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or Balun, and was probably a son or grandson of Wynebald de Balun of Eastington Manor, in Gloucestershire, brother of Hameline de Balun.

[Foss's Lives of the Judges; Dugdale's Origines Juridic. (Chron. Ser.); Courthope's Historic Peerage.] J. A. H.

BAAN. [See De Baan.]

BABBAGE, CHARLES (1792–1871), mathematician and scientific mechanician, was the son of Mr. Benjamin Babbage, of the banking firm of Praed, Mackworth, and Babbage, and was born near Teignmouth in Devonshire on 26 Dec. 1792. Being a sickly child he received a somewhat desultory education at private schools, first at Alphington near Exeter, and later at Enfield. He was, however, his own instructor in algebra, of which he was passionately fond, and, previous to his entry at Trinity College, Cambridge, in 1811, he had read Ditton's 'Fluxions,' Woodhouse's 'Principles of Analytical Calculation,' Lagrange's 'Théorie des Fonctions,' and other similar works. He thus found himself far in advance of his tutors' mathematical attainments, and becoming with further study more and more impressed with the advantages of the Leibnitzian notation, he joined with Herschel, Peacock (afterwards Dean of Ely), and some others, to found in 1812 the 'Analytical Society' for promoting (as Babbage humorously expressed it) 'the principles of pure *D*-ism in opposition to the *Dot*-age of the university.' The translation, by the three friends conjointly (in pursuance of the same design), of Lacroix's 'Elementary Treatise on the Differential and Integral Calculus' (Cambridge, 1816), and their publication in 1820 of two volumes of 'Examples' with their solutions, gave the first impulse to a mathematical revival in England, by the introduction of the refined analytical methods and the more perfect notation in use on the continent.

Babbage graduated from Peterhouse in 1814 and took an M.A. degree in 1817. He did not compete for honours, believing Herschel sure of the first place, and not caring to come out second. In 1815 he became possessed of a house in London at No. 5 Devonshire Street, Portland Place, in which he resided until 1827. His scientific activity was henceforth untiring and conspicuous. In 1815–17 he contributed to the 'Philosophical Transactions' three essays on the calculus of functions, which helped to found a new, and even yet little explored, branch of analysis. He was elected a fellow of the Royal Society in 1816. He took a prominent part in the foundation of the Astronomical Society in 1820, and acted as one of its secretaries until 1824, subsequently filling the offices, successively, of vice-president, foreign secretary, and member of council. In 1825 he joined with Herschel in repeating and extending Arago's experiments on the magnetisation of rotating plates, reaching the conclusion that 'in the induction of magnetism, time enters as an essential element' (*Phil. Trans.* cxv. 484). The 'astatic' needle in its present form was devised for use in these researches (*ib.* p. 476).

It was at Cambridge about 1812 that the first idea of calculating numerical tables by machinery occurred to Babbage. The favourable opinion of Wollaston encouraged him in 1819 to make a serious effort towards its realisation. Machines, such as had existed since Pascal's time, for performing single arithmetical operations, afforded neither saving of time nor security against error, since the selection and placing of a number of arbitrary figures was no less laborious and uncertain than the calculation itself. The essential novelty of Babbage's design consisted in setting wheelwork to develop the numerical consequences of the law of any given series, thus insuring the accurate calculation of an entire table without any further trouble to the operator than a few original adjustments. The mathematical principle selected by him as the basis of his invention was the 'method of differences,' by which it appears that the numbers composing nearly all arithmetical series can be formed by the repeated addition to fundamental numbers of a common difference or 'element'—a process eminently capable of being performed by machinery.

A small engine, of which he constructed a model on this system between 1820 and 1822, was described by Babbage in a note read before the Astronomical Society on 14 June 1822 (*Memoirs*, i. 309). The announcement was received with enthusiasm, and the highest anticipations were formed as to the results eventually to be derived from the invention (see Baily in *Phil. Mag.* lxiii. (1824) 355, and *Astr. Nach.* No. 46). It was rewarded on 13 June 1823 with the first gold medal bestowed by the society, in presenting which the president, Mr. Colebrooke, declared it to be 'in scope, as in execution, unlike anything before accomplished to aid operose computations' (*Mem. R. A. Soc.* i. 509).

Babbage now proposed to construct a machine upon a greatly enlarged scale, and made his views on the subject public in a letter dated 3 July 1822, addressed to Sir Humphry

Davy, president of the Royal Society. The prospect of vastly increased facility and accuracy in the production of the innumerable tables needed in navigation, astronomy, &c., could not be overlooked by the government, and the practicability of the scheme was on 1 April 1823 officially submitted to the judgment of the Royal Society. Having been favourably reported upon, an interview took place in July between Babbage and the chancellor of the exchequer (Mr. Robinson), at which some indistinct verbal agreement was come to. The upshot was that, aided by a grant of 1,500*l.* from the Civil Contingencies Fund, the works were without delay set on foot, and were continued actively for four years. At the end of that time Babbage went abroad under medical advice, and devoted a year to completing his extensive acquaintance with the resources of British mechanical art by the study of foreign workshops and factories. The results were embodied in an admirable little treatise 'On the Economy of Machinery and Manufactures' (1832, 4th edition 1835), of which the merit was attested by translation into four languages, and by reprints in America.

On his return to England towards the close of 1828 fresh applications to the treasury became necessary, which, after the council of the Royal Society had repeated its verdict of encouragement, and the Duke of Wellington, by a personal inspection of the works, had convinced himself of their satisfactory progress, were liberally responded to. Nevertheless, little more was done. Misunderstandings arose with Clement, the engineer; the previous prompt payment of his bills was suspended; and the removal of his business from Lambeth to the neighbourhood of Babbage's residence, No. 1 Dorset Street, Manchester Square, where the government had caused fire-proof buildings to be erected for the reception of the drawings and workshops, was made the occasion of an extravagant claim for compensation. On its refusal he withdrew his men, carried off (as he was legally entitled to do) the valuable tools made at the expense of his employers, and thus brought about a complete deadlock in the construction of the machine. In the interval of a year and a quarter which elapsed before an accommodation could be arrived at, Babbage's speculative mind had grasped the principle of an entirely new invention. The powers foreseen by him for the 'analytical engine' not only transcended, but superseded, those of its predecessor. It promised to do the work of the 'difference engine' with greatly increased rapidity, besides executing operations of a far higher range of complexity. These views he considered it his duty to communicate to the government, but failed, during *eight years*, to elicit any answer to the question whether, under the altered circumstances, they desired the fulfilment of his original (implied) engagement with them. At length, on 4 Nov. 1842, Mr. Goulburn (Sir Robert Peel's chancellor of the exchequer) acquainted him with the final decision to abandon, on the ground of excessive and indefinite expense, a construction which had already cost 17,000*l.* of public money, besides (probably) about 6,000*l.* of the inventor's private means.

The machine, of which the plan was thus rendered abortive, was to have had twenty places of figures with six orders of differences, and included mechanism for printing its results. A small portion, put together in 1833, capable of calculating to the third difference, gave a highly satisfactory earnest of the working of the whole. It was shown at the International Exhibition of 1862, and is now in the South Kensington Museum. An elaborate article on the subject by Dr. Lardner, published in the 'Edinburgh Review' for July 1834, led to the construction of the Swedish difference engines by Scheutz of Stockholm (whose original inventiveness Babbage was foremost in acknowledging), one of which was used by the late Dr. Farr in computing the 'English Life Table,' No. 3 (1864). As further secondary, but most important, results of Babbage's labours may be mentioned, first, improvements in machinery and tools, stated by Lord Rosse (*Proc. R. Soc.* vii. 257) to have more than repaid the sum expended on the unfinished machine; secondly, the invention of a scheme of notation applicable to the interpretation of all mechanical actions whatever, first explained in a communication by Babbage to the Royal Society, 16 March 1826 ('On a Method of expressing by Signs the Action of Machinery,' *Phil. Trans.* cxvi. part ii. 250), and afterwards more fully developed to meet the requirements of the analytical engine.

The capabilities of the new machine, to the perfecting of which Babbage devoted thirty-seven years of his life and no inconsiderable share of his fortune, were not limited, like those of the difference engine, to the tabulation of a particular function, but extended over a wide range of analysis. Two *sets* of perforated cards, similar to those used in Jacquard's looms, prescribed in the one case the numbers to be worked with ('variable cards'), and in the other the kind and sequence of operations to be performed upon them ('operation cards'). A committee appointed by the British Association in 1872 (including the names of Cayley and Clifford), to report upon the feasibility of the design, recorded their opinion that its successful realisation might mark an epoch in the history of computation equally memorable with that of the introduction of logarithms (*Report*, 1878, p. 100); yet did not counsel the attempt, the state of the drawings not being such as to admit of any reasonable estimate as to cost, strength, or durability, being founded upon them. This extraordinary monument of inventive genius accordingly remains, and will doubtless for ever remain, a 'theoretical possibility.'

Babbage occupied the Lucasian chair of mathematics at Cambridge during eleven years (1828–39), but delivered no lectures. He attended in 1828 the meeting of 'Naturforscher' at Berlin, and the scientific congress of Turin in 1840, when he was received with singular and unexpected favour by the king, Charles Albert (see chap. xxiv. of his *Passages in the Life of a Philosopher*). The drawings and models of the analytical engine exhibited by him on that occasion formed the subject of a valuable essay by Menabrea (*Bibl. Un. de Genève*, t. xli. October 1842), translated, with copious notes, by Ada, Lady Lovelace (TAYLOR'S *Scientific Memoirs*, iii. 666). His outspoken attack upon the management of the Royal Society in a volume entitled 'The Decline of Science in England' (1830) contributed materially to the origin of the British Association in the following year. Of this body he acted as one of the trustees during six years (1832–8), and originated the statistical section at the Cambridge meeting in 1833. The foundation, moreover, of the Statistical Society of London on 15 March 1834 was mainly his work. Amongst his ingenious ideas, that of signalling by 'occulting solar lights,' brought into practice by the Russians during the siege of Sebastopol, deserves mention. It had been recommended by him as a mode of identification for lighthouses (see his tract, *Notes respecting Lighthouses*, 1852). He twice—in 1832 and 1834—unsuccessfully contested the borough of Finsbury on liberal principles. Nor were what he regarded as his equitable claims to remunerative employment under government recognised. He was, however, a member of scientific bodies in all parts of the world, including the Paris Academy of Moral Sciences, the Royal Irish and American Academies.

In his latter years Babbage came before the public chiefly as the implacable foe of organ-grinders. He considered that one-fourth of his entire working power had been destroyed by audible nuisances, to which his highly-strung nerves rendered him peculiarly sensitive. In the decay of other faculties, his interest and memory never failed for the operations of the extensive workshops attached to his house. There what might be called the wreckage of a brilliant and strenuous career lay scattered, and thence, after his death on 18 Oct. 1871, some fragmentary portions of the marvellous engine destined to have indefinitely quickened the application of science to every department of human life, were collected and removed to the South Kensington Museum.

Of the eighty works enumerated by Babbage himself (*Passages*, &c. pp. 493–6) scarcely one, except the 'Economy of Manufactures,' can be regarded as a finished performance. The rest are mostly sketches or enlarged pamphlets, keen and suggestive, but incomplete. The 'Comparative View of the various Institutions for the Assurance of Lives' (1826), however, though not exempt from error, was a highly useful work, and one of the first attempts to popularise the subject. It contained a table of mortality deduced from the experience of the Equitable Society, to the construction of which Babbage had been led by his appointment as actuary to the Protector Life Assurance Company (No. 1) on its establishment in 1824 (see WALFORD'S *Insurance Cyclopædia*, iii. 10). The book was reviewed at length in the 'Quarterly' and 'Edinburgh' Reviews (January and March, 1827), was translated into German, and its table of mortality adopted by the Life Assurance Bank of Gotha, founded in 1829. The 'Table of Logarithms of the Natural Numbers from 1 to 108000' (1827), to the preparation of which Babbage devoted singular care, is still in repute. Several foreign editions were printed from the stereotyped plates. The 'Ninth Bridgewater Treatise' (1837, 2nd edition 1838), a work nobly planned, but very partially executed, was remarkable as one of the earliest attempts to reconcile breaches of continuity with the government of the universe by law, and vindicated the serviceableness of mathematics to religion. A volume entitled 'The Exposition of 1851; or Views of the Industry, the Science, and the Government of England' (1851), is the diatribe of a disappointed man, and, like his autobiographical 'Passages from the Life of a Philosopher' (1864), is disfigured by personal allusions, in giving utterance to which he wronged his better nature.

[Month. Not. R. Astr. Soc. xxxii. 101; Times, 23 Oct. 1871; Athenæum, 28 Oct. 1871; Ib. 14 Oct. and 16 Dec. 1848 (De Morgan); Weld's Hist. R. Society, ii. chap. xi.; Nature, v. 28; Ann. Reg. 1871, p. 159.] A. M. C.

of Messier 32, NGC205, and the Central Region of the Andromeda Nebula," *ibid.*, **100** (1944), 137–146; "A Program of Extragalactic Research for the 200-inch Hale Telescope," in *Publications of the Astronomical Society of the Pacific*, **60** (1948), 230–234; "Stellar Populations and Collisions of Galaxies," in *Astrophysical Journal*, **113** (1950), 413–418, written with L. Spitzer, Jr.; "Basic Facts on Stellar Evolution," in *Transactions of the International Astronomical Union VIII* (Cambridge, 1954), pp. 682–688 (discussion on pp. 688–689); "Identification of the Radio Sources in Cassiopeia, Cygnus A, and Puppis A," and "On the Identification of Radio Sources," in *Astrophysical Journal*, **119** (1954), 206–214, and 215–231, both written with R. Minkowski; "Polarization in the Jet of Messier 87," *ibid.*, **123** (1956), 550–551; and *Evolution of Stars and Galaxies* (Cambridge, Mass., 1963), ed. by Cecilia Payne-Gaposhkin from tape recordings of Baade's lectures at Harvard in 1958.

A list that includes seventy-three papers by Baade and ninety short communications is appended to Heckmann's obituary notice (see below); references to Baade's book (mentioned above) and several other contributions to symposia can be found in Poggendorff, VIIb (1967), 166. Baade's notebooks and other unpublished material are divided between the Mt. Wilson–Palomar Observatories and the Leiden Observatory.

II. SECONDARY LITERATURE. The citation delivered by John Jackson when Baade received (*in absentia*) the Gold Medal of the Royal Astronomical Society was printed in *Monthly Notices of the Royal Astronomical Society* (London), **114** (1954), 370–383; the one by Olin Chaddock Wilson that accompanied the Bruce Medal appeared in *Publications of the Astronomical Society of the Pacific*, **67** (1955), 57–61, and includes a portrait. Obituary notices on Baade include those by Fred Hoyle, in *Nature*, **187** (1960), 1075; Erich Schoenberg, in *Bayerische Akademie der Wissenschaften. Jahrbuch 1960*, pp. 177–181, plus a portrait facing p. 184; Otto Hermann Leopold Heckmann, in *Mitteilungen der Astronomischen Gesellschaft* [Hamburg] *1960* (1961), 5–11, with portrait and list of publications; Allan R. Sandage, in *Quarterly Journal of the Royal Astronomical Society*, **2** (1961), 118–121; and Halton C. Arp, in *Journal of the Royal Astronomical Society of Canada*, **55** (1961), 113–116.

The role Baade played in the early days of quasar research is described in Ivor Robinson, Alfred Schild, and E. L. Schücking, eds., *Quasi-Stellar Sources and Gravitational Collapse* (Chicago, 1965), pp. xi–xiv; and an essay on Baade's life and works by a longtime associate, Robert S. Richardson, constitutes ch. 16 (pp. 260–294) of Richardson's *The Star Lovers* (New York, 1967).

Further accounts of Baade's work are Fred Hoyle, "Report of the Meeting of Commission 28," in *Transactions of the International Astronomical Union VIII* (Cambridge, 1954), pp. 397–399; Hermann Kobold, "Komet 1922c (Baade)," in *Astronomische Nachrichten*, **217** (1923), cols. 175–176, and "Mitteilung über einen von W. Baade entdekten neuen Himmelskorper" [Planet 1924TD, later named Hidalgo], *ibid.*, **223** (1925), cols. 23–24; and R. S. Richardson, "A New Asteroid With Smallest Known Distance" [Icarus], in *Publications of the Astronomical Society of the Pacific*, **61** (1949), 162–165.

SALLY H. DIEKE

BABBAGE, CHARLES (*b.* Teignmouth, England, 26 December 1792; *d.* London, England, 18 October 1871), *mathematics, computer logic, computer technology.*

Babbage's parents were affluent. As a child, privately educated, he exhibited unusually sharp curiosity as to the how and why of everything around him. Entering Cambridge University in 1810, he soon found that he knew more than his teachers, and came to the conclusion that English mathematics was lagging behind European standards. In a famous alliance with George Peacock and John Herschel, he began campaigning for a revitalization of mathematics teaching. To this end the trio translated S. F. Lacroix's *Differential and Integral Calculus* and touted the superiority of Leibniz's differential notation over Newton's (then widely regarded in England as sacrosanct).

After graduation, Babbage plunged into a variety of activities and wrote notable papers on the theory of functions and on various topics in applied mathematics. He inquired into the organization and usefulness of learned societies, criticizing the unprogressive ones (among which he included the Royal Society) and helping found new ones—in particular the Astronomical Society (1820), the British Association (1831), and the Statistical Society of London (1834). He became a fellow of the Royal Society in 1816, and in 1827 was elected Lucasian professor of mathematics at Cambridge. He had not sought this prestigious chair (he described his election as "an instance of forgiveness unparalleled in history") and, although he held it for twelve years, never functioned as professor. This is a little surprising, in that the position could have been used to further the pedagogic reforms he advocated. But Babbage was becoming absorbed, if not obsessed, by problems of the mechanization of computation. He was to wrestle with these for decades, and they were partly responsible for transforming the lively, sociable young man into an embittered and crotchety old one, fighting all and sundry, even the London street musicians, whose activities, he figured, had ruined a quarter of his working potential.

Babbage had a forward-looking view of science as an essential part of both culture and industrial civilization, and he was among the first to argue that national government has an obligation to support scientific activities, to help promising inventors, and

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even to give men of science a hand in public affairs.

Few eminent scientists have had such diversified interests as Babbage. A listing of them would include cryptanalysis, probability, geophysics, astronomy, altimetry, ophthalmoscopy, statistical linguistics, meteorology, actuarial science, lighthouse technology, and the use of tree rings as historic climatic records. Two deserve special mention: the devising of a notation that not only simplified the making and reading of engineering drawings but also helped a good designer simplify his "circuits"; and his insightful writings on mass production and the principles of what we now know as operational research (he applied them to pin manufacture, the post office, and the printing trade).

Computational aids began to haunt Babbage's mind the day he realized that existing mathematical tables were peppered with errors whose complete eradication was all but infeasible. As a creature of his era—the machine-power revolution—he asked himself, at first only half in earnest, why a table of, say, sines could not be produced by steam. Then he went on to reflect that maybe it could. He was at the time enthusiastic about the application of the method of differences to tablemaking, and was indeed using it to compile logarithms. (His finished table of eight-figure logarithms for the first 108,000 natural numbers is among the best ever made.) While still engaged in this work, Babbage turned to the planning of a machine that would not only calculate functions but also print out the results.

To understand his line of thought, we must take a close look at the method of differences—a topic in what later became known as the calculus of finite differences. The basic consideration is of a polynomial $f(x)$ of degree n evaluated for a sequence of equidistant values of x. Let h be this constant increment. We next take the corresponding increments in $f(x)$ itself, calling these the *first* differences; then we consider the differences between consecutive first differences, calling these the *second* differences. And so forth. An obvious recursive definition of the rth difference for a particular value of x, say x_i, is

$$\Delta^r f(x_i) = \Delta^{r-1} f(x_i + h) - \Delta^{r-1} f(x_i),$$

and it is not difficult to show that, specifically,

$$\Delta^r f(x_i) = \sum_{m=0}^{r} (-1)^m \binom{r}{m} f[x_i + (r-m)h].$$

As r increases, the differences become smaller and more nearly uniform, and at $r = n$ the differences are constant (so that at $r = n + 1$, all differences are zero). A simple example—one that Babbage himself was fond of using—is provided by letting the function be the squares of the natural numbers. Here $n = 2$, and we have

x	1	2	3	4	5	6	...
$f(x)$	1	4	9	16	25	36	...
Δ^1		3	5	7	9	11	...
Δ^2			2	2	2	2	...

Two propositions follow. The first, perhaps not obvious but easily demonstrated, is that the schema can be extended to most nonrational functions (such as logarithms), provided that we take the differences far enough. (This is linked to the fact that the calculus of finite differences becomes, in the limit, the familiar infinitesimal calculus.) The second, originated by Babbage, is that the inverse of the schema is readily adaptable to mechanization. In other words, a machine can be designed (and it will be only slightly more sophisticated than an automobile odometer or an office numbering machine) that, given appropriate initial values and nth constant differences, will accumulate values of any polynomial, or indeed of almost any function. (For nonrational functions the procedure will be an approximation conditioned by the choice of r and h and the accuracy required, and will need monitoring at regular checkpoints across the table.)

This is what Babbage set out—and failed—to do. As the work progressed, he was constantly thinking up new ideas for streamlining the mechanism, and these in turn encouraged him to enlarge its capacity. In the end his precepts ruined his practice. The target he set was a machine that would handle twenty-decimal numbers and sixth-order differences, plus a printout device. When he died, his unfinished "Difference Engine Number One" had been a museum piece for years (in the museum of King's College, at Somerset House, London, from 1842 to 1862, and subsequently in the Science Museum, London—where it still is). What is more revealing and ironic is that, during his own lifetime, a Swedish engineer named Georg Scheutz, working from a magazine account of Babbage's project, built a machine of modest capacity (eight-decimal numbers, fourth-order differences, and a printout) that really worked. It was used for many years in the Dudley Observatory, Albany, New York.

Aside from technicalities, two factors militated against the production of the difference engine. One was cost (even a generous government subsidy would not cover the bills), and the other was the inventor's espousal of an even more grandiose project—the

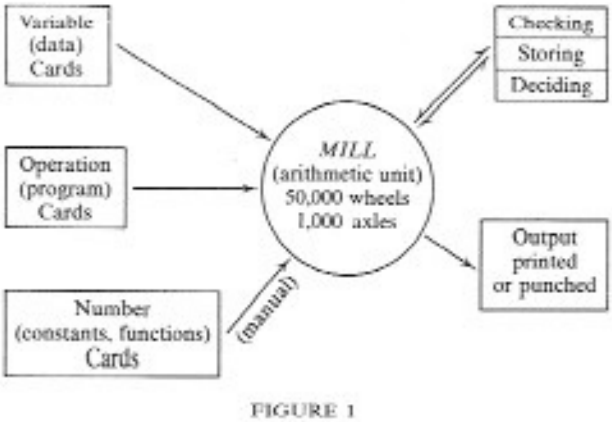

FIGURE 1

construction of what he called an analytical engine.

Babbage's move onto this new path was inspired by his study of Jacquard's punched cards for weaving machinery, for he quickly saw the possibility of using such cards to code quantities and operations in an automatic computing system. His notion was to have sprung feeler wires that would actuate levers when card holes allowed them access. On this basis he drew up plans for a machine of almost unbelievable versatility and mathematical power. A simplified flow diagram of the engine is shown in the accompanying figure. The heart of the machine, the mill, was to consist of 1,000 columns of geared wheels, allowing up to that many fifty-decimal-digit numbers to be subjected to one or another of the four primary arithmetic operations. Especially remarkable was the incorporation of decision-making units of the logical type used in today's machines.

Although the analytical engine uncannily foreshadowed modern equipment, an important difference obtains: it was decimal, not binary. Babbage, not having to manipulate electronics, could not have been expected to think binarily. However, his having to use wheels meant that his system was not "purely" digital, in the modern sense.

All who understood the plans expressed unbounded admiration for the analytical engine and its conceiver. But material support was not forthcoming, and it remained a paper project. After Babbage's death his son, H. P. Babbage, sorted the mass of blueprints and workshop instructions, and, in collaboration with others, built a small analytical "mill" and printer. It may be seen today in the Science Museum, London.

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II. SECONDARY LITERATURE. Practically all the significant material is either reproduced or indexed in the Morrisons' book, the only one entirely devoted to Babbage (see above). The symposium *Faster Than Thought* (London, 1953) has a first chapter (by the editor, B. V. Bowden) that is largely concerned with Babbage. Both of these books carry reprints of a translation and annotation of an article on the analytical engine written by the Italian military engineer L. F. Menabrea (Geneva, 1842). The translator was Lady Lovelace, Lord Byron's mathematically gifted daughter, and her detailed annotations (especially a sketch of how Bernoulli numbers could be computed by the engine) are excellent. It is in the course of this commentary that she finely remarks that "the Analytical Engine *weaves algebraic patterns*, just as the Jacquard-loom weaves flowers and leaves." The sectional catalog *Mathematics, I. Calculating Machines and Instruments*, The Science Museum (London, 1926), contains much useful illustrated information about Babbage's engines, as well as about allied machines, such as the Scheutz difference engine.

NORMAN T. GRIDGEMAN

BABCOCK, STEPHEN MOULTON (*b.* Bridgewater, New York, 22 October 1843; *d.* Madison, Wisconsin, 1 July 1931), *agricultural chemistry.*

Babcock, the son of Pelig and Mary Scott Babcock, received the B.A. from Tufts College in 1866. His engineering studies at Rensselaer Polytechnic Insti-

Appendix C
REFERENCES IN BIOGRAPHICAL DICTIONARIES AND OTHER COLLECTIONS

Note: A Key to Title Codes appears at the end of this appendix.

Agnesi	Alic, Archibald, Britannica (11th), CG, Coolidge, DcScB, Fang, Gomes, Hale, Iacobacci, IntDcWomB, Ireland, Jacotin, Loria, May, Mozans, NCE, Osen, Perl, Poggendorf, Poole, Rebière, Tee, Valentin, WorWhoSci, WS, Zen
Bari, N. K.	CG, Fang, May, Poggendorf, WS, Zen
Bari, R.	DWM73,–81
Bernstein	AmM&WS73,–76,–79,–82, DWM73,–81, LEduc74, WhoAm74, WhoAmW64,–66,–68,–70,–72,–74, WhoWorJ72
Châtelet	Alic, Britannica (15th), CG, Coolidge, DcScB, Fang, Hale, IntDcWomB, Ireland, LinLibL, Loria, May, Mozans, Osen, OxFr, Perl, Poggendorf, Rebière, REn, Tee, Valentin, WorWhoSci, WS, Zen
Cox	AmM&WS73, WhAm81, WhoAm78, WhoAmW58,–61,–64, WomBkWorRec, WS
Fenchel	
Flügge-Lotz	AmM&WS73, NewYTBS74, NotAW80, Siegel, WhAm76, WhoAmW70, WomBkWorRec, WomPar, WS
Geiringer	CG, Dresden, Ireland, NotAW80, Siegel (under von Mises), WomPar, WS
Germain	Alic, Archibald, Britannica (15th), CG, Coolidge, DcScB, Eneström-II, Gomes, Hale, Iacobacci, IntDcWomB, Ireland, Jacotin, Loria, May, Michaud, Möbius, Mozans, Osen, Perl, Poggendorf, Rebière, Tee, Valentin, WorWhoSci, WS, Zen
Granville	Newell, WND, WomPar (under Collins)
Hayes	AmM&WS27,–33, CG, DcNAA, Ireland, OhA&B, Rebière, Siegel, TwCBDA, WhAm43, WhNAA, WomPar, WomWWA, WS
Hopper	AmM&WS73,–76,–79,–82, DWM73,–81, GoodHs, IntDcWomB, NewYTBE71, Owens, WhoAm74,–76,–78,–82, WhoAmW58, –61,–64,–66,–70,–72,–74, WomBkWorRec, WS
Hypatia	Adelman, Alic, Archibald, AsBiEn, Britannica (11th, 15th), Cantor, CG, Coolidge, DcScB, Gomes, GoodHs, Hale, Hays, Iacobacci, IntDCWomB, Ireland, Jacotin, LinLibL, LinLibS, Loria, May, Michaud, Mozans, NewC, Osen, Pauly, Perl, Poggendorf, Poole, Rebière, REn, Schmidt, Tee, WorWhoSci, WS, Zen
Janovskaja	CG, WS, Zen
Karp	AmM&WS73, CG, WhoAmW66, -68, WS, Zen
Kendall	AmM&WS61, AmWom, CG, Owens, WS, Zen
Kochina	IntWW74,–75,–76,–77, Ireland, Zen

Kovalevskaia	Adelman, Alic, Archibald, Bell, BiD&SB, Britannica (11th, 15th), CasWL, CG, Coolidge, DcScB, Eneström-I, Gomes, Iacobacci, IntDcWomB, Ireland, Jacotin, Loria, May, Möbius, Mozans, Osen, Perl, Poggendorf, Poole, Rebière, Riches, Schmidt, Valentin, WND, WorWhoSci, WS, Zen
Kramer	AmM&WS73,-76,-79, ConAu83 (vol. 107), DWM73,-81, Owens, WhoAmW64,-74,-75,-77
Ladd-Franklin	AmBi, AmM&WS27,-33, BiCAW, Britannica (15th), CG, DcAmB, DcNAA, Eells, Ireland (under Franklin), LibW, May, NatCAB26, -B, NotAW, Poggendorf, Rebière, Siegel, TwCBDA, Valentin, WhAm43, WhNAA, WomPar, WorWhoSci, WS
Litvinova	WS, Zen
Lovelace	Alic, CG, IntDcWomB, Jacotin, Michaud, NewC, Perl, Poole, Rebière, Tee, WND, WS, Zen
Macintyre	CG, May, NatCAB48, WomPar, WS
Maddison	AmM&WS49, CG, Eels, Eneström-II, Owens, Poggendorf, Rebière, Siegel, Valentin, WomWWA, WS
Merrill	AmM&WS49, AmWom, BiDAmEd, CG, DcNAA, NatCAB42, Owens, Siegel, WomPar, WomWWA, WS
Morawetz	AmM&WS73,-76,-79,-82, DWM73,-81, WhoAm82, WhoAmW81, WS
Neumann	CG, Kramer, WomBkWorRec, WorWhoSci, WS
Newson	AmM&WS55,-61, AmWom, CG, Owens, Poggendorf, Rebière, Siegel, Valentin, WomWWA, WS
Noether	Britannica (15th), CG, DcScB, Iacobacci, IntDcWomB, Jacotin, Jones, May, Osen, Perl, Poggendorf, Siegel, Wer, WhoNG, WND, WomBkWorRec, WorWhoSci, WS, Zen
Péter	CG, WS
Rees	AmM&WS73,76,-79,-82, CurBio57, DWM81, IntWW74,-75,-76,-77,-78, Ireland, Jones, Owens, WhoAm74,-76,-78,-82, WhoAmW58,-61,-64,-66,-68,-70,-72,-74, WomBkWorRec, WomPar, WS
Robinson	AmM&WS82, DWM81, WhoAm78, WS
Rudin	AmM&WS76,-79,-82, DWM73,-81, WhoAm82, WS
Scott	AmM&WS27,-33, BiDAmS, CG, DcNAA, Eneström-II, IntDcWomB, Ireland, May, NotAW, Osen, Poggendorf, Rebière, Siegel, Valentin, WhAm43, WomBkWorRec, WomPar, WomWWA, WS
Sinclair	AmM&WS55,-61, AmWom, CG, Owens, Poggendorf, WS
Somerville	Adelman, Alic, Alli, BibD, BiD&SB, BrAu19, Britannica, CG, Chambr3, Coolidge, DcEnL, DcScB, DiNB, EvLB, Hale, IntDcWomB, Ireland, Jacotin, May, Mozans, Osen, Perl, Poggendorf, Poole, Rebière, Tee, Valentin, Walford, WND, WorWhoSci, WS, Zen

Sperry	AmM&WS38,–61, AmWom, CG, Owens, WhoAmW58, WS
Stott	CG, WS
Taussky-Todd	AmM&WS73,–76,–79, DWM73,–81, IntAu&W77, WhoAm78, WhoAmW74,–75, WhoWest82, WS
Weiss	CG, WS
Wheeler	AmM&WS55, BiDAmEd, CG, NotAW80, Owens, Poggendorf, Siegel, WhoAm51, WomPar, WS
Young	CG, Eneström–II, Perl, Poggendorf, Rebière, WhLit, Who44, WS

KEY TO TITLE CODES

(Some of the title codes are from *Biography and Genealogy Master Index*, 2nd ed., and *1983 Supplement*, edited by Miranda C. Herbert and Barbara McNeil. Detroit: Gale Research Company, 1980, 1983.)

Adelman	Adelman, Joseph Ferdinand Gottlieb. *Famous Women*. New York: Lonow, 1926.
Alic	Alic, Margaret. *Hypatia's Heritage*. London: The Women's Press Limited, 1986.
Alli	Allibone, S. Austin. *A Critical Dictionary of English Literature and British and American Authors Living and Deceased from the Earliest Accounts to the Latter Half of the Nineteenth Century*. 3 vols. Philadelphia: J. B. Lippincott & Co., 1858–1871. Reprint. Detroit: Gale Research Co., 1965.
AmBi	Preston, Wheeler. *American Biographies*. New York: Harper & Brothers Publishers, 1940. Reprint. Detroit: Gale Research Co., 1974.
AmM&WS	*American Men and Women of Science. Physical and Biological Sciences* (formerly *American Men of Science*). Edited by Jaques Cattell. New York: R. R. Bowker Co., 1927, 1933, 1938, 1949, 1955, 1961, 1971–1973, 1976–1978, 1979, 1982.
AmWom	*American Women; The Official Who's Who Among the Women of the Nation*. 3 vols. Edited by Durward Howes. Los Angeles: American Publications, 1935–1940. Consolidated and reprinted as *American Women 1935–1940: A Composite Biographical Dictionary*. Detroit: Gale Research Co., 1981.
Archibald	Archibald, R. C. "Women as mathematicians and astronomers." *American Mathematical Monthly* 25 (1918): 136–139.
AsBiEn	*Asimov's Biographical Encyclopedia of Science and Technology*. 2nd revised edition. Edited by Isaac Asimov. New York: Doubleday, 1982.

Bell	Bell, Eric Temple. *Men of Mathematics*. New York: Simon and Schuster, 1937.
BibD	*The Bibliophile Dictionary*. Originally published as Volumes 29 and 30 of *The Bibliophile Library of Literature, Art, and Rare Manuscripts*. Compiled and arranged by Nathan Haskell Dole, Forrest Morgan, and Caroline Ticknor. New York and London: International Bibliophile Society, 1904. Reprint. Detroit: Gale Research Co., 1966.
BiCAW	*The Biographical Cyclopaedia of American Women*. 2 vols. Vol. 1: Compiled under the supervision of Mabel Ward Cameron. New York: Halvord Publishing Co., Inc., 1924. Vol. 2: Compiled under the supervision of Erma Conkling Lee. New York: Franklin W. Lee Publishing Corp., 1925. Reprint (both volumes). Detroit: Gale Research Co., 1974.
BiDAmEd	*Biographical Dictionary of American Educators*. 3 vols. Edited by John F. Ohles. Westport, Conn.: Greenwood Press, 1978.
BiDAmS	Elliott, Clark A. *Biographical Dictionary of American Science, the Seventeenth through the Nineteenth Centuries*. Westport, Conn.: Greenwood Press, 1979.
BiD&SB	*Biographical Dictionary and Synopsis of Books Ancient and Modern*. Edited by Charles Dudley Warner. Akron, Ohio: Werner Co., 1902. Reprint. Detroit: Gale Research Co., 1965.
BrAu	*British Authors before 1800: A Biographical Dictionary*. Edited by Stanley J. Kunitz and Howard Haycraft. New York: H. W. Wilson Co., 1952.
Britannica	*Encyclopaedia Britannica*. 11th ed. Cambridge, England: Cambridge University Press, 1910–1911. *The New Encyclopaedia Britannica*. 15th ed. Chicago: Encyclopaedia Britannica, Inc., 1974.
Cantor	Cantor, Moritz. *Vorlesungen über Geschichte der Mathematik*. 3 vols. Leipzig: Teubner, 1922.
CasWL	*Cassell's Encyclopaedia of World Literature*. Edited by S. H. Steinberg in two volumes. Revised and enlarged in three volumes by J. Buchanan-Brown. New York: William Morrow & Co., 1973.
CG	Campbell, Paul J., and Louise S. Grinstein. "Women in mathematics: A preliminary selected bibliography." *Philosophia Mathematica* 13/14 (1976/77): 171–203 + errata from first author.
Chambr	*Chambers's Cyclopaedia of English Literature*. 3 vols. Edited by David Patrick, revised by J. Liddell Geddie. Philadelphia: J. B. Lippincott Co., 1938. Reprint. Detroit: Gale Research Co., 1978.
ConAu	*Contemporary Authors*. 118 vols. Detroit: Gale Research Co., 1967–1986.
Coolidge	Coolidge, Julian L. "Six female mathematicians." *Scripta Mathematica* 17 (1951): 20–31.
CurBio	*Current Biography Yearbook*. New York: H. W. Wilson Co., 1940–1980.

DcAmB — *Dictionary of American Biography*. 20 vols. and 6 supplements. Edited under the auspices of the American Council of Learned Societies. New York: Charles Scribner's Sons, 1928–1936, 1944, 1958, 1973, 1974, 1977, 1980.

DcEnL — Adams, W. Davenport. *Dictionary of English Literature: Being a Comprehensive Guide to English Authors and Their Works*. 2nd ed. London: Cassell Petter & Galpin, n.d. Reprint. Detroit: Gale Research Co., 1966.

DcNAA — *A Dictionary of North American Authors Deceased before 1950*. Compiled by W. Stewart Wallace. Toronto: Ryerson Press, 1951. Reprint. Detroit: Gale Research Co., 1968.

DcScB — *Dictionary of Scientific Biography*. 14 vols. and supplement. Edited by Charles Coulston Gillispie. New York: Charles Scribner's Sons, 1970–1976, 1978.

DiNB — *Dictionary of National Biography*. 63 vols. Edited by Leslie Stephen and Sidney Lee. London: Smith, Elder, & Co., 1885–1901. With 7 supplements covering 1901–1960.

Dresden — Dresden, Arnold. "The migration of mathematicians." *American Mathematical Monthly* 49 (1942): 415–429.

DWM — *Directory of Women in the Mathematical Sciences*. Committee on Women in Mathematics, September 1981. *Directory of Women Mathematicians*. American Mathematical Society, 1973.

Eells — Eells, Walter Crosby. "American doctoral dissertations on mathematics and astronomy written by women in the 19th century." *Mathematics Teacher* 50 (1957): 374–376.

Eneström–I — Eneström, Gustaf. "Bio-bibliographie der 1881–1900 verstorbenen Mathematiker." *Bibliotheca Mathematica* 2 (1901): 326–350.

Eneström–II — Eneström, Gustaf. "Note bibliographique sur les femmes dans les sciences exactes." *Bibliotheca Mathematica* 10 (1896): 73–76.

EvLB — *Everyman's Dictionary of Literary Biography, English and American*. Rev. ed. Compiled after John W. Cousin by D. C. Browning. London: J. M. Dent & Sons Ltd.; New York: E. P. Dutton & Co., 1960.

Fang — Fang, J. *Mathematicians from Antiquity to Today. I: A-C*. Hauppauge, N.Y.: Paideia, 1972.

Gomes — Gomes Teixeira, Francisco. "Conferências sôbre quatro mulheres célebres na História da Matemática." In *Panegíricos e Conferências*, 195–228. Coimbra, Portugal: Imprensa da Universidade, 1925.

GoodHs — *The Good Housekeeping Woman's Almanac*. Edited by Barbara McDowell and Hana Umlauf. New York: Newspaper Enterprise Association, Inc., 1977.

Hale — Hale, Sarah Josepha. *Woman's Record: or Sketches of All Distinguished Women from "the beginning" till A.D. 1850*. New York: Harper, 1853.

Hays — Hays, Mary. *Female Biography*. London: Richard Phillips, 1803.

Iacobacci — Iacobacci, Rora F. "Women of mathematics." *Arithmetic Teacher* 17 (1970): 316–324; also in *Mathematics Teacher* 63 (1970): 329–337.

IntAu&W — *The International Authors and Writers Who's Who*. 8th ed. Edited by Adrian Gaster. Cambridge, England: International Biographical Centre, 1977.

IntDcWomB — *The International Dictionary of Women's Biography*. Edited by Jennifer S. Uglow and Frances Hinton. New York: Continuum, 1982.

IntWW — *The International Who's Who*. London: Europa Publications Ltd., 1974, 1975, 1976, 1977, 1978. Distributed by Gale Research Co., Detroit, Mich.

Ireland — Ireland, Norma Olin. *Index to Women of the World from Ancient to Modern Times: Biographies and Portraits*. Westwood, Mass.: F. W. Faxon Co., 1970.

Jacotin — Dubreil-Jacotin, Marie-Louise. "Women mathematicians." In *Great Currents of Mathematical Thought*, edited by F. LeLionnais, vol. 1, 268–280. New York: Dover, 1970. Translation of revised and enlarged 1962 edition of *Les Grands Courants de la Pensée Mathématique*. Paris: Librairie Scientifique et Technique, 1948.

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Kramer — Kramer, E. E. "Six more female mathematicians." *Scripta Mathematica* 23 (1957): 83–95. In revised form in *The Nature and Growth of Modern Mathematics*, 704–714. New York: Hawthorn Books, 1970.

LEduc — *Leaders in Education*. 5th ed. Edited by Jaques Cattell Press. New York: R. R. Bowker Co., 1974.

LibW — *Liberty's Women*. Edited by Robert McHenry. Springfield, Mass.: G. & C. Merriam Co., Publishers, 1980.

LinLibL — *The Lincoln Library of Language Arts*. 3rd ed. 2 vols. Columbus, Ohio: Frontier Press Co., 1978.

LinLibS — *The Lincoln Library of Social Studies*. 8th ed. 3 vols. Columbus, Ohio: Frontier Press Co., 1978.

Loria — Loria, Gino. "Les femmes mathématiciennes." *Revue Scientifique* (4) (20) (1903): 385–392.

May — May, Kenneth O. *Bibliography and Research Manual of the History of Mathematics*. Toronto and Buffalo: University of Toronto Press, 1973.

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Möbius — Möbius, Paul Julius. "Beiträge zur Kenntnis des Mathematischen Talentes. C. Ueber die mathematischen Weiber." In *Ueber die Anlage zur Mathematik*, 77–86. Leipzig: Barth, 1900.

Mozans — Mozans, H. J. (pseudonym for John Augustine Zahm). *Women in Science*. New York and London: Appleton, 1913. Reprint. Cambridge, Mass.: MIT Press, 1974.

NatCAB — *The National Cyclopaedia of American Biography*. 57 vols. New York and Clifton, N.J.: James T. White & Co., 1892–1977. Reprint. Vols. 1–50. Ann Arbor: University Microfilms, 1967–1971.

NCE — *New Catholic Encyclopedia*. New York: McGraw-Hill, 1967.

NewC — *The New Century Handbook of English Literature*. Rev. ed. Edited by Clarence L. Barnhart with the assistance of William D. Halsey. New York: Appleton-Century-Crofts, 1967.

Newell — *Black Mathematicians and Their Works*. Edited by Virginia K. Newell et al. Ardmore, Pa.: Dorrance, 1980.

NewYTBE — *The New York Times Biographical Edition: A Compilation of Current Biographical Information of General Interest*. New York: Arno Press, 1970–1973. Continued by *The New York Times Biographical Service*.

NewYTBS — *The New York Times Biographical Service: A Compilation of Current Biographical Information of General Interest*. New York: Arno Press, 1974–1979. A continuation of *The New York Times Biographical Edition*.

NotAW — *Notable American Women, 1607–1950: A Biographical Dictionary*. 3 vols. Edited by Edward T. James. Cambridge, Mass.: Belknap Press of Harvard University Press, 1971.

NotAW80 — *Notable American Women: The Modern Period*. Edited by Barbara Sicherman and Carol Hurd Green. Cambridge, Mass.: Belknap Press of Harvard University Press, 1980.

OhA&B — *Ohio Authors and Their Books: Biographical Data and Selective Bibliographies for Ohio Authors, Native and Resident, 1796–1950*. Edited by William Coyle. Cleveland and New York: World Publishing Co., 1962.

Osen — Osen, Lynn M. *Women in Mathematics*. Cambridge, Mass.: MIT Press, 1974.

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Perl — Perl, Teri. *Math Equals: Biographies of Women Mathematicians + Related Articles*. Menlo Park, Calif.: Addison-Wesley, 1978.

Poggendorf — Poggendorf, Johann Christian. *Biographisch-Literarisches Handwörterbuch zur Geschichte der exakten Wissenschaften*. Leipzig: Barth (vols. 1–4), Verlag Chemie (vols. 5–6), 1863–1936. Ann Arbor: Edwards Brothers, 1936. Berlin: Akademie-Verlag (vol. 7), 1981–1984.

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REn — Benet, William Rose. *The Reader's Encyclopedia*. 2nd ed. New York: Thomas Y. Crowell Co., 1965.

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Walford — Walford, Lucy Bethia (Colquhoun). *Four Biographies from Blackwood*. London: Blackwood, 1888.

Wer — *Degeners Wer Ist's?* 10th ed. Berlin: Verlag Herrmann Degener, 1935.

WhAm — *Who Was Who in America*. 8 vols. plus index. Chicago: A. N. Marquis Co., 1943–1985.

WhLit — *Who Was Who in Literature, 1906–1934*. 2 vols. Gale Composite Biographical Dictionary Series, No. 5. Detroit: Gale Research Co., 1979.

WhNAA — *Who Was Who among North American Authors, 1921–1939*. Compiled from *Who's Who among North American Authors*, Vols. 1–7, 1921–1939. 2 vols. Gale Composite Biographical Dictionary Series, No. 1. Detroit: Gale Research Co., 1976.

Who — *Who's Who*. An annual biographical dictionary. New York: St. Martin's Press; London: A. & C. Black, Ltd.

WhoAm — *Who's Who in America*. Chicago: Marquis Who's Who, Inc., 1951, 1974, 1976, 1978, 1982.

WhoAmW — *Who's Who of American Women*. Chicago: Marquis Who's Who, Inc., 1958, 1961, 1964, 1966, 1968, 1970, 1972, 1974, 1975, 1977, 1981.

WhoNG — Wistrion, Robert S. *Who's Who in Nazi Germany*. New York: Macmillan, 1982.

WhoWest — *Who's Who in the West*. Chicago: Marquis Who's Who, Inc., 1982.

WhoWorJ — *Who's Who in World Jewry: A Biographical Dictionary of Outstanding Jews*. Edited by I. J. Carmin Karpman. New York: Pitman Publishing Corp., 1972.

WND — Perl, Teri and Joan M. Manning. *Women, Numbers and Dreams*. Santa Rosa, Cal.: National Women's History Project (P.O. Box 3716, Santa Rosa, Calif. 95402), 1982.

WomBkWorRec — *The Women's Book of World Records and Achievements*. Edited by Lois Decker O'Neill. Garden City, N.Y.: Anchor, 1979.

WomPar — Herman, Kali. *Women in Particular: An Index to American Women*. Phoenix, Ariz.: Oryx Press, 1984.

WomWWA — *Woman's Who's Who of America*. Edited by John William Leonard. New York: American Commonwealth Co., 1914. Reprint. Detroit: Gale Research Co., 1976.

WorWhoSci — *World Who's Who in Science*. Edited by Allen G. Debus. Chicago: Marquis Who's Who, Inc., 1968.

WS — Herzenberg, Caroline L. *Women Scientists from Antiquity to the Present: An Index*. West Cornwall, Conn.: Locust Hill Press, 1986.

Zen — Zenkezich, I. G. *The Fate of Talent (Essays About Women Mathematicians)* (in Russian). Briansk: Pedagogicheskoe Obshchestzo RFSFR, 1968.