time, as encountered in fluid dynamics and electrodynamics. The new machinery and display techniques enhance our picture-drawing capabilities so dramatically that they provide a qualitative as well as quantitative extension of the jobs that can be done.

References and Notes

1. K. C. Knowlton, *Amer. Fed. Inform. Processing Soc. Conf. Proc.* **25**, 67 (1964).
2. ———, "A Computer Technique for the Production of Animated Movies," 17-minute, 16-mm black-and-white silent film. Available on loan from Technical Information Libraries, Bell Telephone Laboratories, Murray Hill, New Jersey.
3. E. E. Zajac, "Two-Gyro, Gravity Gradient Attitude Control System," 7-minute, 16-mm black-and-white silent film. Available on loan from Bell Telephone Laboratories (see *2*).
4. ———, *Commun. Assoc. Comput. Mach.* **7**, 169 (Mar. 1964).
5. J. A. Lewis and E. E. Zajac, *Bell System Tech. J.* **43** (No. 6), 2705 (1964).
6. F. W. Sinden, "Force, Mass, and Motion," 10-minute black-and-white sound film. Available on loan from Bell Telephone Laboratories (see *2*).

Ernst Mach: Biographical Notes

Few of his contemporaries believed him, but few were his equal in physics, physiology, or philosophy.

H. W. Pittenger

Ernst Mach was 23 years old when, as he was to record later, he "began to pay attention to the labors of investigators to whom [he] had occasion to refer. . . . [He] recognized that the salient characteristics of their procedure lay in the choice of the simplest, most economical, most direct means to attain the end desired" (*1*).

This "economy of thought" and clarity in methodology became his stepping-stones across the then still unclear waters of optics, physics, physiology, psychology, and philosophy (*2*). Einstein acknowledged Mach's work as predecessor to his own. In *Science* in 1940 he wrote, "The strange part played by space (or the inertial system) within the mechanical foundation was also clearly recognized, and criticized with especial clarity by Ernst Mach" (*3*).

Mach, an Austrian, was born on 18 February 1838 in Moravia, which now is the south-central section of Czechoslovakia. His boyhood was spent on a farm where his father taught him history, elementary mathematics, geometry, and classical languages. We can imagine that on a farm in the early 19th century he observed the fundamental mechanics of the pulley and the lever. During his boyhood he spent 2 days a week at work with a cabinetworker. The training he received was to show in the straightforward simplicity of his later constructions for experiments.

Although Mach is best known for the work that gave the term "Mach number" to the world, his contributions to other fields were enormous. His lucid, beautiful writing loses none of its poetry in translation. In addition to influencing Einstein, Mach's philosophy of science was probably the inspiration for the quantum mechanics of Werner Heinsenberg (*4*).

In 1860 Mach earned his doctorate in physics at the University of Vienna, which had been the cultural center of Austria for more than 500 years. He remained there, teaching physics, until 1864, when he was appointed a professor at the University of Graz, situated about 225 kilometers southwest of Vienna. Mach taught mathematics and physics at Graz for 3 years, leaving to become professor of physics at the University of Prague. He remained at Prague 28 years before returning to his alma mater. The University of Vienna created for him a new chair, Theory of Inductive Sciences. Long after his death, Mach's influence was felt by his successors, and the chair became the center of the small international group of scientists, engineers, mathematicians, and philosophers who formed the Vienna Circle.

Mach was a prodigious writer on subjects that interested him; and those subjects he attacked with great thoroughness. His *Principles of Physical Optics* (*5*), in addition to being a scholarly critique, is a history of optics. Beginning with Aristotle, Plato, and Euclid, he examines the contributions of more than 200 others in a sprightly and most readable way. His impatience with Descartes, apparent in other of his works, is quite evident here. Speaking of the law of refraction, Mach says of Descartes (*5*, p. 33):

> It was easy for him as an applied geometrician to bring Snell's law [*6*] into a *new* form, and as a pupil of the Jesuits to "establish" this form. Descartes, however, had too little of the disposition or the ways of a scientist to discover the law by observation, and to examine it carefully from a theoretical point of view.

In 1883, Mach's *Die Mechanik in ihrer Entwickelung* (*1*) was published in Leipzig. Now available in English as *The Science of Mechanics* (*7*), this book is at once a dissection of Newtonian concepts and the seed for a new school of philosophy which proclaimed that a statement (and hence a theory) was not valid unless subject to experimental proof or disproof. To Mach "absolute time" and "absolute space" were meaningless, but the world in 1883 took little notice of his acute perception of the meaning of meaning.

Invading the private domain of Newton, he had the audacity to propose the theory that the inertia of a body was a function of that body's distance from all other bodies in the universe. The theory has outlived its detractors and persists today as "Mach's principle."

English translations are also available of Mach's *Popular Scientific Lectures* (*8*), *Space and Geometry* (*9*), and *The Analysis of Sensations* (*10*). The last, parts of which were published in English in volume 1 of the *Monist*, was misunderstood or derided as unscientific by most of his contemporaries. It was here that Mach distinguished between time sensations and the time of the physicist, which

> does not coincide with the system of time-*sensations*. When the physicist wishes to determine a period of time, he applies as his instruments of measurement, *iden-*

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tical processes or processes *assumed to be identical*, such as . . . the rotations of the earth, etc. The fact connected with the time-*sensation* is in this manner made the subject of a reaction, and the result of the latter, the *number* which is obtained, serves, in place of the time-*sensation*, to determine more exactly the subsequent movement of the thought.

Of spatial relations he observed (*9*):

All physical determinations are *relative*. Consequently, likewise all *geometrical* determinations possess validity only *relatively* to the measure. The concept of measurement is a concept of relation, which contains nothing not contained in the measure. In geometry we simply assume that the measure will always and everywhere coincide with that with which it has at some other time and in some other place coincided. But this assumption is determinative of nothing concerning the measure.

Among those of his contemporaries who understood Mach was Karl Pearson, professor of applied mathematics and mechanics at University College, London. In *The Grammar of Science* (*11*) Pearson printed one of Mach's drawings, which is also reproduced here, and quoted him, saying:

This (sense-impression) has been very cleverly represented by the well-known German scientist, Professor Ernst Mach. In the accompanying sketch our professor may be seen lying on his back, having closed his right eye, and the picture represents what is presented to his left eye:. . .

'In a frame formed by the ridge of my eyebrow, by my nose, and by moustache, appears a part of my body, so far as it is visible, and also the things and space about it . . . If I observe an element, A, within my field of vision, and investigate its connection with another element, B, within the same field, I go out of the domain of physics into that of physiology and psychology if B, to use the apposite expression that a friend of mine [J. Popper of Vienna] employed upon seeing this drawing, passes through my skin.'

Mach delighted in the examination of these "mental symbols," as he called them, but discomfited his critics by rigorously separating symbol (and sensation) from fact in his papers and books.

Many of his papers appeared in publications of the Vienna Academy of Sciences, an august body whose members governed all the scientific institutions in Vienna, including those of the university. In 1887 the now-famous paper on shock waves was published in the transactions of the academy (*12*).

To conduct the experiments described in the paper, Mach traveled to Fiume on the Adriatic. Fiume, then politically a part of Hungary, was under the Austrian-Hungarian regime. The city had a fine marine academy, and Mach obtained the collaboration of this academy's Professor Salcher and the full cooperation of the Austrian navy in his work. Shells were fired past a charged Leyden jar; the passage of the shells created enough of a spark to provide a light source for a Schlieren photograph. A knife edge, essential in this light-refraction method of obtaining streak evidence of differing densities of a gas, was positioned both horizontally and vertically for 80 photographs. In view of the state of the art of photography at that time, Mach obtained some remarkable pictures. His illustrations showed a wave angle, which later researchers named the "Mach angle." [It was not until 1929 that the term "Mach number" was coined by Jacob Ackeret of the Institut für Aerodynamik of the Eidgenössische Technische Hochschule in Zurich (*13*).]

Ernst Mach, about 1898.

The experiment at Fiume was not Mach's first experience with photography. As early as 1866 he had photographed successive sections of machines and anatomical preparations on one plate. When these photographs were viewed stereoscopically, the viewer seemed to see through the opaque surface of a solid into the interior.

Mach had an impressive range of interests. "He apparently has read everything and thought about everything," William James said (*14*). James heard him lecture in Prague and sent his card to Mach after the lecture; as James wrote to his wife, Mach "received me with open arms." The lecture was on physiology and, according to James, one of the most artistic he had ever heard. Mach took James to his club for dinner and they talked for 4 hours. This conversation was the beginning of a long friendship by correspondence.

Mach wrote a textbook on thermodynamics. He published an idea for a binocular rangefinder. He investigated and reported on the sugar cycle in grapes. He reported, with his own drawings of the equipment, an acoustical experiment by which an observer could see the wave effect of a tuning fork on a gas flame; the observer saw as many vibrations as he heard (*15*).

For Mach, the physics of music was a natural subject, because he wanted to encompass the whole world of physics; one of his lectures was on the causes of harmony. Another lecture, far afield from science, was on classical literature. And he found time to comment on world affairs, remark-

Out of one eye, Mach contemplates his environment and himself, including the tip of his nose. [From *The Grammar of Science* by Karl Pearson (Everyman's Library; *11*, p. 64). Reproduced by permission of E. P. Dutton & Co., Inc., and J. M. Dent & Sons, Ltd.]

ing on the "absurdity committed by the statesman who regards the individual as existing solely for the sake of the State" (*10*). Lenin attacked him in his *Materialism and Empirio-Criticism* (*16*). Metaphysicians attacked his philosophy, which denied them their vagaries and which he steadfastly maintained was not a philosophy but merely a convenient point of view. Even the great Max Planck attacked some of his theories (*17*). Today Mach is vigorously defended and discussed in the *Philosophical Review* and *Physical Review*.

Of Mach's philosophy, Richard von Mises (*2*, pp. 81–82) has given a clear interpretation:

> Mach does not start out to analyze statements, systems of sentences or theories, but rather the world of phenomena itself. His elements are not the simplest sentences, and hence the building stones of theories, but rather—at least according to his way of speaking—the simplest facts, phenomena, and events of which the world in which we live and which we know is composed. The world open to our observation and experience consists of "colors, sounds, warmths, pressures, spaces, times, etc." and their compounds in greater and smaller complexes. All we make statements and assertions about, or formulate questions and answers to, are the relations in which these elements stand to each other. That is Mach's point of view.

Ernst Mach died at Haar, near Munich, on the day after his 78th birthday in 1916. He had retired from the University of Vienna in 1901, having suffered a stroke, and had spent his remaining years in Munich. The world came to him by mail. In 1913 he wrote (*5*, p. viii):

> I gather from the publications which have reached me, and especially from my correspondence that I am gradually becoming regarded as the forerunner of relativity. I am able, even now, to picture approximately what new expositions and interpretations many of the ideas expressed in my book on mechanics will receive in the future from the point of view of relativity.
>
> It was to be expected that philosophers and physicists should carry on a crusade against me, for, as I have repeatedly observed, I was merely an unprejudiced rambler, endowed with original ideas, in varied fields of knowledge. I must, however, as assuredly disclaim to be a forerunner of the relativists as I withhold from the atomistic belief of the present day.
>
> The ever-increasing amount of thought devoted to the study of relativity will not, indeed, be lost; it has already been both fruitful and of permanent value to mathematics. Will it, however, be able to maintain its position in the physical conception of the universe of some future period as a theory which has to find a place in a universe enlarged by a multitude of new ideas? Will it prove to be more than a transitory inspiration in the history of this science?

Having thus shaken a reproving finger at the relativity theory, he promised to reveal in a future publication the extent to which he discredited the theory. But Europe was preparing for World War I, the publication never appeared, and Mach died, no more to enlarge the universe with a multitude of new ideas.

References and Notes

1. E. Mach, *Die Mechanik in ihrer Entwickelung* (Leipzig, Brockhaus, 1883).
2. R. von Mises, *Positivism, A Study in Human Understanding*, J. Bernstein and R. G. Newton, Transl. (Braziller, New York, 1956).
3. A. Einstein, *Science* **91**, 487 (1940), p. 488.
4. H. Dingler, in *Encyclopedia of the Social Sciences* (Macmillan, New York, 1933), vol. 9, p. 653.
5. E. Mach, *Principles of Physical Optics*, J. S. Anderson and A. F. A. Young, Transl. (Dover, New York, 1953).
6. "The ratio of the sines of the angles of incidence and refraction of light is constant."
7. E. Mach, *The Science of Mechanics* (Open Court, Chicago, 1915).
8. ———, *Popular Scientific Lectures* (K. Paul, Trench, Truebner, London, 1898).
9. ———, *Space and Geometry*, T. J. McCormack, Transl. (Open Court, Chicago, 1906).
10. ———, *The Analysis of Sensations*, C. M. Williams, Transl. (Open Court, Chicago, 1897).
11. K. Pearson, *The Grammar of Science* (Dent, London, 1937).
12. E. Mach, *Trans. Acad. Sci. Vienna* **21** (Apr. 1887); J. Black, *J. Roy. Aeron. Soc.* **54**, 371 (1950).
13. J. Ackeret, personal communication.
14. W. James, quoted by P. Frank, *Erkenntnis* **18** (No. 7), 247 (1938).
15. E. Mach, *Lotos* (Aug. 1873).
16. N. Lenin, *Materialism and Empirio-Criticism*, A. Fineberg, Transl. (Foreign Languages Publishing House, Moscow, 1947).
17. M. Planck, *Physik. Z.* **2**, 1186 (1910), quoted by P. Frank (*14*).

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Bibliography

P. Frank, *Philosophy of Science* (Prentice-Hall, Englewood Cliffs, N.J., 1957).
A. Grunbaum, *Philos. Rev.* **66**, 4 (1957).
M. Jammer, *Concepts of Space* (Harvard Univ. Press, Cambridge, 1954).
V. Kraft, *The Vienna Circle*, A. Pap, Transl. (Philosophical Library, New York, 1953).
E. Nagel, *Sovereign Reason* (Free Press, Glencoe, Ill., 1954).
M. Planck, *A Scientific Autobiography*, F. Gaynor, Transl. (Williams and Norgate, London, 1950).
C. Weinberg, *Mach's Empirio-Pragmatism in Physical Science* (Albee, New York, 1937).

Analysis of a Gene in Drosophila

With variations, the genes of microorganisms and those of *Drosophila* are much the same.

W. J. Welshons

Since the discovery of the helical structure of DNA (*1*), microorganisms have played an increasingly important role in investigations of gene structure and function. Discoveries have come forth so rapidly that one hardly grasps the significance of one before being confronted by another. Because of the flood of exciting disclosures it has been necessary to focus attention upon the gene as it exists in the microbial world. A divergence will be made here to consider how well the concept of the gene derived from studies with microorganisms applies to higher organisms. To do this, the fine structure of the sex-linked Notch locus in *Drosophila* will be examined. Comparisons will then be made with complex loci of microorganisms, from which it is concluded that the functional gene or cistron can be most easily identified in higher organisms if mutants classified as amorphs and lacking all or virtually all of their genetic activity are used for the analysis. When Notch is compared with other complex loci in *Drosophila*, one sees that amorphic mutants may be identified as recessive lethals at one locus and as recessive visibles at another. Cytogenetic considerations suggest that if the Notch locus is correctly

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