BREAKTHROUGHS

A Chronology of Great Achievements in Science and Mathematics 1200–1930

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Foreword by L. PEARCE WILLIAMS

G.K.HALL & CO.
BOSTON

Parkinson, Claire L.
Breakthroughs : a chronology of great achievements in science and mathematics, 1200–1930.

Bibliography: p. 512
Includes index.
1. Science—History. 2. Mathematics—History.
3. Civilization, Occidental. I. Title.
Q125.P327 1985 509 85-7628
ISBN 0-8161-8706-1

BREAKTHROUGHS

A Chronology of Great Achievements in Science and Mathematics
1200–1930

To my mother and father

Foreword

In the last fifty years, the history of science has grown from a subject practiced primarily by retired scientists and taught only on the periphery of the curriculum, to a major discipline that encompasses the growth of science and technology, the philosophy of science, and the mutual effects of science and society. Graduate degrees can be pursued in all the major universities of America and Britain, and undergraduate courses serve to bridge the gap between the sciences and the humanities in universities, colleges, and technical institutes. Recent modifications of undergraduate curricula have pushed the history of science closer and closer to the very center of what is increasingly considered to be the necessary core of higher education.

As the field has grown and prospered, various aids to its understanding and pursuit have been forthcoming. Beginning in 1970, quarto volume after quarto volume of that monument of modern scholarship, the *Dictionary of Scientific Biography* has rolled off the presses until, in 1980, the sixteenth and final volume (Index) appeared. No one who has not had to begin a new research project, or even make up weekly lectures without it, can fully appreciate the value of this work. Its cost and size, however, place it generally outside the study of the average undergraduate or graduate student. And its arrangement as biography makes it difficult to use for those students who are just becoming acquainted with the subject. Even if someone can put a name together with a law or a fact, the DSB is not always helpful. If you want to know what Ampere's law is, you will not find it in the article on Ampere because Ampere had never heard of it. It was Maxwell who gave it that name, long after Ampere had died. Other, smaller, dictionaries of scientific biography, of which there are a number, suffer from the same disability.

More recently, a scholarly and very useful *Dictionary of the History of Science* has been published. This is a history of scientific concepts in which general ideas are described and traced. Again, for the practitioner of the history of science who knows his way around the conceptual map, this work is invaluable. Like the DSB, it provides a good bibliography with which to begin to follow concepts both to their origins and to their consequences. But, like the DSB, it is a difficult work for the beginner to use. Concepts, and particularly scientific concepts, are difficult and subtle for those just introduced to them. For the neophyte, it is a little like coming in to the middle of the first act of a play. It is possible to figure out what is going on, but there is always the lingering sense that something important, even fundamental, has been missed.

What has been needed for years, and what Dr. Parkinson attempts to provide in this volume, is a most basic aid to the study of the history of science. It is, simply, a chronology of scientific discovery and, as such, it deals not with lives, nor concepts, but with much more simple facts. Who discovered what, when? This would seem to be about the simplest and most straightforward question that could be asked about the history of science, but it is not. One of the leading students of the history of science, Thomas S. Kuhn, has, indeed, made it a prominent point in much of his work on the philosophy of science that discoveries and laws and theories are not like continents, to be discovered, but like species that evolve over time. It is, therefore, impossible ever to assign a specific date for their appearance. For Kuhn and his disciples, then, this volume will be a futile exercise. But Kuhn and his disciples are already sophisticated students of the history of science who can easily adjust to this rather controversial notion; beginners are not, and surely it can do little harm to provide them some specific chronological guides as they start their studies. Perhaps later they will agree with Kuhn (not all of us do!) and fuzz their historical perceptions accordingly. For now, this work will permit students to find specific information easily and use it.

But, it may be objected, just how specific is the information? One of the things Dr. Parkinson discovered (as did I when I was asked to advise her) was that there is a good deal of scholarly disagreement over what should be simple matters. Authorities, in short, disagreed both with Dr. Parkinson and with each other, and sometimes the disagreements were quite violent. For example, Dr. Parkinson discovered that the estimates of modern scholars for the accuracy with which Tycho Brahe could observe heavenly bodies ranged from $8'$ to $1''$, which is quite a range! What should be done? Since there are few, if any, criteria for judging which of the experts is *right*, and since life is short and every such discrepancy could not be traced back to original sources, Dr. Parkinson has, I think rightly, gone ahead and published what seemed to her to be the best guess. Her authority for this course is Bacon's famous dictum that truth is more likely to emerge from error than from confusion. Experts who are offended by her entries in their fields may find them to be the starting points for new and interesting researches that may, perhaps, remove the startling inconsistencies among equally competent scholars on matters of fact.

I cannot close this short foreword without a word of praise for Dr. Parkinson's persistence and courage. The task she set herself was a difficult and tedious one, and she has continued with it in the face of considerable adverse reaction about both its possibility and desirability. Her reward, I am sure, will be the gratitude of generations of students who will find the book indispensable to them in both the study of the sciences and the study of its history. Even the scholars, I suspect, will ultimately come around and treat it as a standard handbook.

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Preface

Science has become a vital component of our civilization, influencing our work, our recreations, our goals, our perceptions of ourselves and the universe around us. Yet few of us have much understanding of the historical foundations of that science, and hence of the strengths and weaknesses upon which it and its individual disciplines will flourish or flounder. This volume is intended to convey a sense of the development of the science and mathematics of Western civilization by presenting a chronology of events important to that development from the preliminary introduction of Hindu-Arabic numerals through such varied events of the early twentieth century as the emergence of quantum mechanics and general relativity, the artificial transmutation of chemical elements, the discovery of vitamins and controlled experimentation on dietary deficiency diseases, the hypotheses of continental drift and the Big Bang explosion of the universe, and the determination of unexpected inherent limitations of Western science, as exemplified by the uncertainty principle in physics and Kurt Gödel's proofs of incompleteness in mathematics. The span of years covered is 1202 to 1930.

The central purpose of the book is to provide, in chronological order, concise, clear statements on events or accomplishments contributing to the development of Western science. In the hopes that the casual reader may obtain some understanding or insight as well as facts by browsing through the book, I have tried in some of the entries to include more than a simple statement of what happened when, by adding a flavor of how an accomplishment was made or how it was influenced by other scientific developments. All entries are brief, however, and the reader is encouraged to seek more detailed discussions, especially from primary sources, on those topics that interest him most.

Although I expect the book to be used chiefly as a reference or for random browsing, additional benefits can derive from reading it through as a whole or systematically following a specific topic. The sequence of entries demonstrates the uneven nature of scientific development, important interconnections within and among the various scientific disciplines, and the often extensive development of a subject before the emergence of a key individual providing crucial linking concepts. Examples of the latter include numerous theories of evolution developed before the mechanism of natural selection was suggested by Charles Darwin, with extensive supporting evidence, and the use of differentiation and integration techniques before the fundamental theorem of calculus was formulated and proved by Isaac Newton and Gottfried Leibniz.

A complete chronology of science never could be constructed and has not been attempted. A more realistic goal would be a very selective (and of necessity subjective) listing of the truly major scientific events; but even that has not been attempted. This book simply presents in chronological order a listing of numerous events in the history of Western science, with one aim being to include most of the major events in the disciplines covered and enough of the minor events to add interest and coherency.

sults. Even when the event described centers on a published piece of research and the original source is read and reread, there still remain problems: how to summarize a substantial work in a few sentences; how to indicate fairly what might in hindsight appear to be the most important aspect of a work, although the author clearly had different emphases; how to word entries on theories that have long ago been discounted, while recognizing that our decade has no hold on scientific "truth" and that indeed discarded theories do on occasion reemerge with increased support.

By being concerned with resolving the contradictions, I have avoided repeating many of the errors published elsewhere, but probably not all. I apologize in advance especially for errors, but also for other imperfections within the entries, whatever the cause, and for any serious omissions and all other shortcomings. I ask the reader his forbearance in view of the impossibility of perfectly chronicling Western science. Although incomplete, the book contains a wealth of information and should help the reader to understand something about scientific development and to place given events within the context of other events. It is not meant to be all-inclusive, but it is meant to include enough events and with sufficient detail on the key events to be of interest and value to the general reader. I am aware of and terribly pained by the flaws, but the book covers a vibrant, fascinating subject, and I hope that there are readers who become informed and excited by it.

I thank the many people who have helped me through the final years of this endeavor. Most prominently this includes my brother William Parkinson, who not only has supported me throughout but who recommended an appropriate publisher, plus Janet Campbell, Myrtle Lane, Tony Busalacchi, George Demko, L. Pearce Williams, C. V. Parkinson, and David Atlas, all of whom gave freely of their time and advice at crucial moments during the lengthy review process. I thank those who read through all or portions of the manuscript and offered their suggestions, most notably Donald J. Cavalieri, C. V. Parkinson, L. Pearce Williams, Myrtle Lane, Aaron Ihde, Victor Thoren, Joseph Dauben, Lois Magner, Marshall Walker, Webb Dordick, Albert Carozzi, David Lindberg, and William Coleman. Finally, I thank my employer, Goddard Space Flight Center, and my family and friends who have helped me through the personal sacrifices necessitated when undertaking a project of this scope on top of an already-demanding full-time job. This includes many of the above individuals plus William Campbell, Thomas Heslin, Ann Parkinson, Jennifer Parkinson, Virginia Parkinson, Jean Ryan, and Warren Washington.

Claire L. Parkinson
Greenbelt, Maryland
September, 1985

FIGURE 1. *A woodcut contrasting the use of Hindu-Arabic computation methods (see 1202—*MATHEMATICS *entry) with the older use of a reckoning board. The satisfied expression on the face of the man on the left suggests the greater convenience of the new methods. (By permission of the Houghton Library, Harvard University.)*

Contents

Chronology

1202

MATHEMATICS (Arithmetic)

Leonardo Fibonacci (Leonardo of Pisa, c.1170–c.1250, Italian) writes *Liber abaci* [Book of the abacus], the major work awakening Europe to the advantages over the Roman numeral system of the Hindu numerals and the Hindu-Arabic computation methods. The book deals with arithmetic and elementary algebra, and is based largely on earlier Arabic and Greek sources. Individual merchants and bankers begin using Hindu-Arabic numerals over the next three centuries, but it is not until c.1500 that their use reasonably completely supersedes the use of Roman numerals.

c.1210

CHEMISTRY (Mineral Acids)

As a result of the discovery of mineral acids, a discovery made possible through improvements in stills, chemists become far better able to dissolve substances and create reactions in solution. Previously, weak organic acids had been used.

EARTH SCIENCES (Ocean Tides)

Wallingford (d.1213, English), in the first known recording of tide observations for the purpose of prediction, tabulates the occurrence of floods at London Bridge. For the next 500 years, tide prediction is the central objective of most observational oceanography.

1215

SUPPLEMENTAL (Religion and Science; Aristotle)

The church in Paris forbids the teaching of Aristotle's (384–322 B.C., Greek) metaphysical and scientific works, extending a prohibition on his philosophical works imposed in 1210.

1217

ASTRONOMY (Aristotle)

Through his translation of Alpetragius's (Abū Isḥāq al-Biṭrūjī al-Ishbīlī, fl. c.1190, Spanish) *Liber astronomiae* [Book of astronomy], Michael Scot (c.1175–c.1234, Scottish) awakens Europe to the Aristotelian system of astronomy and its contrasts with the better-known and more mathematical system of Ptolemy. In the Aristotelian system, planets revolve around the earth on concentric spheres, whereas in the Ptolemaic system the planets revolve on small circles (epicycles) which are centered on larger circles (deferents) centered near the earth. Although more complicated, the Ptolemaic system is better able to predict the positions of the planets and explain the changes in their apparent brightnesses. It is detailed in Ptolemy's *Almagest* and available in Latin translation since c.1160.

1220

MATHEMATICS (Geometry; Trigonometry)

In *Practica Geometriae*, Leonardo Fibonacci (Leonardo of Pisa, c.1170–c.1250, Italian) presents much of the material of Euclid's (c.330–c.275 B.C., Greek) *Elements* and of Greek trigonometry, as well as (1) introducing Fibonacci sequences (0, 1, 1, 2, 3, 5, 8, . . .), (2) showing that there exist irrationals other than those classified in Euclid's book 10, and (3) attempting to show that straightedge and compass are not sufficient to construct the roots of $x^3 + 2x^2 + 10x = 20$.

c.1220

BIOLOGY (Classification)

Michael Scot (c.1175–c.1234, Scottish) translates Aristotle's *History of Animals*, *Parts of Animals*, and *Generation of Animals* into Latin, precipitating Albertus Magnus's (c.1200–1280, German) classification of European fauna according to general Aristotelian principles.

EARTH SCIENCES/MATHEMATICS (Stereographic Projections)

Jordanus de Nemore (Nemorarius, fl. c.1220, French) projects a globe onto a plane tangent to it at the North Pole and describes the basic principles of stereographic projection, including the principle that a circle on the globe will retain its property of being a circle when projected onto the plane.

MATHEMATICS (Algebra)

In *De numeris datis*, Jordanus de Nemore (fl. c.1220, French) generalizes arithmetical problems by inserting letters in place of numbers, and examines problems later seen as forerunners to linear and quadratic equations. He accepts the Hindu numerals and Hindu-Arabic computation methods detailed earlier in the century by Leonardo Fibonacci (1202—MATHEMATICS).

PHYSICS (Optics; Lux Concept)

Robert Grosseteste (c.1168–1253, English), influenced by the writings of Saint Augustine, presents a conception of the universe based on light, or *lux*, as fundamental. In *De luce seu de inchoatione formarum* and *De motu corporali et luce* he suggests that light was the first form in matter, that lux propagated in all directions according to mathematical laws, thereby forming dimensionality and determining the structure of the universe, and that the lux concept can be used to explain transformations and differences in many spheres of study. Hence optics is seen as a study fundamental to many others.

PHYSICS (Statics)

Jordanus de Nemore (fl. c.1220, French), or followers of his using his name, writes several treatises on statics in which he includes many results from Aristotle, such as the law of the lever, and proceeds beyond Aristotle in the derivation of laws for bodies positioned on inclined planes, the latter being included in *Liber Jordani de Nemore de ratione ponderis.* In *Elementa super demonstrationem ponderis* [Elements for the demonstration of weights], Jordanus enunciates the principle that the strength required to lift a weight w to a height h is equivalent to that required to lift a weight kw to a height h/k.

1225

MATHEMATICS (Algebra)

In *Liber quadratorum* [Book of square numbers], Leonardo Fibonacci (Leonardo of Pisa, c.1170–c.1250, Italian) solves selected first, second, and third degree determinate and indeterminate equations. Like that of the Arabs, his algebra is based on methods adopted from arithmetic and employs almost no symbolism, although on occasion he generalizes his results by replacing numbers with letters. The work includes the general solution in rationals of a system of three equations in three unknowns, each having quadratic terms. Leonardo rejects negative roots of equations, but does interpret a negative answer to a financial problem as a loss rather than a gain.

c.1230

PHYSICS (Sound)

In *De generatione sonorum,* Robert Grosseteste (c.1168–1253, English) describes sound as a vibratory motion propagating through the air from the sound source to the receiving ear.

SUPPLEMENTAL (Scientific Methods)

In commentaries on the *Physics* and *Posterior Analytics* of Aristotle and in other treatises, Robert Grosseteste (c.1168–1253, English) presents views on proper scientific methodology, encouraging the search for general principles and causes, the testing of theories against experience, and the use of mathematics. He asserts that scientific inquiry should begin with facts (*quia*), either observed or experienced, and should aim at determining the reason behind the facts (*propter quid*), this involving the resolution of the phenomena into more elementary principles and the derivation from these principles of hypotheses which allow a reconstruction of the phenomena. The hypotheses should then be verified or rejected based on observation or on theory which has previously been verified. More specifically, he introduces the Principle of Falsification, asserting that a hypothesis should be rejected if experience proves its conclusions to be false.

1231

SUPPLEMENTAL (Religion and Science: Physics)

Pope Gregory IX (c.1143–1241, Italian) rescinds the general ban forbidding the study of physics, although those writings specifically viewed as heretical remain banned.

c.1231–1235

PHYSICS (Optics; Law of Refraction)

In his "De iride seu de iride et speculo" and other essays, Robert Grosseteste (c.1168–1253, English) describes the science of optics, concentrating especially on geometrical optics and the path of light rays, reflection and refraction. He claims that when a ray is refracted upon entering a denser medium, the angle between its refracted path and the perpendicular to the interface is half the angle the ray would have made if unrefracted. He thereby makes an early attempt at determining a quantitative law of refraction (see 1621—PHYSICS for the modern law of refraction). Although he claims to have verified experimentally specific results, the erroneous nature of some of these throws into question the claims of experimentation.

c.1235

METEOROLOGY (Rainbow)

Robert Grosseteste (c.1168–1253, English), in his works on optics, suggests that rainbows are caused by the refraction of sunlight inside clouds.

SUPPLEMENTAL (Encyclopedias)

Bartholomew Anglicus (fl. c.1250, English) writes *De proprietatibus rerum* [On the properties of things], an encyclopedic work on natural history, combining fact and fiction, and interspersing superstition with observation and theology with science. The influence of the stars on earthly affairs is considered major.

1238

BIOLOGY (Dissections)

In an effort to increase understanding of the human body, the Holy Roman Emperor Frederick II (1194–1250, Italian) is said to have ordered that every five years a corpse be dissected in Salerno. (Whether such an order was actually issued is uncertain.)

1240

HEALTH SCIENCES (Medical Regulations)

Frederick II (1194–1250, Italian) promulgates a set of laws regulating the study and practice of medicine, including the licensing of physicians, the preparation of drugs, and the role of apothecaries. A standard course of medical studies is to take five years, followed by a year of practicing medicine under the guidance of an experienced physician.

c.1240

MATHEMATICS (Arithmetic)

Using Al-Khwārizmī's *Treatise on Calculation with the Hindu Numerals* as a prototype and adding theory from Boethius's sixth-century paraphrase of Nicomachus of Gerasa's *Arithmetica*, John of Holywood (Sacrobosco, c.1200–1256, Irish) writes what is to become a standard university text for centuries: *Algorismus vulgaris*. The book becomes especially popular with the addition of a commentary on it by Peter of Dacia in 1291.

c.1245

BIOLOGY (Falcons)

The Holy Roman Emperor Frederick II (1194–1250, Italian) writes a detailed, meticulously illustrated treatise on falconry, *De arte venandi cum avibus* [On the art of hunting with birds]. In addition to discussing the habits and migrational tendencies of falcons, Frederick describes experiments on the artificial incubation of eggs, and presents an observation-based description of falcon anatomy, including such previously unrecorded details as the form of the sternum and the structure of the lungs.

1250

SUPPLEMENTAL (Encyclopedias)

Vincent of Beauvais (c.1190–c.1264, French) writes the *Speculum naturale, historiale, doctrinale,* a larger and less-conversational encyclopedia than that of Bartholomew Anglicus (c.1235—SUPPLEMENTAL), summarizing the knowledge of the time.

c.1250

BIOLOGY (Bird Migration)

Matthew Paris (c.1200–1259, English) details the migrations of crossbills.

BIOLOGY (Botany; Aristotle)

Albertus Magnus (c.1200–1280, German) helps introduce the work and methods of Aristotle to Europe and writes treatises on a variety of topics, including *De vegetabilibus* [On vegetables and plants] recording his botanical observations. This work classifies plants and vegetables into basic types and describes the structure and function of various parts of the plant, including root, stem, seed, leaf, and flower.

BIOLOGY (Vision)

Albertus Magnus (c.1200–1280, German) rejects the popular "extramission" theory that what makes sight possible is some emission from the eye, advocating instead a modified version of Aristotle's basic concept that the visible object alters the medium between the object and the eye and this alteration is propagated to the eye.

EARTH SCIENCES (Geography, Cartography)

Four maps of Great Britain drawn by Matthew Paris (c.1200–1259, English) locate major roads and towns.

EARTH SCIENCES (Glaciology)

Geographic details of the glaciers and icebergs of Iceland are described by an anonymous author in the Norwegian work *Konungs skuggsjä* [Mirror of the king].