography and Other Papers*. English translation by Frank Gaynor of *Wissenschaftliche Selbstbiographie* (1948) and some other papers by Philosophical Library, New York.

Popper, K.R., 1959. *The Logic of Scientific Discovery*, English translation of *Logik der Forschung*, Vienna, 1934) London, Hutchinson & Co. Reprinted by Harper and Row, New York (1968).

Stanley, M., 2007. *Practical Mystic: Religion, Science, and A.S. Eddington*. Chicago, University of Chicago Press.

Stebbing, L.S., 1937. *Philosophy and the Physicists*. London, Methuen (also in Dover reprints, 1958).

Zeitschrift für Physikalische Chemie, 40 (1902).

Alan H. Batten spent his active career at the Dominion Astrophysical Observatory in Victoria, B.C.,

Canada, where he studied spectroscopic binary systems. He served as a Vice-President of the International Astronomical Union from 1985 to 1991 and is a member of the Editorial Board of this *Journal*. His latest book, *Our Enigmatic Universe*, was published in 2011.