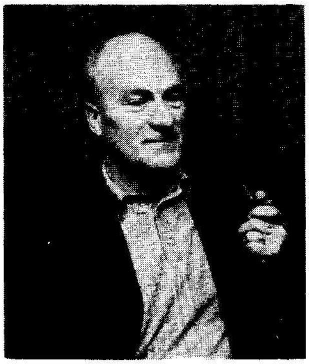
Reprinted from "Assessing Einstein's impact on today's science by citation analysis ," Einstein: The First Hundred Years:(Goldsmith, M., Mackay, A., Woudhuysen, J. eds) Pergamon Press, NY, p.31-40, 1980.

Assessing Einstein's impact on today's science by citation analysis

Tony Cawkell and Eugene Garfield



Tony Cawkell is vice-president, research, of the Institute for Scientific Information; he is based in Uxbridge, Middlesex, England. A fellow of the IERE and IEEE, he is actively engaged in various aspects of information science. He is a council member of the Institute of Information Scientists.

For nearly 30 years Dr Eugene Garfield has been concerned with making scientific and technical information accessible on an economic, timely basis. He is founder and president of the Institute for Scientific Information. Inventor of *Current Contents* and the *Science Citation Index,* he graduated in chemistry at Columbia and later returned there for a master's degree in library science. He was awarded his PhD in structural linguistics at the University of Pennsylvania. In recent years he helped establish the Information Industry Association, on which he has served as president and chairman of the board.

Citation analysis

A convenient way of identifying authors or articles which are likely to be of outstanding interest is to take note of those which are being heavily cited as shown in the *Science Citation Index* (*SCI*). An examination of the citing articles will reveal the nature of that interest or 'impact'.[1] After a period to allow for assimilation of the published material it is unlikely that any significant or controversial article will remain uncited. On the other hand, work which contributes substantially to the advancement of science will eventually become part of the fabric and then may be cited only rarely. Nobel prize winners such as Wilhelm Roentgen or Marie Curie are only occasionally cited today, usually in an historical context, but for some work carried out more than 50 years ago there are notable exceptions; for instance, there must be something extraordinary about the heavily cited works listed in Table 1. Of the 11 articles published before 1912, four are by Albert Einstein.

Table 1. The eleven articles,[2] published before 1912, cited most heavily between 1961 and 1975

Bibliographic details	Times cited
G. Mie, 'Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen', *Ann. Physik*, vol. 25, 1908, pp. 377–445.	521
W. M. Bayliss, 'On the local reactions of the arterial wall to changes of internal pressure', *J. Physiology*, vol. 28, pp. 220–31.	234
A. Einstein, 'Eine neue Bestimmung der Moleküldimensionen', *Ann. Physik*, vol. 19, 1906, pp. 289–306.	227
A. Einstein, 'Die von der molekularkinetischen Theorie der Wärme geförderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen', *Ann. Physik*, vol. 17, 1905, pp. 549–60.	206
H. H. Dale, 'On some physiological actions of ergot', *J. Physiology*, vol. 34, 1906, pp. 163–206.	181
A. Einstein, 'Berichtigung zu meiner Arbeit: Eine neue Bestimmung der Moleküldimensionen', *Ann. Physik*, vol. 34, 1911, pp. 591–2.	158
E. H. Starling, 'On the absorption of fluids from the connective tissue spaces', *J. Physiology*, vol. 19, 1896, pp. 312–26.	150
T. Purdie, and J. C. Irvine, 'The alkylation of sugars', *J. Chem. Soc.*, vol. 83, 1903, pp. 1021–37.	131
C. S. Hudson, 'The significance of certain numerical relations in the sugar group', *J. Amer. Chem. Soc.*, vol. 31, 1909, pp. 66–86.	105
G. N. Stewart, 'Researches on the circulation time and on the influences which affect it', *J. Physiology*, vol. 22, 1897, pp. 159–83.	105
A. Einstein, 'Theorie der Opaleszenz von homogenen Flüssigkeiten und Flüssigkeitsgemischen in der Nähe des kritischen Zustandes', *Ann. Physik*, vol. 33, 1910, pp. 1275–98.	103

The cited works of Einstein

To investigate the connections between a particular author's works and current scientific articles, select an annual *SCI* edition (or five year cumulation), look up the author, and scan down the chronologically ordered list of his works, stopping at the cited item of interest; beneath that item will be found a list of current citing articles. The most recent five-year cumulation covers 1970–74; under EINSTEIN A., each of his cited works is listed followed by those articles published between 1970 and 1974 which cited it. Einstein's entry is, to say the least of it, unusual,[3] but certain heavily cited papers stand out (see Table 2).

De Broglie[4] considers Einstein's major contributions to be as follows; the special and general theories of relativity; Brownian movement and statistical theories; development of quantum theory (from photo-electric research) for which he received the Nobel Prize in 1921, and developments in wave mechanics (the Bose–Einstein Statistics). De Broglie also describes Einstein's later preoccupation with the unified field theory; at an early point in his career[5] Einstein searched for a 'theory of principle from empirically observed general properties of phenomena'; later he became preoccupied with this theme and in 1935 attacked Heisenberg's uncertainty principle, an accepted doctrine, because he was unhappy about its incompleteness.

Because many of Einstein's papers are available in several versions Table 2 does not present all the information; moreover, today's authors, by patterns of citation to particular papers, group Einstein's ideas somewhat differently to de Broglie's arrangement. To provide a picture of Einstein's impact, as indicated by citations, we have consolidated all the available information into Table 3. Table 4 lists major works with the titles translated into English.

The impact of Einstein's works

To find out more about the nature of current scientific work we may take a consensus from the articles which cite Einstein.[6,7] For a first approximation we analysed the frequency of the title words of 'high information content' in the citing articles; words, word strings, or word phrases such as BROWNIAN, PHOTO/, and LIGHT SCATTERING are considered to be 'information rich'; words such as EXPERIMENTAL, DISCUSSION, OF, EFFECT and so on are ignored.

Table 2. The works of Einstein most heavily cited between 1970 and 1974

Bibliographic reference	Subject	Times cited
Ann. Phys., vol. 17, 1905, p. 132	Quantum theory	17
Ann. Phys., vol. 17, 1905, p. 549	Brownian movement	103
Ann. Phys,, vol. 17, 1905, p. 891	Special relativity	55
Ann. Phys., vol. 19, 1906, p. 289	Molecular dimensions	120
Ann. Phys., vol. 19, 1906, p. 371	Brownian movement	29
Ann. Phys., vol. 33, 1910, p. 1275	Theory of mixtures	58
Ann. Phys., vol. 34, 1911, p. 591	Molecular dimensions	95
Ann. Phys., vol. 49, 1916, p. 769	General theory relativity	30
Phys. Z., vol. 18, 1917, p. 121	Quantum theory	16
Meaning of relativity, 1950–6		87
Invest. theory Brownian movement, 1956		45

Table 3. The works of Einstein most heavily cited between 1970 and 1974, classified by subject

Subject	Cited works	Times cited
Special theory of relativity	*Ann. Phys.*, vol. 17, 1905, pp. 891–921; English translation, U. Calcutta, 1920. *Ann. Phys.*, vol. 18, 1905, pp. 639–41	56
General theory of relativity	*Ann. Phys.*, vol. 49, 1916, pp. 769–822; on its own, published by Barth, Leipzig, 1916; together with the special theory, pub. Vieweg, Braunschweig, editions for 1917–20. English popular trans., Methuen, editions for 1920–31. *Meaning of relativity*, U. Princeton, editions for 1921–23	175
Quantum theory	*Ann. Phys.*, vol. 17, 1905, pp. 132–48 *Phys. Z.*, vol. 18, 1917, pp. 121–8 *Phys. Rev.* vol. 47, 1935, pp. 777–80	98
Brownian movement; diffusion	*Ann. Phys.*, vol. 17, 1905, pp. 549–60 *Ann. Phys.*, vol. 19, 1906, pp. 371–81 *Ann. Phys.*, vol. 19, 1906, pp. 289–306 *Ann. Phys.*, vol. 34, 1911, pp. 591–2	147
Mixtures; light scattering	*Ann. Phys.*, vol. 33, 1910, pp. 1275–98	58

Table 4. Selected works of Albert Einstein (with translated titles)

1. 'On a heuristic viewpoint concerning the production and transformation of light', *Annalen der Physik*, vol. 17, 1905, pp. 132–48.
2. 'On the motion of small particles suspended in a stationary liquid according to the molecular kinetic theory of heat', *Annalen der Physik*, vol. 17, 1905, pp. 549–60.
3. 'On the electrodynamics of moving bodies', *Annalen der Physik*, vol. 17, 1905, pp. 891–921.
4. 'Does the inertia of a body depend on its energy content?', *Annalen der Physik*, vol. 18, 1905, pp. 639–41.
5. 'A new method of determining molecular dimensions', *Annalen der Physik*, vol. 19, 1906, pp. 289–306.
6. 'On the theory of Brownian movement', *Annalen der Physik*, 1906, vol. 19, pp. 371–81.
7. 'Theory of opalescence of homogeneous liquids and liquid mixtures in the neighbourhood of critical conditions', *Annalen der Physik*, vol. 33, 1910, pp. 1275–98.
8. 'Confirmation of my work; a new determination of molecular dimensions', *Annalen der Physik*, vol. 34, 1911, pp. 591–2.
9. 'Foundation of the general theory of relativity', *Annalen der Physik*, vol. 49, 1916, pp. 769–822.
10. *A popular exposition of the special and general theory of relativity*, Sammlung Vieweg, Braunschweig, 1917.
11. 'On the quantum theory of radiation', *Physikalische Zeitschrift*, vol. 18, 1917, pp. 121–8.
12. 'Can quantum-mechanical description of physical reality be complete?', with B. Podolsky and N. Rosen, *Physical Review*, vol. 47, 1935, pp. 777–80.

The result of analysing word frequencies from a random selection of 1974–77 citing articles is given in Table 5.

These results indicate that there is a definite subject connection between most cited and citing articles. The presence of the string /POLYM/ (as in COPOLYMER or POLYMERISE) is surprising; this seems to be because Einstein's work in this area has had some very 'practical' consequences, as has his work on light scattering which tends also to be cited in a 'practical' context. The earlier work has become the basis for a range of applications.

By contrast, the more esoteric nature of his work on relativity and quantum theory has prompted intense activity at the basic research fronts of physics and cosmology. In some aspects of this research – for instance, in the detection of gravity waves – Einstein's speculations still await verification, although some very recent research seems almost to provide it.[8]

Having used citations as indicators for assessing the degree of interest today in Einstein's work, we will now review the content of a selection of the current citing articles in order to be more specific.

Relativity

The heart of Einstein's four major papers is as follows. The first 1905 paper contained the hypothesis, subsequently confirmed by experiments, that the speed of light as measured by an observer is the same no matter what the speed of the light source with respect to him, provided that the source is moving at a uniform rate. At the same time Einstein disposed of Maxwell's ether. In the second 1905 paper 4 the equation $E = Mc^2$ is developed. In a 1911 paper, 'On the influence of gravitation on the propagation of light', *Ann. Phys.*, vol. 35,

Table 5. Frequencies of 'high information content' words in the titles of 1974–7 articles citing Einstein's works

Subject	Number of titles examined	'High information content' word	Frequency
Special relativity	25	RELATIV/	12
		EINSTEIN	5
General theory of relativity	20	GRAVIT/	8
		SUN; SOLAR	4
		GAUGE	4
Quantum theory	40	RADIA/	11
		PHOT/	9
		QUANT/	9
		STIMULATED EMISSION/; LASER/; MASER/	5
		EINSTEIN	5
		RELATIV/	4
Brownian movement; diffusion	40	PARTICLE/; POWDER/; BEAD/	12
		/POLYM/	9
		SOLUTION/; SUSPENSION/	9
		DIFFUS/	6
		BROWNIAN	5
Mixtures; light scattering	25	LIQUID/; FLUID/; SOLUTION/	10
		LIGHT SCATTERING	8
		/POLYM/	6

1911, pp. 898–900, the 'principle of equivalence' is introduced. Here Einstein argued that the effect of uniform constant acceleration on an observer was indistinguishable from, and so equivalent to, the observer being at rest but acted on by a uniform gravitational field.

In the 1916 paper on general relativity Einstein formulated equations describing the geometry of space-time. The new geometry provides for the geodesic (curved) propagation of light-rays in the presence of gravitational fields; in weak fields Newtonian laws remain very nearly correct, and the Einstein field equations include a 'stress energy tensor' term for dealing with the interaction between matter, space-time, and gravitation. Einstein also predicted the red-shift of starlight in the presence of gravitational fields. Later he added a 'cosmological term' to make his equations conform to the then existing idea of a static universe. Friedmann (1922) found that this term was superfluous for an expanding universe (a theory to be confirmed later by Hubble) and showed that Einstein's original equations had a solution for this situation. The flavour of current work directly based on these discoveries is easily conveyed. In a well-publicised 1972 paper[9] an experiment with round-the-world travelling clocks was said to have resolved the 'clock paradox' introduced by Einstein in the first 1905 paper. In 1978 it was claimed that Einstein had made a mistake, and that the 1972 experiment was inconclusive.[10] This claim in turn has been rebutted,[11] but the rebuttal has been rejected.[12] Another article[13] about space, time, and gravity, based upon the principle of equivalence, cites the 1911 paper in which Einstein discusses this idea; since it contains a lengthy discussion about the possible effects of inertial acceleration upon clocks, and continues with the field equations, it also cites a translated version of the 1916 paper. From a consideration of standard relativity theory, but especially from 'extended principle of equivalence' equations, the authors show that time-keeping by terrestrial clocks should be latitude-dependent because of the earth's rotation. By comparing the difference between the time-keeping of a number of caesium standard clocks at different latitudes to an accuracy of one part in 10^{15} (taking account of residual errors, gravitational red-shift, velocity, and acceleration), they conclude that inertial acceleration does offset ideal clock rates. The implications of this for international time-keeping are discussed.

Articles embodying current applications of Einstein's theories in particle physics,[14] cosmology[15] and mathematical concepts[16, 17] are numerous, of which those cited here are but a few examples; in one unusual article, Einstein's principle of equivalence is cited in the context of a discussion of direction-finding by hornets in search of food.[18] Current progress in the hunt for gravitational waves has also been discussed.[19] Here there is an exposition of Einstein's 1916 predictions; but in many current articles Einstein's contribution is considered to be so well known that the author only inserts a reference *en passant* following phrases like 'In recent years the problem of quantising non-Abelian gauge fields has received much attention'.

Finally, it is interesting to note that an author starting his article with the words 'Black holes are now the subject-matter of at least half the papers in general relativity' supplies only one *en passant* reference to Einstein attached to the phrase ' . . . so that the global hyperbolicity requirement is obeyed'.[20]

Quantum theory

Quantum theory is about the study of h – the position, path and velocity of wave packets or particles within prescribed limits of uncertainty. In the early years of the twentieth century interest was concentrated on black body radiation in the form of energy quanta or electromagnetic fields – according to Wien, Planck and Rayleigh. Einstein's first major paper explained the radiation of energy in terms of independent energy quanta and the release of electrons by the action of light, a much more precise explanation. This is the paper which Einstein called 'very revolutionary'. The apparent relationship of Einstein's equation ($e = hvn$) to Planck's work is misleading since the idea of a gas-particle-like radiation *was* truly revolutionary. In 1917 article, Einstein developed Planck's radiation formula further, introducing the concept of energy level transitions. This laid the foundation for the idea of the wave–particle duality of light,[21] leading to the work done in the late 'twenties by Pauli, Schrödinger, Dirac, Jordan, and Heisenberg, and to the development of modern quantum mechanics.[22,23]

The reason why some of today's articles citing Einstein's quantum theory contain the words STIMULATED EMISSION/, LASER and MASER (Table 5) is that his 1917 article 'enunciated the basic theory and was then largely ignored; the first successful device was operated in 1954'.[24] Precisely the same comment is made by Arthur Schawlow,[25] colleague of C. H. Townes – inventor of the maser, and optical maser (laser) pioneer. Einstein's first paper is considered to be the major step towards the huge amount of work which followed later in the century on photo-emission from metal surfaces.[26]

Controversies in quantum mechanics are still going strong. Einstein's 1935 paper and an article by Freedman[27] were co-cited by 10 papers published in 1977. Freedman took issue with Einstein's ideas about underlying deterministic structures; later authors cite both papers in the course of developing their arguments about the conflicting viewpoints.

Some mention should be made here of the Bose–Einstein Statistics; they are usually considered to be an aspect of quantum theory. S. M. Bose published an article in *Z. Phys.*, 1924 about a way of counting the possible states of light quanta that gave support to Planck's theories. Einstein applied this idea to counting particles of an ideal gas because of his deep conviction about the analogy between light and matter (A. Einstein, *Sitzungsber. Preuss. Akad. Wiss.*, Berlin, vol. 22, 1924, p. 261). Evidently these statistics are important today for understanding the behaviour of certain gases – for instance, in helium mixtures.[28]

Brownian movement; diffusion

Work in this area is usually considered to be part of Einstein's 'statistical theories'; it is often included with quantum theory because it shares the same basic approach. It is more convenient here to separate these areas because of the applied nature of current work based on Brownian movement.

Einstein's first article about this subject (number 2 in Table 4) dealt with the molecular-kinetic theory of heat, the motion of Brownian particles suspended in a liquid composed of molecules which are very small compared with the particles, and the rate of diffusion of the particles due to random collisions with molecules. The equation ('Einstein's diffusion equation') is $D = kt/f$, where D is the diffusion coefficient, k Boltzmann's constant, t absolute temperature, and f resistance to particle mobility; sometimes it is written $D = Kt \times b$, where b is mobility. In his articles 5 and 8 in Table 4, Einstein worked out some more details about elastic constants – in particular the bulk stress of a fluid and the equation $\mu^* = \mu(1 + 5\phi/2)$, where μ^* is the effective viscosity, μ the viscosity of the suspending fluid and ϕ the volume fraction of the particles.

Einstein demonstrated the reality of molecules when knowledge about the structure of matter was in its infancy. His work in this area is often associated with M. V. Smoluchowski;[29] authors co-cite the work of both men.

The repercussions of Einstein's work are evident in a remarkable variety of disciplines. We find citing articles published in journals such as *Tectonophysics, Polymer engineering and science, Rheologica Acta,* and *Industrial and engineering chemistry.* The relationship between article 2 about Brownian motion and diffusion and articles 5 and 8 about molecular dimensions and elastic constants is well described by Batchelor.[30] Current articles citing article 2 are about applications of the diffusion equation. What could be more topical than the mechanics of aerosol particles in their interaction with the atmosphere[31] or more unexpected than the properties of milk and its casein micelles?[32] Einstein's equations play an important part in both subjects. In an article about semiconductors we learn that 'Einstein's work on diffusion about seventy years ago led to a fundamental relation between diffusivity and mobility of charged carriers . . . of great importance in semiconductor physics for device analysis and design'.[33] The wide impact of Einstein's work is equally well demonstrated in an article about black holes. In this case the reference is to the 'density of states of a dissipative system discovered by Einstein in the course of his work on Brownian motion',[34] with no reference to his work on relativity.

Literature citing articles 5 and 8 is often about composite materials and plastics (see Table 5). Here, current work often starts with a modified version of the viscosity equation to take account of the higher volume loading of filled polymer systems. The rheology and strength properties of the set materials depends upon these considerations.[35,36] In a different field the equation is used in connection with the effects of the shape of suspended particles upon viscosity.[37]

Light scattering

We have several times mentioned the problem of considering one aspect of Einstein's work in isolation from the remainder. Article 7 is perceived as being isolated by a number of today's authors. In this article a fluctuation theory is proposed for explaining critical opalescence in a one-component system. Smoluchowski[29] also made some proposals independently about the problem. This work was developed for studying two-component systems by Debye and others.

In present-day applications light-scattering is used as a sensitive measure of a change of state; for instance, the 'Spinodal' is the point of phase separation – say the appearance of droplets in suspension in a binary solution. Critical light scattering is a method of determining the spinodal of polymer solutions based on the multi-component development of Einstein's work by Zernicke and Stockmayer. Commercial light-scattering apparatus is available for measuring the light scattered at several angles. The technique is used in metallurgy, glass technology and polymers, and may also be used for determining z-average molecular weights[38] and for gas system studies by X-ray scattering.[39]

Conclusion

We noted that four out of the 11 early articles most heavily cited today were by Einstein (Table 1). In 1977, no less than 105 of the articles processed for the *SCI* had the word EINSTEIN in the title from which it may be assumed that the subject-matter was substantially connected with his work. In 1977 EINSTEIN A., received 452 citations in total. Considering the time which has elapsed since Einstein published his most important articles, the direct influence and on-going interest in his work is quite extraordinary. We have examined a sufficiently large sample of the citing articles to note that a high proportion of them stem directly from his research or contain discussions of developments prompted by his various theories. The number of these articles, their interdisciplinary character and the comments made by their authors confirm the outstanding influence and direct impact of Einstein's work on today's science.

Notes

1. E. Garfield, 'Citation indexing for studying science', *Nature*, vol. 227, 1970, pp. 669–71.
2. E. Garfield, 'Highly cited articles. 26. Some classic papers of the late 19th and early 20th centuries', *Current Contents*, no. 21, 1976, pp. 5–9.
3. Although Einstein died in 1955, a large number of his cited works, published between 1901 and 1973, are listed in the *SCI*. Some, exhibiting bibliographic variations, were 'created' idiosyncratically by citing authors, but others are translations or selected works republished after his death. For example, three almost identical works each collect a number of citations: R. Fürth, ed., *Untersuchungen über die Theorie der Brownschen Bewegungen*, 1922; R. Fürth, ed., A. D. Cowper, trans., *Investigations on the theory of Brownian movement*, 1926; and A. Einstein, *Investigations on the theory of Brownian motion*, Dover Publications, 1956. Each of these includes the 1906 *Annalen der Physik* paper and authors cite this paper or one of the republications as convenient. Similarly any of the translations of the 1917 survey of relativity (in German) into Spanish, Italian, Russian, French, Hungarian, Yiddish and Hebrew are cited.
4. L. de Broglie, 'A general survey of the work of Albert Einstein', in P. A. Schilpp, ed., *Albert Einstein: philosopher scientist*, Harper & Row, 1949.
5. M. J. Klein, 'Thermodynamics in Einstein's thought', *Science*, vol. 157 (3788), 1967, pp. 509–16.
6. The *Science Citation Index* commenced publication in 1961; the *SCI* ('SCISEARCH') file is available on-line (from 1974) in Lockheed's DIALOG service, Palo Alto, California, and is accessible in the UK by direct dialling. Lists of citing articles may be printed out by submitting a 'cited reference' question to DIALOG. For instance a list of the articles with titles citing A. EINSTEIN. ANN. PHYS., 17, 549, 1905, will be printed out on request for any particular year. The generation of lists in this manner is quicker than manual look-up followed by writing or typing from the printed *SCI*.

   The citing articles can also provide another kind of consensus; if n of them cite an earlier article A and also an earlier article B, there may be some relationship between the *co-cited* articles A and B – particularly if the value of n is high. For example, out of the 23 1977 articles which cite ANN. PHYS., 19, 289, 1906, and the 16 which cited ANN. PHYS., 34, 591, 1911, eleven articles cite *both* the Einstein papers ($n = 11$). This is hardly surprising in view of the subject relationship between these two articles (see Table 4). Computer programs have been developed for operating on *SCI* data to identify pairs of co-citing articles for selected values of n; this leads to some interesting new ways of citation analysis (see reference 7). As perceived by co-citing authors, the relationship between the work of Einstein and the work of other scientists has been identified by this method, and will be referred to later.

   We may note, in passing, that Einstein's original major articles in *Annalen der Physik* themselves contained very few references – an indication of their originality. His four major articles, published in 1905, contained a total of 12 references, seven of which were in one article. His 1905 article on special relativity contained no references; in the second he needed 750 words to revolutionise physics; he concluded with the classic understatement 'Es ist nicht ausgeschlossen, daß bei Körpern, deren Energieinhalt in hohem Maße veränderlich ist z.B. bei den Radiumsalzen, eine Prüfung der Theorie gelingen wird' ('It is not impossible that with bodies whose energy content is highly variable, for example as with radium salts, the theory will be successfully tested').
7. H. G. Small and B. C. Griffith, 'The structure of scientific literatures. 1. Identifying and graphing specialities', *Science Studies*, vol. 4, 1974, pp. 17–40, and B. C. Griffith, H. G. Small, J. A. Stonehill and S. Dey, 'The structure of scientific literatures. 2. Towards a macro- and micro-structure for science', *Science Studies*, vol. 4, 1974, pp. 339–65.
8. J. H. Taylor, L. A. Fowler, P. M. McCullouch, 'Measurements of general relativistic effects in the binary pulsar PSR 1913+16', *Nature*, vol. 277, 1979, pp. 437–39.
9. J. C. Hafele and R. L. Keating, 'Around-the-world atomic clocks', *Science*, vol. 177 (4044), 1972, pp. 166–8.
10. L. Essen, 'Relativity and time signals', *Wireless World*, vol. 84 (1514), 1978, pp. 44–5.
11. D. Griffiths, 'Relativity and time signals', *Wireless World*, vol. 84 (1516), 1978, pp. 57–8.
12. L. Essen, 'Relativity and time signals', *Wireless World*, vol. 84 (1516), 1978, p. 58.
13. W. H. Cannon and O. G. Jensen, 'Terrestrial timekeeping and general relativity – a discovery', *Science*, vol. 188 (4186), 1975, pp. 317–28.
14. J. Bailey (and 11 others), 'Measurements of relativistic time dilatation for positive and negative muons in a circular orbit', *Nature*, vol. 268 (5618), 1977, pp. 301–4.
15. E. R. Harrison, 'Observational tests in cosmology', *Nature*, vol. 260 (5552), 1976, pp. 591–2.
16. H. A. Atwater, 'Transformation to rotating coordinates', *Nature*, vol. 228 (5268), 1970, pp. 272–3.
17. C. H. McGruder, 'Field energies and principles of equivalence', *Nature*, vol. 272 (5656), 1978, pp. 806–7.

18. J. Ishay and D. Sadeh, 'Direction finding by hornets under gravitational and centrifugal forces', *Science,* vol. 190 (4216), 1975, pp. 802–4.
19. J. Hough and R. Drever, 'Gravitational waves – a tough challenge', *New Scientist,* vol. 79 (116), 1978, pp. 464–7.
20. F. J. Tipler, 'Black holes in closed universes', *Nature,* vol. 270 (5637), 1977, pp. 500–1.
21. See F. Hund, *The history of quantum theory,* Harrap, 1974.
22. Subsequently Einstein, believing quantum mechanics to be incomplete, argued inconclusively with Bohr. In 1935 he published a paper dealing with what is usually known as the 'Einstein–Podolsky–Rosen paradox' – a two particle problem which appeared to be unsolvable in terms of current theory. A supporting paradox was also introduced by Schrödinger ('Schrödinger's cat'). The unified field concept came nearer in 1978 as a result of experiments with the Stanford accelerator.
23. L. E. Ballantine, 'Einstein's interpretation of quantum mechanics', *Amer. J. Phys.,* vol. 40, 1972, pp. 1763–71.
24. W. A. Gambling, 'Lasers and optical electronics', *Radio and electronic engineer,* vol. 45 (10), 1975, pp. 537–42.
25. A. L. Schawlow, 'Masers and lasers', *IEEE Trans. Electron Devices,* vol. ED-23 (7), 1976, pp. 773–9.
26. M. L. Glasser and A. Bagchi, 'Theories of photoemission from metal surfaces', *Progr. Surface Sci.,* vol. 7 (3), 1976, pp. 113–48.
27. S. J. Freedman and J. F. Clauser, 'Experimental test of local hidden-variable theories', *Phys. Rev. Letts.,* vol. 28 (14), 1972, pp. 938–41.
28. E. G. Cohen, 'Quantum statistics and liquid helium-3-helium-4 mixtures', *Science,* vol. 197 (4298), 1977, pp. 11–16.
29. M. V. Smoluchowski, *Ann. Phys.,* vol. 21, 1906, p. 756.
30. G. K. Batchelor, 'The effect of Brownian motion on the bulk stress in a suspension of spherical particles', *J. Fluid Mech.,* vol. 83 (1), 1977, pp. 97–117.
31. Y. I. Yalamov, L. Y. Vasiljeva and E. R. Schukin, 'The study of various mechanisms of in-cloud scavenging of large, moderately large, and small aerosol particles', *J. Colloid and Interface Sci.,* vol. 62 (3), 1977, pp. 503–8.
32. R. K. Dewan and V. A. Bloomfield, 'Molecular weight of bovine milk casein micelles from diffusion and viscosity measurements', *J. Dairy Sci.,* vol. 56 (1), 1973, pp. 66–8.
33. R. K. Jain, 'Calculation of the Fermi level, carrier concentration, effective intrinsic concentration, and Einstein relation in n- and p-type germanium and silicon', *Phys. Stat. Sol.,* vol. (a) 42, 1977, pp. 221–6.
34. P. Candelas and D. W. Sciama, 'Irreversible thermodynamics of black holes', *Phys. Rev. Letts.,* vol. 38 (23), 1977, pp. 1372–5.
35. R. J. Crowson and R. G. C. Arridge, 'The elastic properties in bulk and shear of a glass bead reinforced epoxy resin composite', *J. Materials Sci.,* vol. 12 (1977), 1977, pp. 2154–64.
36. D. M. Bigg, 'Rheology and wire coating of high atomic number low density polyethelene composites', *Polymer Eng. and Sci.,* vol. 17 (10), 1977, pp. 745–50.
37. P. H. Elworthy, 'The structure of Lecithin micelles in benzene solution', *J. Chem. Soc.,* part 2, 1959, p. 1951.
38. J. Goldsbrough, 'Spinodal – its impact on metallurgy, glass technology and polymer science', *Sci. Progr.,* vol. 60 (329), 1972, pp. 281–97.
39. B. Chu and J. S. Lim, 'Small angle scattering of X-rays from carbon dioxide in the vicinity of its critical point', *J. Chem. Phys.,* vol. 53 (12), 1970, p. 4454.