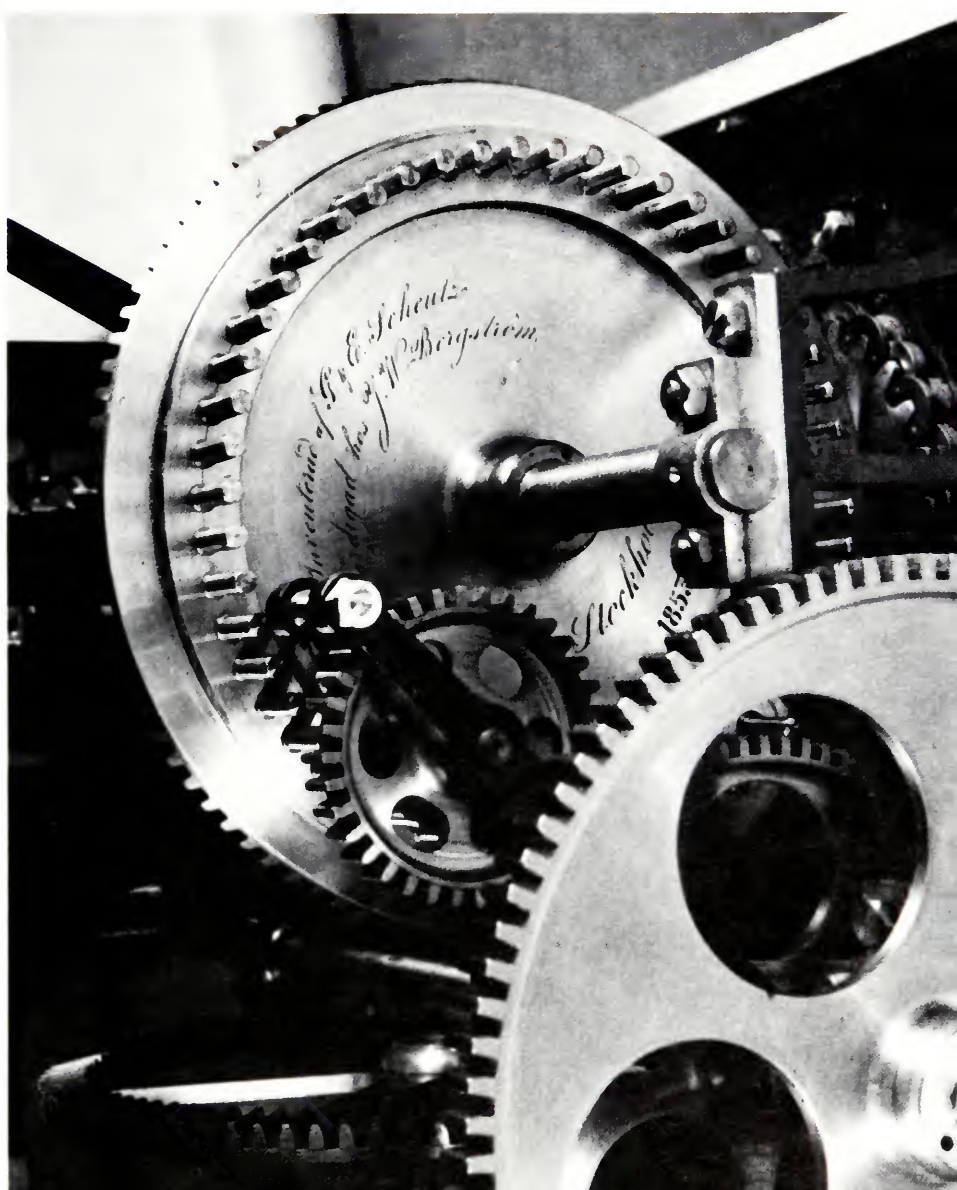
Georg Scheutz and the First Printing Calculator

Uta C. Merzbach

SMITHSONIAN INSTITUTION PRESS



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ABSTRACT

Merzbach, Uta C. Georg Scheutz and the First Printing Calculator. *Smithsonian Studies in History and Technology,* number 36, 74 pages, 35 figures, 1977.—The Swedish publisher Georg Scheutz (1785–1873) was a man who combined literary, political, scientific, and technological interests. Inspired by the difference engine of Charles Babbage, he and his son, the engineer Edvard Scheutz (1821–1881), designed and constructed a machine to compute tabular differences and print the results. The machine, built with a grant from the Swedish government and underwritten by a group of Swedish supporters of Scheutz, was completed in 1853. It was patented in Great Britain in 1854, shown at the Paris Universal Exhibition in 1855, and purchased for the Dudley Observatory in Albany, New York, in 1856. A copy of the machine was constructed in 1857. For a short time, in 1858, work contracted by the United States Department of Navy for the Nautical Almanac Office was performed on the machine. Because of the departure (resulting from a major dispute) of the astronomer Benjamin A. Gould and his assistants from the Dudley Observatory, the machine was used rarely in later years and gradually fell into total disuse.

The arguments surrounding the construction, purchase, and use of the machine portray two recurring themes in the history of technology. One is the conflict between defenders of established procedures and those of new innovations within a given field. The other is the influence of social, economic, or political currents on the activities in that field.

The Scheutz calculator is significant because it made feasible the concept of a machine that computes and then retains results in printed form.

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Introduction

The story of Georg Scheutz and the first printing calculator is the story of an innovative contribution to technology, born of currents of thought and action that characterize the times as well as the place in which they were shaped. It also depicts vividly the commonality and diversity of intellectual factions in some of the countries that dominated Western thought in the 1800s. At the same time, the story of Georg Scheutz again raises questions about a man who distinguishes himself by doing that which supposedly cannot be done in his time.

In recent years there have been attempts to establish models of scientific and technological national growth, usually influenced by the concept of "stages of economic growth." Frequently, these models are constructed by juxtaposing developments between and within major power nations and emerging nations. Such nations usually exhibit a strong native tradition, or a combination of native tradition with methods superimposed by a ruling power. This limits the utility of the model. There is a third group of countries, however, which offers a unique opportunity to view the adoption of competing technological or theoretical systems or ideas on more or less neutral ground. This group is composed of independent nations which, by virtue of geography and relatively extended periods of neutrality, are in a position to interact simultaneously with several major powers exhibiting distinctive or competing patterns.

Modern Sweden has played this role of serving as a neutral testing ground in several periods. In the eighteenth century it made a place for the forging of Newtonian ideas onto continental concepts. In the nineteenth century it provided a distinctive setting for the adoption of technological products, such as the railway, the postage stamp, and the telegraph, then sweeping the Western countries. A tendency by scholars to neglect these activities has deprived historians of a valuable resource. It has also led to superficial treatments of superior contributions by Swedish inventors or entrepreneurs, causing them to be considered either as totally derivative, or as the products of geniuses. The first printing calculator, a Swedish contribution, provides a vivid example of an achievement that owed as much to the trends and currents of the times as it did to the talents of the remarkable Georg Scheutz.

Acknowledgments.—Thanks are due to Christine Bain, librarian of the Dudley Observatory, Albany, for making available for study and photography a set of the extant refraction tables; to Jane Pugh of the Science Museum in London for taking time to answer several questions about the Scheutz-Donkin engine, and for providing photographs and copies of documentation not available elsewhere; to Reidar Norby of the National Museum of History and Technology, Smithsonian Institution, for assisting in translating some passages pertaining to the early history of Swedish postage stamps; to Sheila Ford for aiding with that portion of the bibliography dealing with events at the Dudley Observatory; to Donna J. Elliott for preparation of the typescript; and to Audrey B. Davis for reading and giving critical comments on the typescript. Margaret Kober Merzbach gave invaluable assistance by translating for me

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Bergstedt's essay on Scheutz from the Swedish, and by providing an analysis of the source journals Scheutz used in his *Journal för manufakturer.*

Georg Scheutz

Georg Scheutz is best known outside of Sweden for his difference engine, a special-purpose calculating machine designed after a similar one proposed by the English mathematician Charles Babbage in the 1820s. Babbage has been resurrected in our times because in his design for a different machine, the "Analytical Engine," he outlined very clearly the concept of today's automatic computer. Neither of Babbage's machines was ever completed. He had received a government grant for the construction of the difference engine; yet neither this support nor the money he invested personally sufficed to produce a finished product.

It has become fashionable to speculate on the cause of Babbage's failure to achieve a working machine. Some commentators follow Babbage's lead by attributing his problem to the stupidity, if not the ill will, of those on whom he had to depend, particularly those within the scientific and political power structures of Victorian England. Others assign the common but meaningless explanation that he was a man ahead of his time. Still others refine this by declaring that the technology of his time was not up to the task he had set for it. Yet another, more knowledgeable few suggest the failure lay in his being more of a mathematician than an engineer. Whatever the explanation, none account for the fact that a contemporary of Babbage, who lived in a country which at that time derived much of its technological know-how from England, who was neither mathematician nor engineer, and who, like Babbage, opposed the ruling powers of his homeland during much of his life, designed a machine intended to do precisely what Babbage's difference engine was intended to do, and saw it completed, purchased, and used. That man was Georg Scheutz.

Early Influences

Georg Scheutz was born in Jönköping, Sweden, on 23 September 1785 (Figure 1). His mother counted a well-known hymn-writer, Andreas Lenaeus, among her ancestors. His paternal grandfather, a German immigrant, had been a cook in the royal

Figure 1.—Georg Scheutz.

Danish service. Georg Scheutz's father, Frederik Christian Scheutz, born in Copenhagen and also trained as a cook, became an innkeeper in Jönköping.

At the time of his birth, Jönköping was a town of some 2000 inhabitants. Because of its strategic location at the southern tip of Lake Vettern, it was an important stopping point for travelers in a country that had been one of Europe's leading powers in the seventeenth century and had demonstrated leadership in the science of the eighteenth. The Scheutz inn gained the reputation of being Jönköping's foremost hostelry. Presumably, questions of political and scientific leadership were of less concern to Scheutz's parents than were everyday realities, such as the fires that repeatedly devastated the town, one of the major ones occurring just a few months before Scheutz's birth. As late as 1812, Jönköping could still be described by travelers (Thomson, 1813:284) as

> a small town consisting chiefly of two parallel streets running east and west. It is . . . the seat of the superior Court of Justice for . . . Gothland. It is said to contain about 3000 inhabitants. The houses are almost all of wood, and covered on the roof either with turf or wood.

At his home, the inn, young Georg was exposed to representatives of a variety of classes and professions. Since his father's business interests included the importation of wines and Mediterranean fruits, and for some time catering services for the famous spa at Medevi, the boy's early contacts acquainted him with languages and life styles far beyond those to be expected in an average community fitting Jönköping's description.

Georg Scheutz received his early formal education at the local elementary school. The teachers there encouraged their better students. Ludvig Borgström (1788–1862), who shared with his friend Scheutz a two-fold interest in literature and science, told of his teachers at Jönköping supplementing the curriculum by providing him with free instruction in Latin, German, and French. Similarly, Georg Scheutz obtained special guidance from the school's co-rector, G. Von Alander, who roomed at the Scheutz inn. Georg completed his secondary schooling at the gymnasium of Växjö. He compensated for the lack of formal scientific training in these schools by frequent and extensive field trips in the country with groups of his contemporaries.

In 1803 Scheutz matriculated at the University of Lund, where in 1805 he took the juridical examinations that ordinarily were preliminary to the final preparation for the *Bergexamen*. He soon became vice-actuary at the Gota Supreme Court, a position that led to his serving as judge from time to time. Although he attended the University of Uppsala briefly, it appears that he did not complete the *Bergexamen,* presumably for lack of funds. Instead, he moved to Stockholm where, about 1812, he entered government service. After a short period of working in one of the ministries, he became vice-auditor with the Swedish artillery, a position that led to the title of auditor but to no salary.

The period of Scheutz's university studies and subsequent judicial apprenticeship had provided few opportunities for communicating on scientific matters. His contemporary, Ludvig Borgström, who had spent a portion of this period in Stockholm studying under Johan Jacob Berzelius, upon his return to Jönköping singled out Georg Scheutz as being the only one there whose scientific interests and knowledge he could enjoy and admire.

If Jönköping provided little scientific stimulation, the opportunities in literature were greater. In particular Scheutz's superior at the Gota court, the Honorable J. Wetterbergh, opened his home to the young Jönköping men of Scheutz's generation for hours of discussion on literary topics. Wetterbergh, like Scheutz, had chosen a legal career from necessity. His primary inclinations favored literature and scholarship. He combined a preference for traditional literary style with a politically liberal outlook—not surprising in a man known to regard Voltaire, Pope, and Helvetius as his heroes (Borgström, 1836). Wetterbergh had sponsored Jönköping's first newspaper in the days of Gustavus III. Having run afoul of the censors of this monarch's regime, this activity brought him a certain renown as a champion of freedom of the press. The new constitution of 1809 set the stage for the gradual restoration of freedom of the press. The topic was one that was to become a well-known issue over the next decade and a major factor in Georg Scheutz's career.

Scheutz's last years in Jönköping marked the beginning of his life-long publishing activities. In 1809 appeared his translation into Swedish of an account of far-off Brazil by the German traveler and geographer, Eberhard August Wilhelm Zimmermann (1743–1815). Scheutz's choice of this work is characteristic. Throughout his career he was to translate, publish, or print works that fed a reader's imagination with information surrounded by an aura of adventure, or tales of adventure through which shone an ever-recurring practical realism.

Scheutz's early literary efforts also included attempts at poetry and other forms of belles-lettres. However, his greatest literary contributions were to come through his translations, his editing, and his nonfictional prose writings.

In 1816, Scheutz's translation into Swedish of Shakespeare's *Julius Caesar* appeared. It was the first translation into Swedish of this particular work, and only the second of any Shakespearean work, having been anticipated by Erik Gustaf Geijer's (1783–1847) version of *Macbeth* in 1813. Scheutz's translation was published by Cederborgh & Co. in Stockholm. The next year, Scheutz, freed of governmental service by the dissolution of the Second Artillery, and having recently come into a small inheritance, went into partnership with Fredrik Cederborgh in the publishing enterprise thence known as "Cederborgska boktryckeriet."

Fredrik Cederborgh, who was a year older than Scheutz, was making a name for himself. At a time when Swedish readers had to rely heavily on translations for fictional prose entertainment, Cederborgh had endeared himself to the public by producing two spicy novels. His picaresque realism found less favor with the school of the "New Romantic" critics clustered about Uppsala; but it gave him a place in the history of the Swedish novel, setting him at the beginning of a line that was to lead to Nobel prize height within less than a century. In 1816 Cederborgh embarked on another activity that was to make his name equally familiar among those in government circles not inclined to reading novels. He published a weekly, *Anmärkaren,* that marks the start of the trend in opposition journalism in nineteenth-century Sweden. Scheutz's name soon became linked with that of Cederborgh in this pioneering activity.

Publisher and Publicist

The Cederborgh-Scheutz venture involved a good share of simple muck-racking. Thus it was *Anmärkaren* that brought to public notice in 1819 the false murder confessions obtained by torture from the innocent family of a servant who alone had been guilty; the steady pursuit of the case by the publishers resulted in the acquittal of the innocent and the removal from office and imprisonment of a high ranking responsible official. For three years Scheutz and Cederborgh divided the work on *Anmärkaren*—for a while their contract stipulated that Cederborgh would be responsible for the odd numbers of the paper, Scheutz for the even ones! In 1820 Scheutz took over Cederborgska boktryckeriet, which henceforth bore his own name.

In 1819 Scheutz had taken out a permit for a new journal, *Anmärkarne;* the earlier journal, *Anmärkaren,* soon thereafter passed to another publisher. *Anmärkarne* in turn became *Argus,* which was to gain fame as Sweden's leading political opposition journal of the 1820s. Scheutz continued to print *Argus* through 1836 and remained its coeditor until 1831, although it soon became identified with the active intelligence of his associate, Johan Johansson (1792–1860). Strictly speaking, there were seven *Argus* magazines during this time. Under the "liberty of the press" regulations of 1812 the publication regularly lost its license to the government censor. This meant reissuance of a new license to a different applicant for a publication with a "new" name. When Scheutz lost the license for *Argus* in January 1822, the engraver J. Malm obtained a license for *The Second Argus* the following day. Before the end of the year there was a *Third Argus,* and by 1834, a license for a *Third New Argus* was issued to a printer's apprentice.

Many of the men with whom Scheutz came into contact during the *Argus* period were to play a significant role in the growth of the emerging industrial Swedish nation. Presumably their shared points of view, as well as their respect for the indefatigable Scheutz, were factors in providing him with the support he eventually needed to bring about the production of his calculator. Not least among these men was Lars Hierta (1801–1872), who collaborated on *Argus* in the midtwenties, prior to founding the influential Stockholm paper *Aftonbladet.*

During the next decades, Scheutz's political activities appeared to recede behind his literary and technological interests. In fact, however, these overlapped. His championship of free speech and governmental justice was reflected in the selections of works published and translated, whether it was one of the "subversive" writings of Crusenstolpe in the 1830s or a Victor Hugo satire of the 1850s. Similarly his opposition to protectionism, manufacturers' associations or the guild system did not wane or become less effective by being transferred to the pages of the economic and technological journals that he produced.

The 1820s marked a widening of Scheutz's nonjournalistic literary endeavors. His initial translating and publishing efforts had been geared largely to potential bestsellers. *Julius Caesar* had been followed by translations of works by La Motte-Fouqué, Werner, Kotzebue and Boccaccio in 1817 and 1818. Gradually such tales of romance and adventure were complemented by the classical works of Aristophanes and Xenophon, native literature such as the historic plays of Per Henrik Ling (1776–1839), and language readers for learning Latin or Italian. Scheutz's most noted literary achievement of the decade was the first Swedish publication of the collected works of Shakespeare; the translations were his and those of the literary scholar Bishop Johan Henrik Thomander (1798–1865).

Science and technology assumed a prominent place in Scheutz's pursuits during the 1820s. Even without prior inclinations in this direction, as head of a printing establishment Scheutz could not have long escaped the implications of the technological advances of his time. He had entered the printing profession while this was undergoing revolutionary change. The iron press, rotary printing, stereotyping, zincography were but a few of the major innovations that captured the attention of European and American printers of the age. The introduction of these products in Sweden tended to lag behind, clustering around the year 1830. Thus, the first Stanhope press was introduced and purchased by Norstedt in 1828, nearly three decades after its invention. The first major cylinder press, a multipurpose machine made by Applegarth and Cowper in London, was purchased in 1829 by Nils Magnus Lindh of Örebro, whose brother had established one of the first major Swedish type-foundries in Stockholm. A second cylinder press was soon acquired by Lars Hierta for printing his newspaper *Aftonbladet.* Stereotyping came to Sweden in 1832. However, though the importation of these important tools of the trade lagged behind the rest of Western Europe, and native manufacture proceeded even more slowly, there had been considerable interest in such matters for years.

Georg Scheutz not only studied and propagated word of the significant inventions of the time, but tried his own hand at similar contributions. There were unsuccessful efforts at devising a color-grinder and a letter-etching device; and as early as 1823, he invented a cylinder press that incorporated special features to allow for regular bookwork, stone lithography, and zincography. Neither this press nor Scheutz's other inventions of the period were developed and exploited; but they are indicative of Scheutz's creative drive and his sense of the timely.

More influential than his inventions were Scheutz's contributions to the diffusion of technological and scientific knowledge through his publications. These took a variety of forms, prominent among which were the journals edited, published, and printed by him. Scheutz also published a series of translations of handbooks and modern classics in technology and science. What the *Encyclopedia Metropolitana* was to English readers, Scheutz's *Bibliotek för konst, slöjd och tillämpad vetenskap* provided for the Swedish in the 1830s. Here were handbooks on dyeing and brewing, works by Lacroix and Terquem on surveying and algebra, Bailly on natural science, Brunton on mechanics, and Hermbstädt on technology. Works that were not included in their entirety in the *Bibliotek* were excerpted and serialized in one of the journals.

Characteristic of his approach was Scheutz's handling of the *Journal för manufakturer och hushållning.* It was essentially a digest containing articles from the major scientific and technological journals of England, Germany, and France. Besides standard publications, such as the *Bulletin de la Société d'Encouragement pour l'Industrie Nationale* or *Dingler's Polytechnisches Journal,* newcomers like the *Journal of the Franklin Institute* were included, along with summaries of recently issued patents, reports on industrial expositions, and recipes for the homemaker. The *Journal för manufakturer* had first appeared in 1825; after a seven-year period of dormancy, it reappeared in 1833.

First Encounter with Babbage's Work

The year 1832 had been an exciting one for promoters of technology in Sweden; the events taking place must have appeared auspicious for resurrecting a journal dealing with manufacturing. The Göta Canal was completed, stereoplating was introduced, a major Industrial Exhibition opened in Stockholm. Questions pertaining to the economy of machinery and manufacturers were foremost discussion topics in Georg Scheutz's circles. It is not surprising that an English mathematician's book on that topic appearing in 1832 should capture Scheutz's attention and appear worthy of thorough treatment in the *Journal för manufakturer.* The work was Charles Babbage's *Economy of Machinery and Manufactures.*

Charles Babbage (1792–1871), a banker's son, had studied mathematics at Trinity College, Cambridge (Figure 2). As an undergraduate, he was a co-founder in 1812 of the Analytical Society, a student organization designed to promote the mathematical methods, notation, and techniques found in the works of Lagrange, Laplace, Lacroix, and other continental mathematicians following Leibnizian traditions in analysis, in opposition to the Newtonian method of fluxions and its associated English geometric tradition. This student venture is memorable, not only because it led to reform in the teaching of mathematics at Cambridge and pointed to the direction of subsequent English research in algebra and analysis, but also because the orientation of the Analytical Society is mirrored in Babbage's subsequent work. Emphasis on algorithmic procedures and interest in the effect of the use of signs dominate the mathematical papers he wrote in the decade following his graduation from Cambridge, as well as the many areas of applications that concerned him throughout

FIGURE 2.—Charles Babbage.

his life. As a co-founder of the Astronomical Society of London in 1820 his interests were channeled toward the application of repetitive machine action to the computation of astronomical tables. This led to the concept of the mathematical machine that he called a "difference engine." Encouraged by an award from the Astronomical Society and the promise of government support by the Chancellor of the Exchequer, Babbage spent several years of concentrated effort on this machine during the 1820s, interrupted by a continental tour in 1827–28, during which he familiarized himself with foreign techniques related to machines and manufacturing processes in general. Shortly after his return, Babbage, having been appointed to the Lucasian chair at Cambridge, received a new grant for the construction of the difference engine. By this time, designs for the machine had been drawn and redrawn, the difficulties of precision-parts manufacture had been faced, and the production of tools and parts was underway. Babbage now summarized his findings and conclusions on machinery and manufactures. The result, at one point intended as a series of lectures to be given at Cambridge, was the book *Economy of Machinery and Manufactures* that gave Babbage a niche in the history of industrial management. It quickly passed through three editions. Scheutz selected several chapters from the third edition as the basis for the translations and paraphrases that he published in his *Journal för manufakturer*.

Calling attention to general principles governing the construction of machinery, Babbage implied a rationale for scientific design of machinery, and tried similarly to suggest the existence of general rules governing the management of manufacturing processes. His stated aim in writing the book (Babbage, 1833:1) had been

> to point out the effects and the advantages which arise from the use of tools and machines;—to endeavour to classify their modes of action;—and to trace both the causes and the consequences of applying machinery to supersede the skill and power of the human arm.

In addition to the timeliness of the general topics Scheutz presumably welcomed many of Babbage's specific examples and analyses, such as those used to argue against certain forms of organized labor.

The chapter dealing with the topic that was to become of central importance for the involvement of Scheutz in the history of computing technology was that "On the Division of Mental Labour." Babbage stressed the applicability of the principle of the division of labor to mental, as well as mechanical, labor. He related the story of the French mathematician Baron de Prony (1755–1839), who was charged by the French government with the production of the logarithmic and trigonometric tables necessitated by the French attempt to extend use of the decimal system to the division of the circle into 100 parts. While pondering the organization of this massive undertaking, Prony is said to have chanced upon a copy of Adam Smith's *Wealth of Nations*. Scanning the introductory chapter, on the division of labor, it occurred to Prony to divide the "manufacture" of the mathematical tables in a fashion analogous to that which Smith described for the manufacture of pins. Prony decided upon the following schema. He established three sections of work. To the first section he assigned five or six distinguished mathematicians. Their sole function was to select, from numerous available analytic expressions for a certain function, that formula most easily computed by a large number of individuals working simultaneously. To the second section he assigned seven or eight competent mathematicians charged with giving numerical values to the formulas selected by the first section, on which the actual computations would be based. The members of the second section also verified subsequent calculations by analytic means. To the third section Prony assigned 60 to 80 individuals who needed no mathematical knowledge beyond the ability to add and subtract. This section carried out the required computations. Babbage noted that the work of this third section, which had produced 17 folio volumes of computations, could be mechanically executed by a machine.

As Babbage explained, this technique of computing mathematical tables was based on the method of differences. This method allows any table giving the values of a mathematical function to be formed by a sequence of additions and subtractions. Suppose the desired function $f(x)$ equals x^2. This means a table of squares is to be constructed. To determine its values for integral values of x, four columns of figures are necessary. The first one contains the values of integers x; the second contains the values $f(x)=x^2$; the third contains the differences Δ of successive squares; and the fourth contains the difference Δ^2 of these, or the "second differences." The second difference will always be constant for $f(x)=x^2$.

x	$f(x)$	Δ	Δ^2
1	1		
		3	
2	4		2
		5	
3	9		2
		7	
4	16		

Therefore, it suffices to know the values of x^2 for $x=1$, $x=2$, and $x=3$. Now all the following values $x=i$ can be found by simple subtractions and additions as follows: The values of the initial two first differences are obtained by subtracting $f(1)$ from $f(2)$, and $f(2)$ from $f(3)$. The first subtraction, $4-1$, gives 3; the second, $9-4$, gives 5. Obtaining the difference of these first differences, $5-3$, gives the second difference, 2. Since this is known to be constant, the column Δ^2 of the second differences can now be filled by simply inserting 2 as often as necessary; the column Δ of first differences can be completed by adding the second difference to the first difference that has been obtained last: $5+2=7$, $7+2=9$, $9+2=11$, etc. Now the column $f(x)$ of the functional values to be tabulated can be filled in by adding these first differences to the corresponding values of $f(x)$: $9+7=16$, $16+9=25$, $25+11=36$, etc.

The entire method hinges only on knowing the order of the constant differences, or, for functions that have no constant differences, knowing what assumptions may be made, or formulas employed, to obtain a sufficiently close approximation. Making these determinations was the task Prony assigned to his best-trained group; computing the initial values, corresponding to first obtaining $f(1)=1$, $f(2)=4$, $f(3)=9$ in our example, was the task assigned to the second group; the subtractions and additions that remain to fill in the table were the assignment of the third group, which Babbage wished to give to a machine. To illustrate the feasibility of this concept, Babbage asked his readers to consider three clocks, A, B, and C, each having a dial divided into 1000 numbered divisions and each having one hand. Each clock is arranged so that when a string is pulled, a bell on that clock strikes a number of times equal to the number at which the hand of the clock points. In addition, when the bell strikes n times on clock C, this causes clock B to advance n units; similarly, the bell on clock B causes A's hand to move forward. Babbage noted that if the clocks are initially set at A=1, B=3, and C=2, this corresponds exactly to the square-number table, with clock A representing the values $f(x)=x^2$, B the first differences, and C the second differences.

Intrigued by this account in Babbage's *Economy*, Scheutz discovered a more detailed discussion of Babbage's machine, which appeared in the *Edinburgh Review* for July 1834. In this issue, Dionysius Lardner (1793–1859) reviewed a set of seven publications pertaining to the machine, ranging from Babbage's accounts of 1822 and 1823 to the 1829 report by a committee of the Royal Society. Lardner used the opportunity of the reviews to treat in detail three major aspects of the problem of publishing mathematical tables. First, he presented a sketch of several major tables produced over the preceding 50 years, using these to illustrate the difficulty and importance of producing large quantities of error-free copies relatively cheaply and rapidly. Secondly, he described for the reader, in relatively nontechnical fashion, the working of the machine, and Babbage's concept of mechanical notation. Finally, after a brief review of previous efforts at mechanical calculation, he reviewed the history and status of the actual construction of Babbage's engine. Things had not gone well with the construction of the machine since 1830.

Work had been suspended, the laborers dismissed, and Lardner's article concluded with a plea to all concerned to air their problems and not let the considerable investment made by the British government and by Babbage himself be wasted.

Lardner's writings, the work of a noted scientific author and initiator in 1829 of the *Cabinet Cyclopedia,* may have been of particular interest to Scheutz. Although it was not the first means by which Scheutz learned of the machine—despite a frequently repeated statement to that effect, apparently circulated by Babbage himself—Lardner's article was undoubtedly the most useful, reflecting the expository talent of the author. While not sufficiently specific to permit exact copying of Babbage's design, Lardner's discussion clearly conveyed the basic concept of the machine and at least a general outline of its mechanical action and composition.

Creation of the Calculator

Having read of Babbage's machine, Georg Scheutz satisfied himself that such a device was indeed feasible. After familiarizing himself more closely with computational techniques and the construction of the difference "engine" he built a small model of wood, wire, and cardboard, which appeared to prove the point. This model might well have joined Scheutz's earlier inventions as an example of his alertness to the currents of the day, to be remembered when someone else's practicable version came along. That this did not happen is due to Georg Scheutz's son Edvard.

Edvard Scheutz, the Engineer

Edvard Scheutz was 16 when he undertook the construction of a model of the difference engine (Figure 3). Born in Stockholm on 3 September 1821, he had attended the New Elementary School in that city until his early education was interrupted as the result of a leg injury. In 1835 he entered the Technological Institute, then in its first decade of existence, and remained there until 1841. Little is known of Edvard Scheutz's interests outside the field of mechanical technology. It seems clear, however, that he worked closely with his father. He even wrote a comedy published by the Scheutz firm in 1836, when Edvard was 15!

Figure 3.—Edvard Scheutz.

During the summer vacation of 1837, Edvard asked and was granted his father's permission to enlarge upon the rough model of a difference engine, and produced a metal version. It pleased his father sufficiently to approach the Swedish Academy of Sciences that fall with a request that the academy support a grant application to the Swedish government for the construction of a full-scale difference engine. After a rather lengthy period of deliberation, the academy—perhaps influenced by the ominous stories of Babbage's machine—refused to support the request because of the high cost of such a venture.

Edvard and his father continued their efforts, despite this initial rejection. The older Scheutz sent out feelers to other institutions of learning. Thus, the Paris Academy of Sciences recorded that in December 1838 the Minister of Public Instruction transmitted a note from Scheutz regarding "a calculating machine, announced as being simpler and hence less costly than that of Mr. Babbage." The younger

Scheutz continued to tinker on the model, making use of a home workshop that his father had helped him install in 1837, in return for his undertaking work on the machine. By 1840 he had a five-place machine that would compute one order of differences. Within another two years the machine had been increased to compute up to three orders of differences. At last, early in 1843, the printing mechanism was completed. Fittingly, that February, during the first year of Edvard's majority, Georg Scheutz turned over to his son the printing establishment.

Performance Tests of the Model

With the proper integration of the printing component, the complete machine model was ready for trial. The Royal Swedish Academy of Sciences was invited to inspect the machine and, after several tests, a three-man commission delivered its verdict.

The three members of the Academy's commission were Johan Jacob Berzelius (1779–1848), the world-famous chemist, who was secretary of the academy; N. H. Selander (1804–1870), astronomer and geodesist, who since 1837 served as the academy's astronomer, holding the title of professor; and C. B. Lilliehöök (1809–1890), professor of physics at the Higher Artillery School at Marieberg. Their statement read in part as follows (*Specimens,* 1857:x):

> The apparatus in question is composed of three parts.
>
> 1st. The Calculating Machine.—It cannot compute series of a higher degree than the third, nor does it give complete terms exceeding five figures; but in the nature of the mechanism, there is nothing to prevent its extension to the working of series of any degree whatever, and to terms of as many figures as the purpose may require.
>
> 2nd. The Printing Machine.—Every term given by the calculating apparatus is expressed by printed figures, closely arranged in lines, as in a printed table, the lines being impressed on some softer material, adapted to receive galvanoplastic or stereotyped copies. All the lines succeed each other very correctly in the same vertical column.
>
> 3rd. The Numbering Machine.—With the printing machine, another apparatus is combined, which prints the arguments before every term. The machine is put in motion by turning the handle of a winch, by means of which, and without further manipulation, the calculation, as well as the printing and arranging of figures and lines, are effected.

The cautious statement of the scientific committee certified the conceptual and technological soundness of the proposed machine. What remained to translate the working model into a saleable product was supporting capital. This was beyond the means of the Scheutzes.

A Period of Waiting

In 1844 Georg Scheutz requested 10,000 riksdollar from the Swedish crown to construct a full-scale model. But the academy, while attesting to the physical possibility of building such a machine, was not prepared to guarantee from its construction an advantage to the nation commensurate with the cost. Lacking assurance that building a difference engine would be in the national interest, the government denied Scheutz's request, and the model lay dormant for some years.

Direct attempts to find a buyer for a full-size machine failed. Foreign references to the endeavor tended to associate it with the money-consuming Babbage effort, or to overlook the progress that had been made in demonstrating the feasibility of such a construction since Scheutz's first announcement in 1838. The first interpretation is illustrated by the negative reactions received by the Swedish ambassador to England, Count Björnstjerma (1779–1847), when he transmitted the Scheutzes' offer to construct for purchase a machine that would print 17-digit tables computed with seven orders of differences. The second is reflected in a report on the state of the art of the calculating machine for the Committee of Mechanic Arts of the French Society for the Encouragement of National Industry, presented by the French mathematician Theodore Olivier (1793–1853) in 1843. This included an observation that Scheutz's invention, announced in 1838, had not been executed and that its author had not revealed its mechanism.

While the model was put aside, numerous trains of events converged to make certain groups in Sweden more receptive to the idea of the Scheutz machine. The senior Scheutz continued to support the growth of Sweden's fledgling industrial economy, notably through his editorial and publishing activities, resulting in industrial and polytechnic journals and new reference works similar to those mentioned before, and became Secretary of Sweden's Society of Industrial Progress. At the same time, Scheutz expanded his pursuits in the scientific field, thus establishing closer ties with members of the Swedish Academy. In 1842 he had signed a contract with Lars Hierta, making him a regular contributor to

Aftonbladet, with the special responsibility of keeping the public informed on scientific subjects. In 1843, his introduction to a massive textbook on natural history was printed by the firm of Lars Hierta. Intended to serve as a textbook and for self-study, it combined the qualities of a dictionary, travelog, and economic atlas. A few years later Scheutz authored a treatise on the solution of numerical equations (*Nytt och enkelt sätt att lösa nummereqvationer)* based on the writings of J. M. Agardh (1812–1862), astronomer at the University of Lund, who had been raised by his uncle Carl Adolph Agardh (1785–1859) one of Sweden's leading scientists and a senior member of the academy.

By 1850, Scheutz's efforts to promote knowledge of scientific, mathematical, and technological developments were by no means unique. Interested readers who did not subscribe to *Bibliotek för vetenskap* could find scientific reading matter in the comparable series *Bibliotek i popular naturkunnighet* published by Zacharias Haeggström in Stockholm. In 1846 this even included a translation into Swedish of Babbage's *Ninth Bridge-water Treatise,* which contained a brief reference not only to the difference machine but also to the concept of the analytical engine, a machine that could perform an arbitrary sequence of algebraic calculations. Further Babbage materials were available in the library of the Polytechnic Institute in Stockholm, which by 1848 contained a German translation of his work on life-assurances, a French translation of the *Economy,* and a copy of his *Reflections on the Decline of Science* (Stockholm, 1849).

Scheutz's name also remained before the literary public. In particular, his earlier Shakespearean studies were recalled, when in the spring of 1847 his version of *King Lear* was performed at one of Stockholm's major theaters (F. Dahlgren, 1866).

What added to Scheutz's reputation and following more significantly than any of these particular activities was the fact that the movements Georg Scheutz had supported for so many years were on the ascendant. After some bitter struggles brought about by its opposition to Charles xiv, the Bernadotte king, the Swedish press was becoming a powerful force in the growing nation. The change was symbolized by the action of the 1844–45 Parliament which repealed the government's right to suppress newspapers; Lars Hierta's *Aftonbladet,* often identified as the driving political force of the press, had been strongly influential in bringing this about. Soon after the ascendance to the throne of Oscar i in 1844, the protectionist policies that had been the target of the attacks launched by Scheutz and his friends were reviewed and replaced by more liberal trade legislation. Scheutz could take particular pleasure in the repeal in 1846 of compulsory guild membership. The relaxation of trade restrictions coincided with a similar policy in Peel's England. These circumstances, combined with the general technological and industrial expansion of the age, led to an unprecedented exchange of goods and information between the two countries. If the rise of the Swedish sawmill industry was encouraged by England's need for timber and paper, so England's leadership in transportation and communication served as a model for Sweden in establishing its modern postal service and banking systems, and, somewhat later, its railroad and telegraph networks.

Within Sweden's parliament, the Riksdag, the stronghold of the movements which Scheutz supported was the chamber of burghers. Until 1862, the Riksdag consisted of four chambers: those of the nobles, the clergy, the burghers, and the peasants (*bonde*). The chamber of burghers contained the core of the liberal opposition, and was the source of a variety of reform measures. It was here that a motion was brought in 1851 to support the construction of a large working calculator based on the Scheutzes' design.

Obtaining a Government Grant

In January 1851, Scheutz presented a new request to the crown for government funds to support building a larger working machine. It was for 3333 riksdollar and 16 skilling—one-third of the amount asked in 1844. It was pointed out that the money could be used in part to support travel abroad to present the model, especially to those countries that published annual nautical almanacs and astronomical tables. The request was accompanied with a statement from the Royal Swedish Academy of Sciences, two of whose members had again examined the machine in December 1850. They were Fabian Wrede (1802–1893) and L. I. Wallmark (1810–1855). Wrede, member of an old, established, and distinguished Swedish family, had held military rank in the Gotha artillery and had taught physics and mechanics at the Higher Artillery School at Marieberg since the 1830s. His fellow academicians recognized him for his theoretical investigations in physics and physical chemistry. Wallmark was director of the Royal Technical Institute, Edvard Scheutz's alma mater. At the age of thirty he had been manager of the Motala mechanical works. After experience as draughtsman there, as custodian of physical instruments at the Academy of Sciences, and as inspector of various technological enterprises, he was equally well-qualified to assess the machine.

The 1851 statement from the academy was far more supportive than the evaluation given seven years earlier. It endorsed Scheutz's request on the basis that

> the auditor Scheutz and his son have expended much effort on the machine and expenditures that are not inconsiderable in relation to their income. In addition, the auditor for a long time has disseminated knowledge in his fatherland concerning useful inventions. All of this, as far as is known to the Academy, has been done without any assistance from the State; for this reason, and since he now seeks a donation that does not come to 1% of that which England paid for the Babbage machine, the Academy advises most humbly that the humble petition of the auditor Scheutz be granted. In addition, it takes the liberty to suggest that the machine be retained in the possession of the Messrs Scheutz, since the support sought otherwise would not be sufficient recompense for the private sacrifices which have been made for an invention that will doubtless be in the interest of science and honor of the fatherland. (Sweden, Riksdagen, 1851, no 294:15-16; translated by author).

The request was denied by the crown for lack of funds. In the chamber of burghers, however, A. M. Brinck, 57-year old merchant of Stockholm and a leading member of the opposition, on 29 April sent a motion to the parliament's Select Committee, recommending a grant to the Scheutzes.

The Select Committee pondered the matter and on 2 August 1851 a modified proposal emerged (Figure 4). The committee noted that on the basis of the statement from the Academy of Sciences it did not doubt the advantages of the calculating machine in question; but it felt that it was not in a position to recommend unqualified payment. The Select Committee, therefore, proposed that the chambers vote to put at the disposal of the Crown the amount of 3333 riksdollar and 16 skilling from the treasury to be paid to Scheutz if, after due examination, His Majesty found that the machine invented by the Scheutzes had been completed and fulfilled its intended purpose (Sweden: Riksdagen, 1851, 294:16). The reason for the committee's modification of Brinck's original proposal emerges from a minority report in which several members of the chamber of nobles expressed their reservations on the grounds that the Academy of Sciences in certifying the practicability of the calculator had only gone so far as to say that they "had reason *to suspect* that it is useful." (Sweden: Riksdagen, 1851, 328:17).

The question of "a government grant for the support of a machine invented to calculate, compose and print mathematical tables" came to a vote two weeks later (Sweden, 1851, no. 294). The chamber of the clergy took up the proposal on the 14th of August and approved it. The other three chambers voted on the following day. In the chamber of nobles there was a certain amount of discussion, during which some of the same members who had expressed reservations in the Select Committee led the opposition to the motion. Nevertheless, it passed. It also passed—easily—in the chamber of burghers. Only the *bonde,* the peasants, declined to adopt the motion. Among those bringing procedural arguments to bear against it in their chamber was Ola Månsson (1808–1892) nowadays remembered as the paternal grandfather of Charles A. Lindbergh (1902–1974).

Approval of the three chambers was sufficient; but under the terms of the motion adequate funds would not be paid out until the machine was completed.

14 *Stats-Utskottets Utlåtande. N:o 294.*

N:o 294.

Ank. till Exp.-Utsk. den 2 Aug 1851, kl. 1 [illegible]

Utlåtande, i anledning af väckt motion om statsanslag till bekostande af en uppfunnen machin [illegible] uträkning, sättning och tryckning af mathematiska tabeller.

FIGURE 4.—Resolution by the 1851 Select Committee of Sweden's Parliament supporting construction of the Scheutz calculator.

To initiate its construction, some individual or group had to be willing to supply the capital and to run the risk of loss if the project proved unsuccessful. A group of underwriters was found. This group included scientists and technologists, members of the academy, and liberal members of the Riksdag. Well represented among the subscribers were the publishers and journalists who claimed Georg Scheutz as one of their own; prominent among them were men associated with *Aftonbladet,* including Lars Hierta and two of his successors.

With financial backing assured, work on the full-scale machine could at last begin. It was performed under the supervision of Edvard Scheutz. Space, equipment, and supporting expertise were furnished by J. W. Bergström (Figure 5) and his mechanical works. Bergström (1812–1881) was a rising industrialist. The son of a joiner in Samuel Owen's foundry, he had been trained as a glass blower and by the 1830s he had established himself in the glass business. In the early 1840s he became interested in the new daguerrotype process and became Stockholm's leading daguerrotypist. In 1846 he opened his mechanical works, which quickly became a well-known, respected establishment. Here the Scheutz calculator was built (Figure 6), which bears the inscription: "Inventerad af G. & E. Scheutz / Förfärdigad hos J. W. Bergström. / Stockholm / 1853."

FIGURE 5.—J. W. Bergström.

FIGURE 6.—Detail of the Scheutz calculator. Inscription reads: "Inventerad af G. & E. Scheutz/Förfärdigad hos. J. W. Bergström. / Stockholm / 1853." (SI photo 74–11265)

Structure and Operation of the Scheutz Calculator

By 1 February 1852, the first working drawings of the ultimate design were finished. The machine itself was completed in October 1853 (Figure 7). The machine could handle numbers of 15 digits and tabulate functions with 4 orders of differences, the fourth being constant.

The tabular values and differences were represented by number wheels arranged horizontally in a 15 by 5 array. The top row of 15 figures represented the tabular values; the second row, the first differences; the third row, second differences; the fourth row, third; and the fifth row, the constant fourth differences. This arrangement corresponded to that described by Lardner for a smaller machine, although Babbage had inverted the rows and columns. As Lardner had explained, to compute a table by the method of differences, these rows had to be connected so that a number could be added from one row to the row above it.

At the outset of a computation, the number wheels were set manually (Figure 8*a*). Each wheel was toothed at the bottom; the number of teeth depended on the numbers to be represented by the wheel. These ranged from 0 to 9 for the most part, but there were a few wheels adapted to computation in minutes and seconds, which ranged from 0 to 5 only. The wheels had no spokes or other parts touching the vertical axes around which they were rotated. Rather, each was simply enclosed in a fixed concentric ring or ring segment supported by a shelf forming part of the main frame of the machine.

Each wheel had an adding mechanism, consisting of a "catch-and-trap" combination (Figure 8*b*). An upward catch was attached to the upper part of the wheel, the corresponding trap to the central axis surrounded by that wheel, at a point approximately midway between it and the wheel above it. As the axes rotated, the traps revolved within the calculating wheels. Each trap had an arm which touched the catch of the wheel below it as the trap revolved. Depending on the direction of this revolution, it either pressed down a portion of the catch and passed it freely, or was caught by it and raised. When the trap was raised, it engaged the number wheel above it, thereby turning it. A related stud and lever mechanism provided for carrying as the upper wheel passed from 9 to 0 (or 5 to 0, in the case of the "sexial" wheels) (Figure 8*c*). A small stud between these two digits pushed against a lever when a wheel

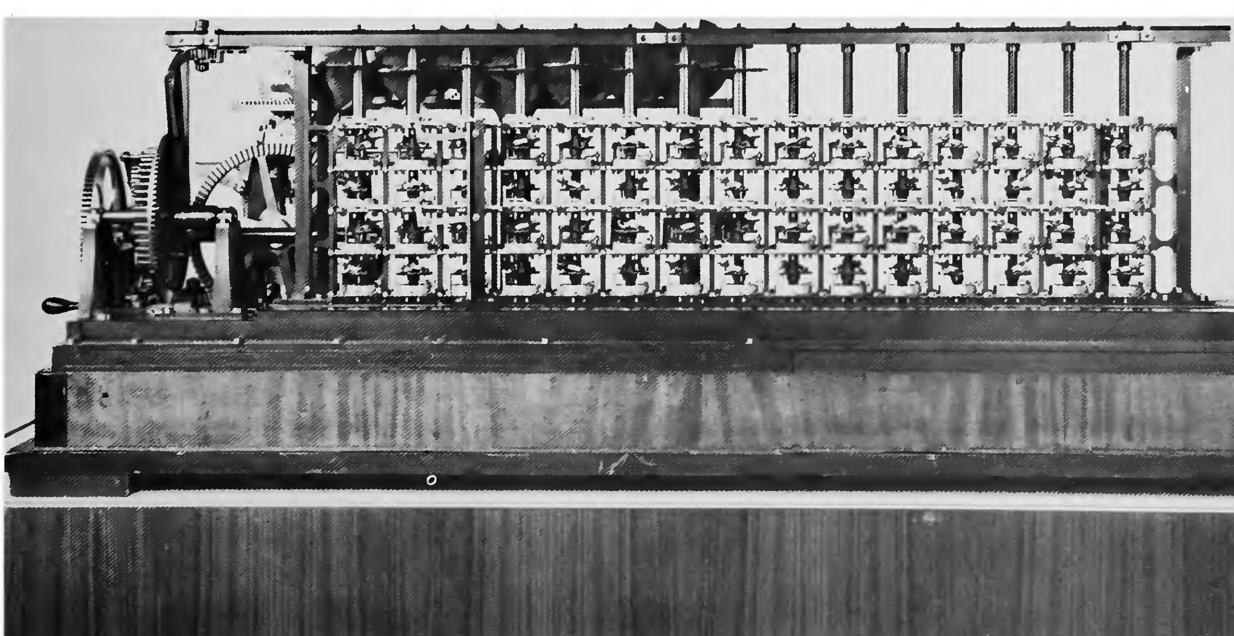


FIGURE 7.—The Scheutz calculator. (SI photo 74–11266)

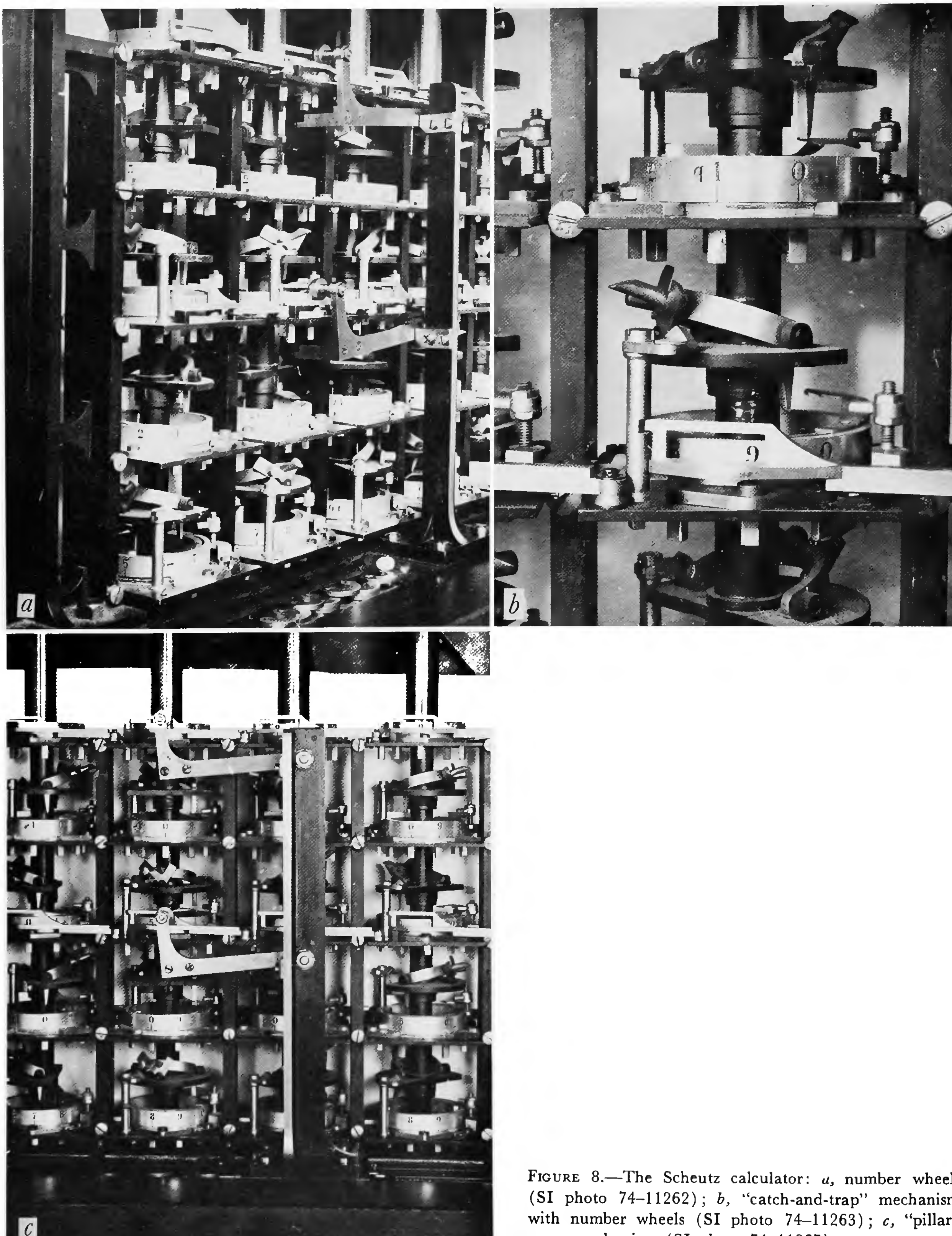


FIGURE 8.—The Scheutz calculator: *a*, number wheels (SI photo 74–11262); *b*, "catch-and-trap" mechanism with number wheels (SI photo 74–11263); *c*, "pillar" carry mechanism (SI photo 74–11267).

passed from 9 to 0. This lever extended to the left in front of the preceding wheel. The carrying action was prompted by a moving upright "pillar." If the stud had pressed against the lever, this then came into contact with the pillar, causing a pivot arm on that pillar to engage the wheel behind the lever and to move it forward one unit, thus effecting the carry.

The concept of adding number wheels was not new. Blaise Pascal (1623–1662) had demonstrated an effective carry mechanism in the seventeenth century; numerous counting and adding mechanisms had been devised since then; and in the *Economy,* Babbage had devoted a chapter to registering devices. In his design for the "difference engine," Babbage had accepted a new challenge: that of effecting simultaneous additions of several orders of these multiple-place figures. As Lardner had explained, to minimize the strain on the machine imposed by a large number of simultaneous additions and carries Babbage designed the machine to do the work in four stages: In the first stage, the even rows were added to the odd rows, omitting carries; in the second, the carries accompanying the preceding additions were completed; in the third, the odd rows were added to the even rows; in the last, the remaining carries were completed. Lardner provided a general description of the mechanisms intended to perform these operations, without, however, including any drawings but some sketches of dial faces. The Scheutz machine effected the required simultaneous additions as follows:

The machine was crank-operated (Figure 9). Turning the crank set into motion a mangle wheel attached to a bevel wheel arrangement. Connected to this was a vertical toothed sector that engaged with a rack and pinion combination placed on the frame above the top row of number wheels and caused the 15 vertical axes to rotate. Because of the mangle-sector arrangement, the axes rotated alternately in a clockwise and counterclockwise direction. Turning the crank also caused the pillars to move in two grooves on either side of the rows of number wheels. This was effected by fastening the pillars to a chain geared to a set of pinions driven by a bevel wheel arrangement connected to the mangle wheel (Figure 10*a*). Turning the crank caused them alternately to move in opposite directions. By means of latch sets, one acted on the rows of odd differences,

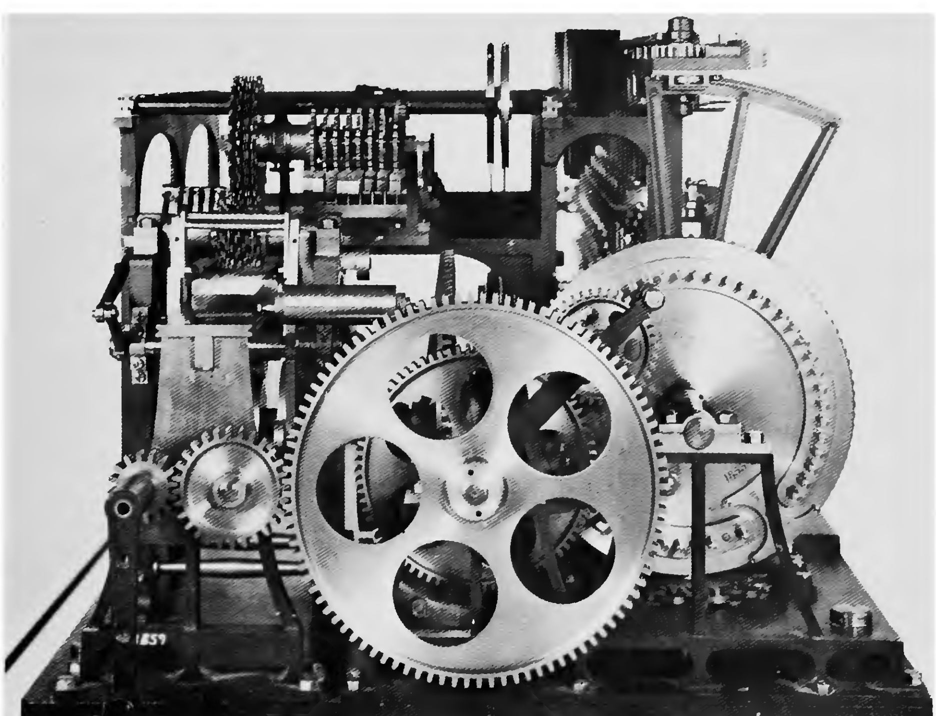


FIGURE 9.—Crank and initiating mechanism of the Scheutz calculator. (SI photo 74–11268)

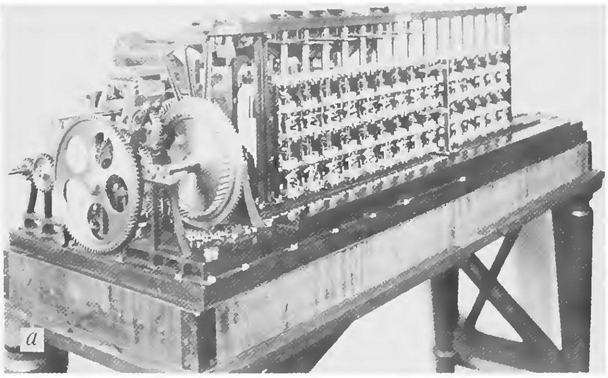
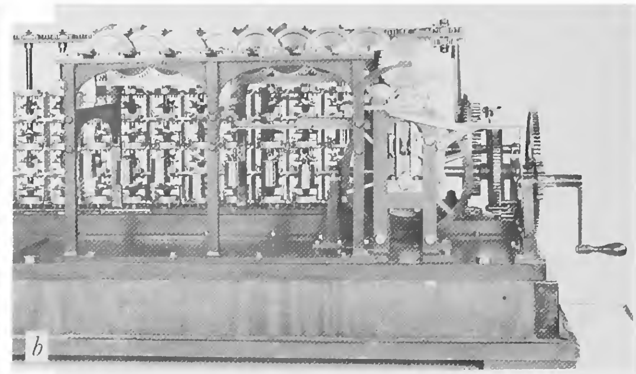



FIGURE 10.—Scheutz calculator: *a,* chain drive for pillars (SI photo 74–7812); *b,* side view (SI photo 74–11270)

FIGURE. 11.—Top view of Scheutz calculator showing printing apparatus. (SI photo 74–11261)

the other one on the row of even differences and the top row of tabular values or "zeroth differences." The wheels in successive rows were numbered in opposite directions. Given the adding and carrying mechanisms just described, this entire arrangement allowed the machine to add all odd differences simultaneously, followed by the addition of all even differences; this in turn was followed by the next addition of odd differences, etc. Carrying took place between additions.

Finally, there was the printing apparatus (Figure 11). This had been Babbage's stumbling block. The Scheutzes solved the problem. Since only final values needed to be printed, it had to be joined only to the top row of the machine. It extended to eight places. A set of horizontal shafts was placed at right angles to the rows of number wheels. By means of a set of eight cams and "snails" (stepped cylindrical segments) these shafts linked the vertical axes corresponding to the eight leading digits to a set of racks geared to eight type wheels. The racks were parallel to the rows of number wheels. A bar kept the type wheels stationary while the machine added. Once the calculations had been completed, the bar was removed, releasing a set of weights (Figure 10*b*). Being suspended from disks attached to the horizontal shafts, these weights were connected to the eight leading number wheel axes by the snail and cam combinations. Upon release, they set the type wheels into action, impressing 8-digit figures onto 8-inch-long strips of papier mâché (Figure 12). These strips were usually covered with black lead to facilitate production of stereotype plates from them.

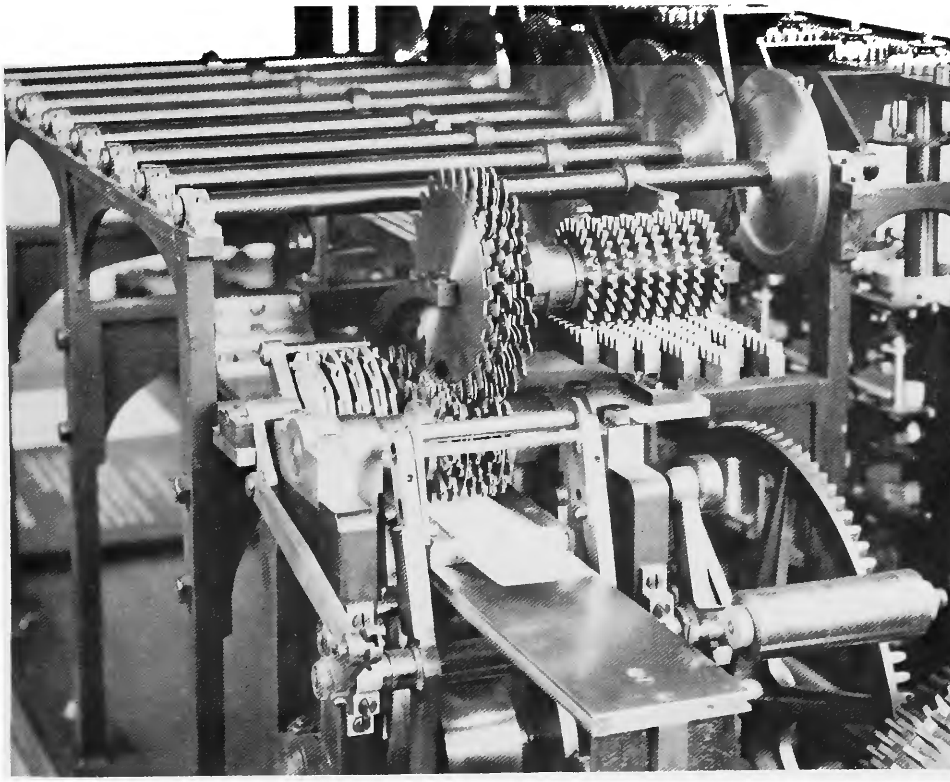


FIGURE 12.—Detail of Scheutz calculator showing type wheels and papier-mâché strip. (SI photo 74–11269)

Promotion of the Calculator

With the completion of the machine began a period of promotion, during which "the Swedish Calculating Machine" gained fame, a buyer, and an offspring. Discussions about the machine ranged over two continents and involved some of the most distinguished scientists, mathematicians, and engineers of the day.

FINDING A BUYER IN EUROPE

In 1854, plans were laid to take the machine to England. Here a number of individuals collaborated in seeking a buyer for the calculator.

The Scheutz Calculator traveled to England under the auspices of the firm of Bryan Donkin and Company. This establishment had a distinguished record, especially in matters pertaining to the manufacturing of paper and special-purpose printing devices. The firm had been founded by Bryan Donkin (1768–1855). Introduced to the paper-making business by John Hall in the 1790s, his first independent venture had been a factory for manufacturing molds for handmade paper. After 1800, Donkin supervised the work of the first English "Fourdrinier" paper machine, initially at Hall's works at Dartford, then at a factory at Bermondsey. Over the next two decades, Donkin manufactured and sold over forty of the machines. However, while the Fourdriniers, with whom Donkin had a royalty arrangement, went bankrupt, Donkin, whose firm had constructed 191 paper machines by 1851, had intensified his production efforts. It was Bryan Donkin and Company that built the automatic printing machines designed to carry out the multiple-color printing process patented by William Congreve (1772–1828) in 1820; these machines were used for printing postage and other government stamps in various parts of the British Empire, and related models for printing the notes of the Bank of England. Bryan Donkin's patents included numerous devices related to writing, printing, counting, and recording. Among these were a rotary printing machine, invented in collaboration with Richard Mackenzie Bacon; a counting machine; a counter invented in 1818 and given prominent mention by Babbage in his discussion of recording devices in the *Economy*; a tachometer for measuring machine speeds; and—as early as 1808—a steel writing pen. Among his numerous other enterprises were construction of astronomical apparatus; invention of a dividing engine; purchase, with Hall and John Gamble (holder of the English "Fourdrinier" patents), of the English rights to the Appert food canning process; collaboration with Brunel in work on the Thames River tunnel; and design and construction of water wheels, and later of water turbines for use by paper mills. Finally, Donkin's firm had supplied parts for Babbage's calculating machine. Babbage himself was among the numerous English engineers, scientists, and men of state with whom Bryan Donkin had maintained a good working relationship. Common interests brought the two men together, either at meetings of clubs or societies, such as the Institution of Civil Engineers of which Bryan Donkin had been a founder, or on committees, such as that appointed by the Bank of England in the 1830s to inspect the Oldham system.

Bryan Donkin had retired from his firm in 1846, leaving the business in the hands of his three sons. The oldest, John, died in 1854, the year that his brother, the second Bryan, had the Scheutz machine brought from Sweden.

Considering Sweden's stake in the manufacture of paper and other wood products, it is not surprising that Swedish businessmen would have had contacts with Bryan Donkin and Company. Among such men was Per Ambjörn Sparre (1828–1921), member of an old aristocratic Swedish family, who was in London to obtain advice and equipment for his recently established printing firm (Figure 13). After a year at the University of Uppsala, the young businessman had studied at the mechanical works in Motala from 1848 to 1850. In 1850 he had become manager of the Tumba Paper Mill, a branch of the State Bank of Sweden, where Swedish bank note paper was produced. After two years at Tumba, Sparre was ready to embark in business on his own. Having specialized in the production of security paper, necessary for printing stamps as well as bank notes, he established a small printing firm, from which emerged Sweden's first postage stamps in 1855. Part of the printing equipment Sparre had invented himself. The rest of his machines, as well as books, were largely purchased in England. The related negotiations brought Sparre to London the year the Scheutz calculator was completed.

FIGURE 13.—Per Ambjörn Sparre.

Upon its arrival in London, the calculator was taken in hand by William Gravatt (1806–1866). An engineer whose career had brought him closer to railways and bridges than calculators and printing presses, Gravatt soon became an enthusiastic champion and care-taker of the Scheutz machine. Presumably he became involved in the project because of a certain amount of debt to the Donkins. While in his teens, Gravatt had been apprenticed to Bryan Donkin, Sr., by his father, who was inspector of the Royal Military Academy at Woolwich. Having obtained thorough training in mechanical and civil engineering Gravatt went to work for Brunel, being put in charge of machinery and management of the "shield" for the Thames River tunnel, the part of the project that involved the Donkin firm. When the Thames project was interrupted in 1832, Gravatt, on Donkin's recommendation, obtained a position as engineer to Calder and Hubble Navigation, where he made a name for himself by his bridge designs. He subsequently was employed by several railway builders, as well as by Brunel. In this connection he designed the well-known "dumpy" level, and made improvements in several other surveying instruments. In the decade preceding the arrival of the Scheutz machine, Gravatt had been caught in several unsuccessful ventures: Working for overextended railway promoters, he was left with surveying debts but no salary. Having been in charge of designing and supervising the construction of the world's largest achromatic telescope, built by George Rennie, the collapse of that enterprise left him unemployed. However, having counted the instrument-maker Edward Troughton (1753–1835) and the physician and scientist William Hyde Wollaston (1766-1828) among the companions of his youth, along with Donkin and Brunel, subsequent membership in organizations such as the Royal Astronomical Society gained him the friendship and respect of men like the mathematicians Augustus De Morgan and Charles Babbage.

Publicity and a Patent

The Scheutzes and their machine arrived in England in the fall of 1854. On the 17th of October they petitioned for a patent and deposited the necessary provisional specifications with the Office of the Commissioner of Patents (Appendix I). On the 16th of November, the Royal Society learned from a letter sent by Gravatt to its vice-president and treasurer, Colonel Sabine, that "the Swedish Calculating Machine constructed by Mr. Scheutz" had arrived in London (Royal Society, 1854). The machine was initially brought to the Donkins' Bermondsey works, where it was studied, particularly by William Gravatt, who was to become its principal demonstrator.

Georg and Edvard Scheutz left England during the winter and signed the full patent specifications before the British Consul in Stockholm on 9 March 1855; Sparre served as one of the witnesses. The patent, which was sealed on the 13th of April in the Great Seal Patent Office in London, resulted in issuance of Letters Patent No. 2216 (A.D. 1854) "for the invention of 'Improvements in Machinery or Apparatus for Calculating, and Printing the Results in such Calculations'." Issuance of the patent resulted in a certain amount of publicity. On 25 April, the *London Daily News* carried an account of the machine. During the following weeks, a number of journals and magazines directed at mechanics and engineers presented reviews of the patent and descriptions of the machine. During the spring and summer, however, efforts to gain favorable notice for the machine were concentrated in two specific directions: the Royal Society of London and the Universal Exposition of 1855 in Paris.

For some time in 1855 the machine was set up in the quarters of the Royal Society at Somerset House. There, too, a committee appointed by the Council of the Royal Society to examine the machine had opportunity to study it closely. The committee consisted of the newly elected secretary of the Royal Society, the mathematician and physicist G. G. Stokes (1819–1903), as chairman; the crystallographer W. H. Miller (1801–1880); the physicist and inventor C. Wheatstone (1802–1875); and R. Willis (1800–1875), inventor, architectural archeologist, and professor of mechanics. The committee prepared a report which described the basic problem of tabulating the values of functions, noting Babbage's origination of the concept of a difference engine, and briefly mentioning the analytical engine, before proceeding to outline the operation of the Scheutz machine. The report noted that although Scheutz had adopted Babbage's suggestion of operating oppositely on odd and even differences, so these could be handled simultaneously, the mechanism of the Scheutz machine is different from Babbage's. The report concluded that the close tabulation of functions that the machine carries out is usually required only in table computation and that the Scheutz machine could be useful in that context. Noting that the standard logarithmic and trigonometric tables had been computed a long time ago, the committee suggested with appropriate caution that it might be worthwhile to construct other tables, "could it be done with the ease and cheapness as would be afforded by the use of the machine" (Royal, 1856a). The report finally noted that the machine would prove worthwhile even in reprinting old tables, because it could "calculate and print more quickly than a good compositor could set the type, and that without risk of error" (Royal, 1856a). Stokes added an individual postscript to the published version of the report, noting Babbage's suggestion, which had been communicated to him in the meantime, of using his engine when the last differences are not constant.

The committee's report was presented to the Society at its meeting on the 21st of June 1855. The following Monday Prince Albert went to see it and had its operation explained to him by Gravatt and Donkin. The weekend edition of the *Illustrated London News* carried a spread with two illustrations and a concise summary of the machine's operation.

The Paris Exposition

In the meantime, Swedish and English supporters of the machine had laid plans to bring it to world attention at the Universal Exposition in Paris that year. This major exhibition, which was to attract nearly 24,000 exhibitors, had been scheduled to open on 15 May 1855. Most of the exhibits actually were not opened to the public until July; many of Sweden's contributions had arrived at Dieppe in mid-June, a month after the formal opening. Nevertheless, if the Scheutz machine was to arrive in Paris in time to be viewed and judged by potential users, as well as other visitors, there was little time left for Londoners to see the machine at home that summer.

Preparations for showing the machine in Paris included not only the physical arrangements for transporting and exhibiting it, but also strategy for according it suitable publicity. By his zealous participation in the coordination of these activities, Charles Babbage settled what had become a subject for speculation: his feelings about the Scheutz machine. Babbage had a reputation for crustiness, and there were those who had expected him to be antagonistic toward the Scheutzes. He was known for his outspokeness and did not hesitate to attack if he felt a matter of standards, honor, or justice was involved. His own difference machine lay incomplete, his repeated efforts to gain support for new calculators and computers had been turned down, his attempt to gain broad exposure and honor for his machine designs at the Great Exhibition in London's Crystal Palace in 1851 had failed. How great was the surprise of many—including the Scheutzes, who attested to having come to England with a certain amount of trepidation—when Babbage foiled the soothsayers. If he had any regret that it was not his own machine traveling to the Continent for a chance at world acclaim, this was submerged in his support of the Swedish machine that could demonstrate the soundness of his original concept. His communications during the early summer of 1855, to the *Illustrated London News,* to Stokes, to the British Association for the Advancement of Science, and to others, had conveyed a polite interest in the machine and a reminder of his own contributions to the concept. The opportunity to bring the calculator to the attention of the international public spurred Babbage to more concentrated positive effort. In the end, he proved to be a veritable godfather.

The machine was installed at the Paris Exposition in August 1855. On the 29th of that month, Gravatt sent Babbage the somewhat disquieting news from Paris (London, 1856, ms 37196:302) that

> the machine . . . was terribly shaken in its transport. I was told it was to go by water but instead of that they put it on a common railway truck without so much as a wisp of straw under it.—They have not yet been able to get the Jury to look at it.

While Gravatt concerned himself with getting the machine in order, Babbage worked on circulating information about it, and prepared for his own trip to Paris in October. Before his arrival, the French Academy of Sciences received a communication from Babbage, read at their meeting of 1 October, calling attention to the presence of the machine at the Exposition and transmitting his son's drawings on his mechanic notation applied to the Scheutz machine. Henry Prevost Babbage's drawings and the accompanying explanation by his father were presented at the next meeting, which took place on the 8th of October. Babbage spent his time in Paris touting the Scheutz machine, making sure that accompanying French and English information was properly distributed, and presumably discussing it when he lunched with Michel Chasles and other mathematicians and scientists. Meanwhile, Brandstrom, the Swedish commissioner, presented the machine to Prince Napoleon. Acclaimed as the first machine with the means of calculating and printing the results, the Scheutz difference engine was not lost on the author of the Exposition's major souvenir album either. After briefly noting the efficacy of two French calculators, the "Arithmaurel" of Maurel and Jayet, and the arithmometer of Charles Thomas, both of which had won honorable mention, the Scheutz machine was described by Baron Brisse (1857:194) as follows:

> This machine, among the most ingenious, solves equations of the fourth degree and of even higher orders; it operates in every number system; in the decimal system, in the sexagesimal system (for trigonometry) or in any other system . . . scientists who vaunt their calculating powers, as a divination of the laws of nature, will be advantageously

replaced by a simple machine, which, under the nearly blind drive of an ordinary man, of a kind of movement, will penetrate infinite space more surely and profoundly than they. Any man knowing how to formulate a problem and having the machine of the Messieurs Scheutz at his disposal for solving it, will replace the need for the Archimedes, the Newtons or the Laplaces. And observe how in the sciences and arts, all is held together and intertwined: this nearly intelligent machine not only effects in seconds calculations which would demand an hour; it prints the results that it obtains, adding the merit of neat calligraphy to the merit of calculation without possible error: the stereotyped numerals emerge grouped at the will of the operator, and separated, as he desires, by blanks, lines or any arbitrary typographic symbols. If a simple machine can tell us the distance of stars, the extent of celestial globes, the path which the great comets traverse on their parabolic course, what limit can henceforth be assigned to mechanism? What world of impossibilities will not be cleared?

In February 1856 Georg Scheutz was elected a member of the Swedish Academy of Sciences in the Class of Practical Mechanics. Shortly thereafter, father and son wrote to Babbage expressing their appreciation for his efforts in their behalf. Edvard commented "inventors are usually see[n] to look with jealousy on them which strive in the same way. I ought not to conceal that it was prognosticated even to us, that we should meet an adversary in you; and we have found a protector!" (London, 1856, ms 37196:419). True to form, father Georg put it more poetically: "We came as strangers; but you did not receive us as such: conforming to reality you received us but as champions for a grand scientific idea. This novel disinterestedness offers so exhilarating an oasis in the deserts of humanity that I wishes [sic] the whole world should know it as I do and feel its soothing effect, as I do; it would be so much the better for the comfort and happiness of mankind" (London, 1856, ms 37196:418).

The Scientists Debate

Unfortunately, French scientists did not share the enthusiasm of Babbage or of some of the viewers at the exposition. After the closing of the exhibition in December 1855, the difference engine was taken to the Paris Royal Observatory, to be tested in day-to-day operations. The expectation was that if it proved satisfactory purchase would be recommended. U. J. J. Leverrier (1811–1877), the renowned director of the observatory, however, found it impractical. He felt that the operation still left too much work with the machine operator, and that a well-organized computing program like that at the observatory, making use of human calculators, was at least equal to, if not more efficient than, any mechanical calculator—ingenious though it might be.

While the fate of the machine was undecided in Paris, Babbage continued his efforts on its behalf from England. He corresponded with the astronomer Villarceau at the Paris Observatory, who in January had informed him of the director's interest in printing first differences as well as the function values in his tables. Babbage was unaware of the whereabouts of the machine, and for a while made concerned inquiries. He was elated when he was informed that the machine had been deposited at the Paris Observatory by order of the emperor to be put at the disposal of members of the Bureau of Longitude. Mistaking the deposit for a purchase Babbage shared his enthusiasm about the sagacity and enlightenment of the emperor with Lyon Playfair and other scientists. When notified of the true state of affairs, there was still a good deal of ammunition ready to spread the fame of the machine. Earlier in the winter, Babbage (1856) had prepared a broadside against the Royal Society of London for not considering Scheutz in their award of medals for the year 1855. The pamphlet, based on an address given from the floor at the society's meeting, presented a short history of Scheutz's efforts and successful achievement of the machine, recalled its success at the Paris Exposition and its deposit in the Paris Observatory, and duly noted the illustrations prepared by Henry Babbage "for the use of the jury" that awarded the exposition's medal to the machine. Babbage gave much thought to the distribution of this publication, which was sent to a wide range of potentially interested individuals and institutions, ranging from Prince Albert to the Smithsonian Institution. In addition, he worked diligently on the distribution of a French version. This was sent to the Academy of Belgium, French-speaking scientists, and the emperor, as well as appropriate members of his court. In the latter communications Babbage suggested making Scheutz a member of the Legion of Honor. The letter to the King of Sweden commended Scheutz to his sovereign's attention and exuded:

The science of mathematics is becoming too vast in its details to be completely mastered by human intellect and the time is approaching when the whole of its executive department will be transferred to the unerring power of mechanism . . . Whenever that day shall arrive due honor must always be given to Sweden as the country which first produced mechanism to print the results of calculations regulated by a mathematical law (London, 1856, ms 37196: 461-462).

Babbage's letter was sent and reached the Swedish court during the first week of April 1856, a month that turned out to mark several significant developments. On the 21st of April, the Scheutzes received the gold medal of the Paris Exposition from Prince Charles in ceremonies at the Royal Palace in Stockholm; still much later that month Scheutz was made a knight of the Order of Wasa. In the same week, the machine was the subject of discussion at the Paris Academy of Sciences.

Babbage, a member of the academy, had transmitted his *Observations* (1856) to that body with a request that it examine the merits of the machine. The mathematician M. Chasles (1856) presented Babbage's paper. In the subsequent discussion, Leverrier praised the ability of the Scheutzes but expressed his reservations about the machine. Another noted mathematician, A. L. Cauchy, supported Leverrier's position. Charles Dupin (1784–1873), while being careful to acknowledge the superior merits of the observatory's calculators, spoke strongly in favor of encouraging the inventors to make further improvements on the machine and to promote the art of mechanic computation generally. Citing other examples from the recent history of technology, especially photography, Dupin argued that abandoning a new invention because it had not reached a desired state of perfection would have caused most innovations to fail. The aging mathematician concluded by reminding his fellow academicians that for them the greatest merit must be invention itself. Speaking for the acceptance of calculating machines in general he (Dupin, 1856:800) noted:

> Discoveries of genius must be received without worrying whether the new means are more or less expeditious than previously existing means. The parts where the contrived machines are inferior to established procedures must be regarded not as an obstacle before which one must stop, but as the object of further research and new discoveries.

Despite the academician's noble plea, it appeared that Leverrier's judgment would prevail on practical grounds. No director of an organization with established procedures and periodic deadlines seemed inclined to invite the disruption and delays that the introduction of the new calculating machine would bring with it. If there was any hope of putting the machine to work it lay elsewhere.

For weeks, no Paris buyer appeared. In May, the emperor was visited by Prince Oscar of Sweden; together with the Archduke Ferdinand-Maximilian they toured the observatory. Edvard Scheutz had returned to Paris; but, despairing of finding a home for the machine there, he decided to try his luck in England, and so advised Bryan Donkin, asking Donkin what his chances might be. Donkin relayed the inquiry to Babbage. Charles Babbage had an answer.

Purchase and Use in America

While the efforts of Babbage, Donkin, and Gravatt had left Old World scientists debating the question whether a machine calculator should replace a team of human computers, there was more receptivity to the idea in the New World. Here, the subject of computation was one close to the hearts of a scientific community in which mathematical activities were geared almost exclusively to the needs of the navigator and the astronomer. The emphasis lay not so much on following established procedures as on finding new methods to solve given problems, and the young computer teams in institutions like the Nautical Almanac, the Coast and Geodetic Survey, or various observatories included many individuals with interests and aspirations that lay beyond routine computations.

Babbage's New World Supporters

Babbage's efforts had been followed with special interest by the small group of New England scientists that came to be known as the scientific Lazzaroni and was instrumental in determining the course of science in America. At least one of their members, the astronomer Benjamin Apthorp Gould (1824–1896) (Figure 14) was personally acquainted with Charles Babbage. Babbage had explained his difference machine to Gould in 1845, when the young Harvard graduate had made his first trip to Europe. In 1851, Babbage and Gould again discussed the advantages of mechanical computation. Other members of the group had corresponded with Babbage and sought his advice on the question of occulting lights in lighthouses. At the 1853 meeting of the American Association for the Advancement of Science, at which a leader of the group, Harvard mathematician Benjamin Peirce (1804–1881), presided, a resolution

FIGURE 14.—Benjamin A. Gould.

was adopted expressing "deep interest" in the completion of Babbage's analytic engine,

believing that its results would be of high value in the present condition of applied mathematics and astronomy, and that the practical difficulties to be surmounted in its construction would tend in this, as in Mr. Babbage's difference engine, to the material advancement of the mechanic arts (AAAS, 1856: 143).

A special 3-man committee, consisting of Peirce, Gould, and Alexander Dallas Bache (1806–1867), superintendent of the United States Coast Survey, was appointed to convey the sentiments of the association to Babbage.

During the same period, the group of American Babbage supporters became involved in a new enterprise at Albany, New York. Here a new observatory (Figure 15), incorporated in 1852, was being built with subscription funds donated by a group of Albany citizens, supported by contributors from New York City, Boston, Providence, and the surrounding upstate New York area. At the 1855 meeting of the AAAS, Bache suggested to one of the trustees of the observatory that a cooperative arrangement be established with the United States Coast Survey. Under the proposed arrangement, the observatory was to purchase a heliometer, which the Survey needed but was unable to purchase; in return for its use the Survey was to furnish to the observatory a transit and a team of observers free of charge. This was agreed upon, and shortly thereafter, at the suggestion of Peirce, a scientific council was established for the observatory, consisting of Peirce, Bache, Gould, who was then in charge of longitude observations at the Coast Survey, and Joseph Henry, Secretary of the Smithsonian Institution.

At the end of September 1855, Gould went to Europe to purchase instruments for the Dudley Observatory and the Coast Survey. Visiting the Paris Exposition, he met Babbage who showed him the Scheutz machine. He appears also to have met with Leverrier, recently appointed director of the Royal Observatory at Paris, for he subsequently referred to Leverrier's skepticism that a meridian circle could be built, completed, and delivered to America in time for the Dudley Observatory's inauguration in July 1856, something the Berlin instrument-maker Albrecht Martins (1816-1871) promised to do. It is unlikely, however, that Leverrier's opinion impressed the American scientists at the time, as they had been at odds with the French astronomer since the dispute over the discovery of the planet Neptune in the 1840s. Gould did not stay long in Paris, but proceeded to Germany where he contracted for a number of astronomical instruments, and returned home before year's end.

Shortly thereafter, the head of another American scientific enterprise expressed interest in the Scheutz machine. He was Charles H. Davis (1807–1877), superintendent of the American Nautical Almanac. Work on the American Ephemeris and Nautical Almanac had been authorized in 1849. It was conducted in Cambridge, Massachusetts, where Benjamin Peirce, brother-in-law of Davis' wife, not only contributed to the formulation, computation, and solution of pertinent problems, but gave advice which served "to regulate the theoretical department of the work, especially as to new methods of computation" (U.S. Navy, 1856:479). In February 1856, following the appearance of the committee's report on the machine in the *Proceedings of the Royal Society of London* (1856a), Davis wrote to Stokes, asking him to transmit an inquiry concerning the machine to Scheutz. Noting that the machine as

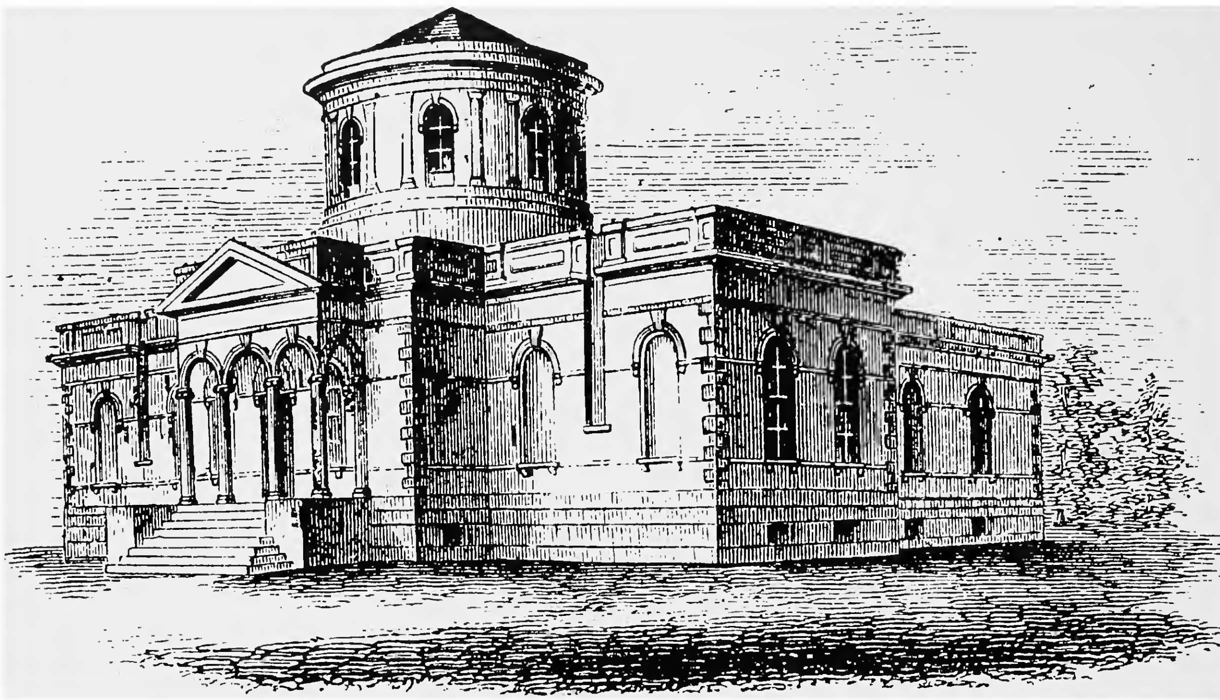


FIGURE 15.—Dudley Observatory at Albany, New York, in the 1850s.

described in the Royal Society's *Proceedings* was of great importance to the work of the Almanac Office, Davis requested drawings and further details of the machine, suggesting that perhaps someone should examine it on behalf of his office to consider its usefulness for aiding with the calculations of the ephemeris. Davis' letter was not transmitted to the Scheutzes until June, when Edvard was back in England. In the meantime, another letter had been received from America. It was from Benjamin Gould and it was addressed to Charles Babbage.

Effecting the Purchase

Gould's letter, written on 28 April, was prompted by the visit in Europe of two Americans, traveling partly on behalf of the observatory at Albany (London, 1856, ms 37196:483–486). One, Charles Spencer (1813–1881), of lens-making fame, was charged with the construction of the heliometer for the observatory; the other, John E. Gavit (1817–1874), an engraver interested in the production of postage stamps and bank notes, was to become a co-founder of the American Bank Note Company. In his letter, Gould, who had spent the intervening months since his return to the United States in the Mobile-New Orleans area on Coast Survey business, introduced Spencer and Gavit to Babbage and asked that they be shown the Scheutz engine. His main purpose in writing was to elicit specific information from Babbage. Explaining that he had not had an opportunity to see the report published in the Royal Society's *Proceedings,* Gould asked about the capacity of the machine, the maximum number of differences that it could handle, the motive force required, the speed of operation, the form of the results—whether in matrices, in stereotype plates or printed on paper —and, in the first place, whether it was for sale and if so, for how much.

> These questions are in consequence of some consideration I have given the subject, with reference to its possible purchase or employment in the Dudley Observatory,—an idea which I have communicated to no one whomsoever, and which may not be feasible, although should further reflection lead in that direction, I should be inclined to use my best efforts to this end.—There are a great many auxiliary tables which it would compute admirably but I fear that its application otherwise would be restricted to the computation of approximate ephemerides, for newly dis-

covered planets & comets,—with such subsidiary tables as might be required from time to time and which might be manually computed with not much greater trouble. If it were only an Analytical Engine!—

Is there any way in which such an engine could be applied to the solution of equations of condition?

I have been thinking too of the possibility of a machine which should receive in its hopper[?] the three observations (6 quantities) of a newly discovered heavenly body,—the three lines of observation & the six quantities which give the sun's right ascension & Distance,—making in all fifteen quantities;—and should give out the solution of an orbit by the Gaussian method, with excentricity (in character of the conic section).—I suppose the An. Engine might have been set to do this,—might it not?—Certainly the problem is not an impossible one,—for every operation is purely mechanical & may be represented geometrically. And the subsidiary quantities taken from the tables, may all be determined with absolute accuracy by a diff^ce Engine.—

You see the purport of my queries. It would be a source of legitimate & honorable pride to have first introduced this engine into practical usefulness.—But I fear much that its scope is not large enough to make its purchase a proper one to be strongly advocated at present. Will you please advise me? (Gould in London, 1856, ms 37196:483–486).

When, on 28 May, Bryan Donkin asked Babbage for his opinion to answer Edvard Scheutz's request for advice on selling the machine, Babbage apprised him of the inquiry from America. Donkin in turn informed Scheutz that there was "a possibility of selling the machine for about £1000 to go to a foreign country (London, 1856, ms 37197:43). Edvard Scheutz replied promptly "I accept the sum . . .," a formulation that concerned Babbage momentarily since no firm offer had been made. (London, 1856, ms 37197:42). However, word was passed to Gould. In due time, following the formal inauguration ceremonies for the observatory in August, scheduled to coincide with the meeting of the AAAS taking place in Albany that year, he alerted the trustees to the availability of the calculator.

J. H. Armsby, medical man, secretary of the Board of Trustees and chief promoter of observatory affairs, was impressed by Gould's account of the calculating machine. After some consideration of which observatory supporter would be worthy of having his name attached to the purchase, Armsby and his friend, the banker Thomas W. Olcott, agreed that $5000 subscribed by John F. Rathbone of Albany should be diverted to this purchase. With Mr. Rathbone's consent, obtained early in November, this was done. On 7 November Gould expressed his pleasure to the trustees:

In securing the calculating engine, I see the inauguration of a new era, for which the world will be indebted to Mr. Rathbone and the Dudley Observatory. The invention has long been made, and only the self-reliance was needed, which should induce an institution to adopt it, and put it into action. It is like the steamboat for navigation—the computer's locomotive (Albany, Dudley, Trustees, 1858: 30).

Fearing competition once word of their interest got out, Armsby and Olcott urged Gould to obtain an option on the machine and to proceed speedily and discreetly with the purchase, through Babbage if possible, so as to keep their identity a secret until the sale was confirmed (Gould, 1859:220–222). Negotiations proceeded successfully, so that in December 1856, Gould was able to send final instructions for consummating the purchase to Edvard Scheutz in London. George Peabody and Company in London had been advised to pay Scheutz £1000 upon receipt of the bill of lading and a certificate from Scheutz and Donkin stating that the machine had been "securely and safely packed in good order." Gould had heard via Babbage that Scheutz was supervising the production of a set of tables, noting that it was "but fitting that . . . the first fruits of the engine, should be raised under your supervision and culled by your own hand" (London, 1856, ms 37197: 136–137). He told of his own hopes for the machine, expressed his high regard for Scheutz, and closed with the request that any published remarks concerning the purchase should call attention to the fact that its use for the observatory at Albany had been made possible by "an enlightened and public spirited merchant of that city, John F. Rathbone, Esq., . . . who most cordially and readily embraced the suggestion and is one of those men whom it is a privilege to know and a joy to honor" (London, 1856, ms 37197:136–137).

The Calculator at Work

In the meantime the machine had returned to London. Edvard Scheutz had spent June and July of 1856 shuttling between Paris and London. By the end of July, Gravatt reported that the calculating machine was ensconced at his home, and that Edvard, delayed by illness, had just arrived. There followed another period of intense activity, during which Gravatt and Scheutz had the machine produce a variety of sample tables for publication, Donkin and Scheutz prepared for the construction of a second machine, and all three men negotiated with appropriate government officials, including Prince Albert, for the purchase of this second machine. Babbage advised all concerned on these projects, and arranged to have the specimen tables printed by the firm of Longman, Brown, Green, Longmans and Roberts.

First proofs of the tables were ready before spring. They included the logarithms of the natural numbers from 1 to 1000 to five decimal places, as well as selected samples of other tables, displaying values of fourth degree polynomials, life-assurance, ordnance, and astronomical functions.

At the end of January 1857, the machine was exhibited in the library of the Institution of Civil Engineers (1857a), where Babbage and Gravatt explained it to the members after a meeting of 27 January. They also displayed a portion of the logarithm table that it had produced, again stressing both the speed of its operation and the avoidance of errors. Other proofs of the tables to be printed were ready before spring. Gravatt supplied an explanation of the operation and setting up of the machine, which was prefixed to the tables (Appendix II). An anonymous historical introduction, based on information supplied by the chief participants and by correspondents of Babbage, appears to have been compiled by Babbage. Despite some errors and inaccuracies it became the main source of information about the history of the machine. The entire publication was dedicated to Babbage "by his sincere admirers, Georg and Edward [sic] Scheutz." Copies of the work were autographed by Edvard Scheutz and distributed internationally, a fact that caused the publication to be attributed to the Scheutzes (Figure 16*a,b*).

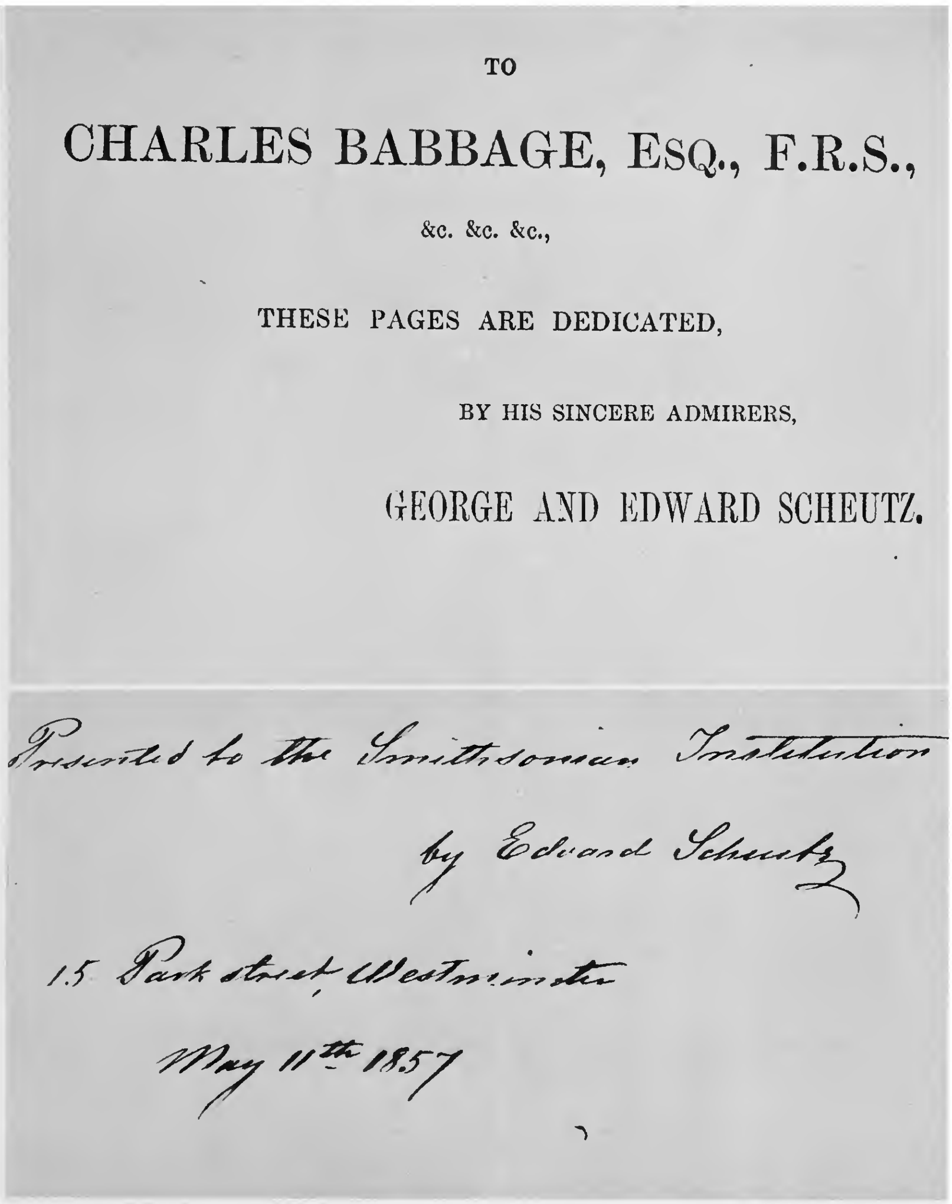
While the publication of the *Specimens* was being completed, the machine itself traveled to America. It arrived in Albany in April 1857. Gould who was still residing in Cambridge, Massachusetts, made it the subject of an address at the next monthly meeting of the American Academy of Arts and Sciences, not failing to link it with Babbage's work. However, the machine was not unpacked until the following winter, when Gould established residence in Albany. The delay was caused by Gould's unwillingness to start active operation of the observatory until he had means at his disposal "to assure continuity, reduction and publication" of observations. In January 1858, at the instigation of Bache, the Board of Trustees put him in charge of the observatory. By that time, Gould had yielded to local pressure, and resigned himself to the fact that he and his assistants would continue to earn their bread by longitude determinations for the Coast Survey while starting the observatory on their own time (Gould, 1858c:54).

Gould apparently hoped that the machine could be used to produce some revenue for the observatory, for in March he requested permission from the Board of Trustees to set aside income derived from the use of the machine for increasing the amount of allowable incidental expenses, such as fuel, lighting, stationery, and furniture. Gould's technical assistant reported to the Scientific Council that the machine could be maintained for approximately $28 per annum, and that even in case of a repair the yearly expenditure should be under $120.

Two objectionable features of the machine's operation soon became apparent. One was the introduction from time to time of a computational error, presumably caused by the malfunctioning of one of the traps. While corrections could easily be made when an error was discovered, there appeared to be no way of eliminating the malfunction. The other drawback was an occasional error in the printing part of the mechanism, which Gould hoped to eliminate (Albany, Dudley, Scientific, 1858:74). Nevertheless, Gould derived the necessary formulas for setting up the machine and turned over the subsequent preliminary computations and operation of the machine to one of his assistants.

It appears that, once started, work with the machine proceeded fairly rapidly. Gould requested and received an appropriation of $200 from the Board of Trustees for putting the machine in order. As it turned out, however, he chose not to use this money, finding that he could place the machine in operation with minor work at minimum expense. In a report made the following year, Gould noted that no specific instructions had come with the machine, the only explanation consisting of a set of drawings and a letter of Edvard Scheutz, explaining the procedure of converting the machine from operation in one number system to another. After a thorough cleaning of the machine and some test runs, the machine was put to work (Gould, 1859:141–142):

> The strictly algebraic problems for feeding the machine made quite as heavy demands upon time, and thought, and perseverance, as did the problem of regulating its mechanical action; but all was soon in operation, and by the aid of my zealous and enthusiastic assistants, Messrs. Batchelder and Searle, the True Anomaly of Mars was computed and stereotyped for intervals of a tenth of a day throughout



TO

CHARLES BABBAGE, Esq., F.R.S.,

&c. &c. &c.,

THESE PAGES ARE DEDICATED,

BY HIS SINCERE ADMIRERS,

GEORGE AND EDWARD SCHEUTZ.

Presented to the Smithsonian Institution
by Edvard Scheutz
15 Park street Westminster
May 11th 1857

FIGURE 16.—Dedication and autograph from the *Specimens* (top: SI photo 74–7805; bottom: SI photo 74–7806).

the cycle; and a sufficient number of the plates electrotyped, to enable me to be confident that all difficulties were surmounted. Since that time the Eccentric Anomaly of Mars, and the logarithm of its Radius-Vector have been computed and stereotyped by the machine in like manner, for the same interval, making a series of tables upon which the reputation of the engine may well be rested.

This description of the first "real" work done by the machine omits one important detail, which assumes historic significance: The sponsorship of the Mars tables marks the first contractual commitment by the United States government for machine-produced printed computations.

A Government Contract

In his letter of December 1856 to Edvard Scheutz finalizing the purchase arrangements, Gould had alluded to the possibility of applying the machine to the computation of ephemerides in the Nautical Almanac. Davis and Gould had discussed the need for work on the orbit of Mars long before this. Gould had turned down an offer to perform this work for the Almanac in October 1849, during the first year of the Almanac Office's operation, explaining that he had no time, especially for anything "entailing such purely mechanical labors." Davis, who had shown early interest in the machine, was succeeded as superintendent of the Nautical Almanac by Joseph Winlock (1826–1875) in 1857. Arrangements between the Nautical Almanac Office and Gould were agreed upon during the fiscal year 1857–1858, and Gould reported his readiness to proceed with the Mars tables in April 1858. On 1 May Winlock replied:

> I am surprised to find that you are getting on so rapidly with the machine. It will not be necessary to change it so that it will give numbers for .2 of the argument. On the contrary it is very desirable that the argument should proceed decimally for which purpose the unit must be 2 days instead of one. If I had supposed you were so nearly ready to begin with the actual computation of the Tables I might have added some remarks but you must not wait for anything if your own ideas are clear. The anomaly should be diminished by the constant 2′30″0 or 2′10″0 to make room for the perturbations (Washington, National Archives, 1858(2): 133-134).

Winlock instructed Gould to present monthly vouchers to the office for services rendered by Gould's assistant Batchelder in conjunction with this project. On 8 August, Winlock acknowledged to Batchelder receipt of the machine plates and requested a meeting prior to their electrotyping. This was to be done through the publisher Weld, to whom some of the plates had been transmitted already.

In his annual report to the Secretary of the Navy, dated 11 September 1858, Winlock summarized the project as follows (U.S. Navy, 1858:441):

> In addition to the preparation of the annual volumes, as much labor has been bestowed on the improvement of the planetary tables and methods of computation as could be spared without interfering with other departments of the work. One of the most important of the elliptic tables of the planet Mars has been computed by the calculating engine of the Dudley Observatory, at Albany. The computations have been made, and the results printed on lead plates, by the machine. The object has been to ascertain, by a trial that would involve a very small expense, whether this extraordinary instrument could be employed with advantage on the work of preparing the Nautical Almanac. A complete report has not been received from the director of the observatory, who has had charge of these computations, but the result thus far has not been such as to demonstrate to my satisfaction that any considerable portion of the Almanac can be computed more economically by this machine than by the ordinary methods, or that it would be expedient to continue, at present, the trial further than the completion of the tables already begun. At the same time, what has been done may justly be regarded as a wonderful triumph of ingenuity; and the encouragement that it affords to the hope that the immense labor of astronomical calculations may be materially diminished by the aid of machinery would render it in the highest degree desirable that some special provision should be made for improving and fairly testing the powers of this machine, which offers much greater promise of success than any that has yet been tried.

Winlock's judicious assessment left open the door for further special projects in which the machine could be employed and improved, while the routine work of the office proceeded as before. Neither the Nautical Almanac Office nor other agencies were to pursue this course. The reason for this failure is attributable to events in Albany.

On the date that Winlock wrote his report to the Secretary of the Navy, noting that he had not yet received a full report from the Director of the Observatory, this observatory no longer had a director. As the result of mounting friction between Gould and the Scientific Council on one side, and certain members of the Board of Trustees, led by Olcott and Armsby, on the other, the board had fired Gould on 3 July. On the surface, the conflict appears to have centered on the question of whether the observatory was to be under the control of the out-of-town scientists represented by the Scientific Council, or the citizens of Albany, represented by the Board of Trustees. In fact, more complex issues were involved, including factional differences among the Albany citizenry. The bitter arguments, in which the purchase of the Scheutz machine played a role, led to a sequence of published charges and countercharges. Important for the history of mechanical computation is the fact that this quarrel put an end to the program Gould had envisioned for the machine. He and his Coast Survey assistants continued to reside and work at the observatory for six months before being physically evicted in January 1859. When they left Albany, the calculator remained.

Propagation of Recording Calculators

While in America disputes stalled further use of

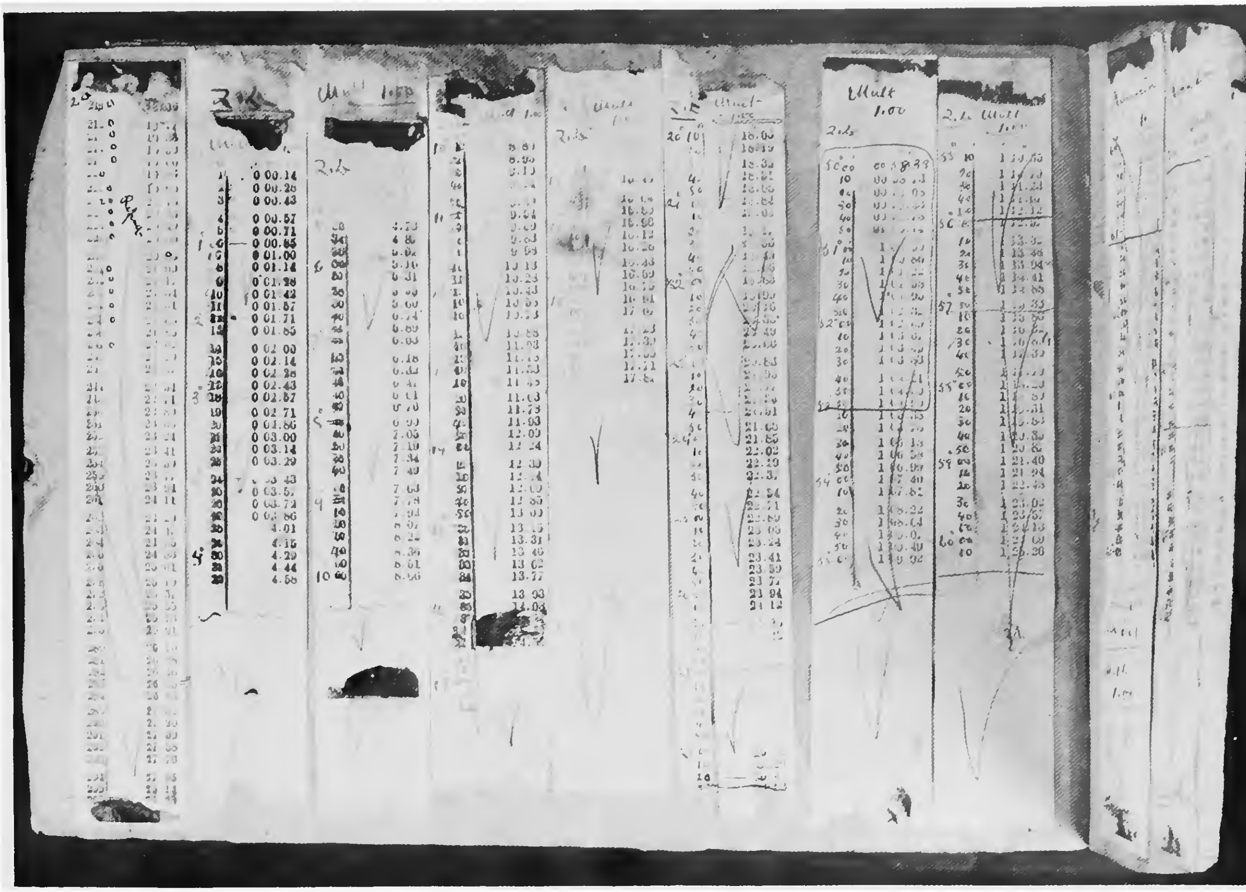


FIGURE 17.—Sample printouts from computations of refraction tables at the Dudley Observatory, Albany. (Courtesy of Dudley Observatory)

the machine, in England a second Scheutz difference machine was being put to work. It was followed by a sporadic sequence of printing and listing machines, until, by the end of the century, printing calculators were no longer a novelty.

DIFFERENCE MACHINES

In 1856, when Edvard Scheutz and Bryan Donkin had sought an English buyer for a second difference engine, they had found a supporter in William Farr (1807–1883), superintendent of the General Register Office. One of England's foremost statisticians, he prepared, among other things, more than 40 volumes of *Reports of Births, Deaths and Marriages.* In the 1850s he was engaged in work that was to result in one of his major achievements: *The English Life Tables* (Great Britain, 1864). Based on the registration of births and deaths between 1838 and 1854, as well as census figures of the population in England and Wales in 1841 and 1851, it involved a large number of computations—nearly 6.5 million deaths, sorted by age, were included. The tables were designed to show life annuities, broken down for single lives and for two lives, with formulas for computing them for any number of lives. These in turn were arranged by various combinations of age and sex. Noting that the tables could be computed by series using difference methods, it was brought to the attention of the Registrar General that this work could be done by machine. An example of a table of male life expectancy had been included in the *Specimens* computed and printed by the first Scheutz machine. The Registrar General, supported by the Astronomer Royal, passed the request on to the Secretary of State for the Home Department. As a result, the English government contracted for a machine, which Scheutz and Donkin offered to build for £1200.

The Scheutz-Donkin calculator followed the basic construction of the first machine, although it differed in some details. According to Bryan Donkin, as cited by Farr (in Great Britain, 1864:cxl), the machine consisted of "about 4,320 [sic] pieces, of which 2,054 are screws, 364 composed the chain, and 902 are other parts of the mechanism. The weight of the machine . . . is . . . about 10 cwt." Like the first machine, this one handled 15-place numbers to 4 orders of differences and could transmit 8 places to the printing mechanism. There were variations in design between it and its predecessor, the most obvious one being a slight rearrangement of the drive transfer mechanism (Figure 18).

The first tables calculated and stereotyped on the new machines were a set of mountain barometer tables, designed to help determine the difference in the level of two stations, based on readings at both stations of the height of the barometer, the temperature of the mercury and the air in the shade. As noted by William Gravatt (1862), they could be used not only to determine the height of mountains, but to determine the depth of mines. Gravatt, who had been elected a member of the Swedish Academy of Sciences in October 1858, had set up the tables and accompanied their publication in 1859 and 1862 with a short explanation.

The major work for which the machine had been

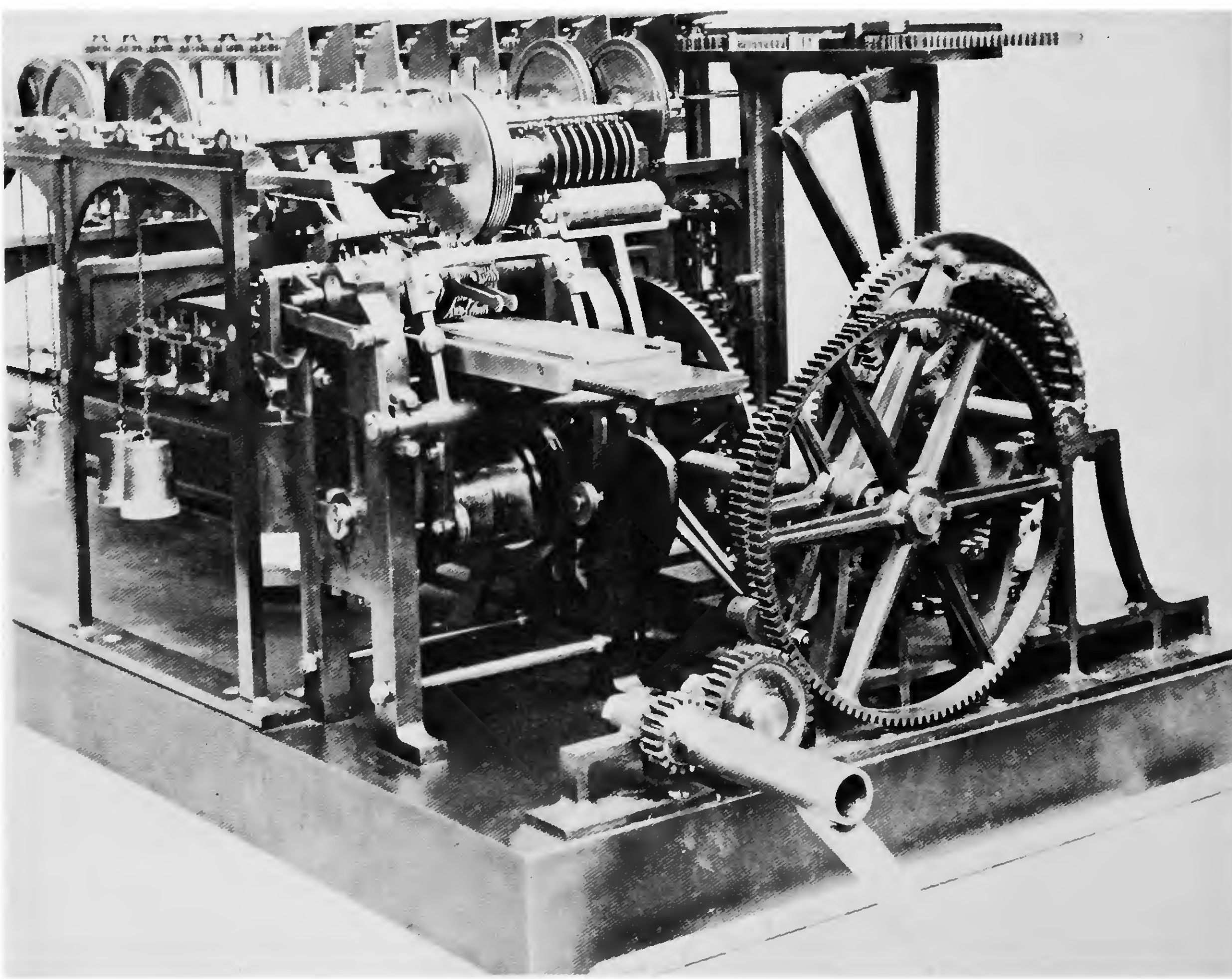


FIGURE 18.—The Scheutz-Donkin calculator. (SI photo 74–7810)

purchased, Farr's *Life Tables,* appeared in 1864 (Figure 19). Farr accompanied it with a brief discussion of the machine and a description of its use in forming one of the tables. The work for this project had been conducted at Somerset House. Clearly, considerable human effort had accompanied that of the machine. Farr's account mirrored that of Gould and his assistants in Albany. First, the machine had had to be readjusted after transportation from the Donkin factory. At the beginning of each computation, the differences had to be set manually; results had to be checked; errors, caused by the occasional slippage of parts, had to be corrected, and the parts re-set. Of the major portions of the machine, the printing apparatus was again said to require the most improvement. Nevertheless, Farr felt that the machine had lived up to expectation. He summarized (in Great Britain, 1864:cxliii) the problems by noting that "it is a delicate instrument, and requires considerable skill in manipulation . . . . It approaches infallibility in certain respects, but it is not infallible, except in very skilfull hands."

While work on the tables was in progress, preparations were made for the Industrial Exhibition to be held in London in 1862. Portions of Babbage's difference engine were to be shown, and Babbage wished to have the Scheutz No. 2 machine included as well. A description of the machine was sent, along with samples of its work, of the stereotyped plates, and of papier-mâché molds, stamped by its printing apparatus. Farr and his associates, however, demurred to the suggestion that their entire activities be transferred to the exhibition hall. Justifying his refusal to move the machine, Farr made two basic points: First, he noted that enough time had passed during which machines had been shown off in public displays to acquaint the public with the concept of a mechanical calculator. Second, there still were no criteria to determine the practical usefulness of such devices; only by doing "real" work would actual error and cost comparisons between human and mechanical labor be obtained. The environment of an exhibition, with "the possible clang of musical instruments, discordant sounds, or noises in the ears of the operators" (in Great Britain, 1864:cxl) was not likely to benefit such an endeavor. He continued:

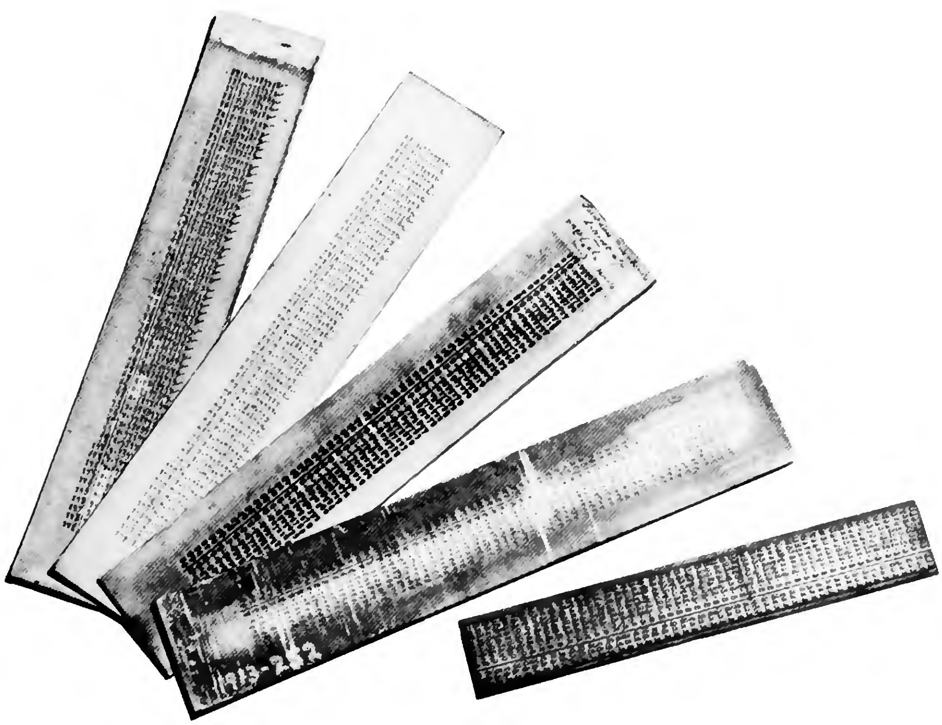


FIGURE 19.—Stereomolds of life tables produced by Scheutz-Donkin calculator in 1864 by William Farr. (British Crown copyright; courtesy Science Museum, London)

Of the first watch nothing is known, but the first steam-engine was indisputably imperfect; and here we had to do with the second Calculating Machine as it came from the designs of its constructors and from the workshop of the engineer. The idea had been as beautifully embodied in metal by Mr. Bryan Donkin as it had been conceived by the genius of its inventors; but it was untried. So its work had to be watched with anxiety, and its arithmetical music had to be elicited by frequent tuning and skilful handling, in the quiet most congenial to such productions.

After completion of the *Life Tables,* which marked the high point of the careers of Farr and of the Scheutz No. 2 machine, it remained at the General Register Office until it was given to the Science Museum in London (South Kensington) in 1914. Donkin and Edvard Scheutz failed in their efforts to find further buyers for difference machines, which, after taking a loss on the construction of the No. 2 machine, they offered to produce at wholesale discounts for £2000 apiece. Nevertheless, and despite their limited accessibility, the two Scheutz machines received considerable publicity, and for a while were identified with the concept of calculating machines. For example, readers of certain popular English-language encyclopedias in the 1860s, desirous to learn about calculating machines, might read that "a machine of this kind is in use at the Dudley Observatory in Albany. It is is the only one ever completed" (Calculating Machine, 1865:172). In another work giving an account of contemporary calculators, they were informed that the Scheutz machine was "the most important calculating machine that has ever been actually finished" (Calculating Machine, 1866:137). In midst of a lengthy account, based largely on the 1854 patent and Babbage's writings, they also read that a second machine in England "has been for some time actually at work in computing tables for the Nautical Almanack, and some other purposes" (Calculating Machines, 1866:137). Despite factual errors, such accounts helped to keep alive interest in mechanical calculation generally, and in difference machines in particular.

At least two more nineteenth century machines may be singled out as having been inspired by the Scheutz effort. They were the difference machines of Martin Wiberg in Sweden and of George B. Grant in the United States.

For financial reasons, Martin Wiberg (1826–1905) had turned from the study of medicine to that of science and received a doctoral degree from the University of Lund in 1850 (Figure 20). Attuned to the technological progress of the times, he wished to develop a composing machine. To raise money for this venture, he decided to publish a set of interest tables, hoping to use the Scheutz machine for computing and printing these. When it was sold to the Dudley Observatory, his attention turned to the construction of his own calculating machine. He was particularly intrigued by the challenge of building a machine that would be smaller than that of the Scheutzes.

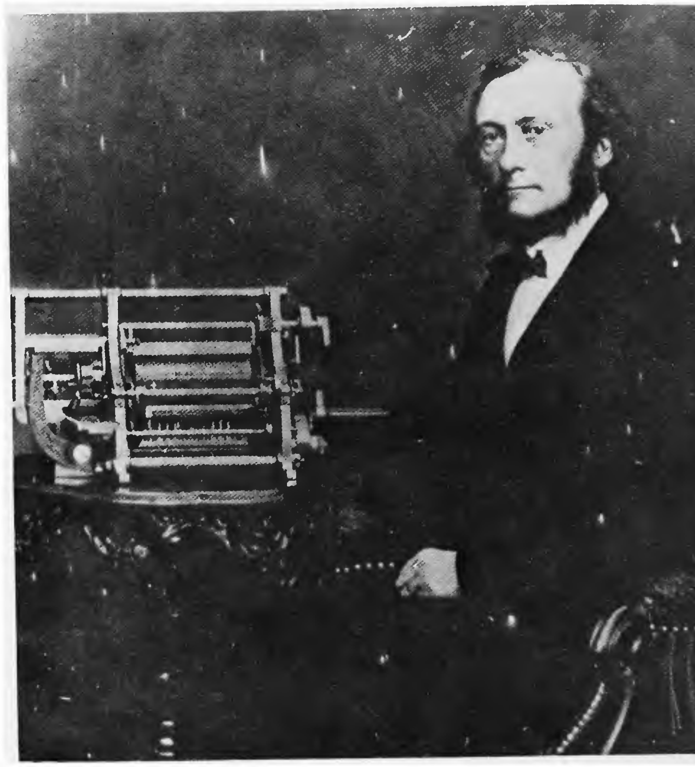


FIGURE 20.—Martin Wiberg and his difference engine.

With the support of a group of influential Swedes, including the future King Oscar II, then duke of Ostergötland, a company was formed under whose auspices the tables were to be created. A successful desk-size machine was built and the interest tables appeared in 1860. For this work, Wiberg was awarded 8000 kronen by the Swedish government, received several medals and awards, was noticed by Napoleon III, and praised by the prominent marine engineer John Ericsson. The machine was brought to the attention of the French Academy of Sciences, where it received favorable notice, and was described in a report by Mathieu, Chasles, and Delaunay. The machine had the same capacity as those of the Scheutzes; it could compute fourth differences of 15-digit numbers. Instead of the rectangular array of number wheels that had characterized the Scheutz machines, however, Wiberg's calculator was made more compact by substituting identical metal disks for the counting wheels used by Babbage and Scheutz, and by arranging these linearly along a common axis (Figure 21). This meant that 75 disks were arranged in 15 groups of 5, each group corresponding to the tabular values and the first, second, third, and fourth difference, arranged from left to right. A second axis, parallel to the first, carried 30 hooks which could cause as many of the disks to be acted upon at the same time, making possible the simultaneous addition of two sets of 15-digit figures. Thus, one of the operating features of the Scheutz machine had been preserved: one turn of the crank caused even differences to be added, another turn, odd ones; carrying was again effected separately, after the rest of the addition had been completed. Results were once more impressed on lead or papier-mâché, from which stereotype plates could be produced. The academy's reporting committee (1863) stressed that the machine could do nothing that the Scheutz machine had not done, but commended it for its efficient mechanical construction, which had led to a substantial saving of space and utmost reliability.

Wiberg was to become a prolific inventor, whose contributions ranged from mechanical letterboxes, heating devices for railroad carriage components, speed controls, match-manufacturing machines to self-propelled torpedoes, and automatic breech-loading weapons, to name just a few. His calculator became especially well known through a set of logarithm tables, which included logarithms of the trigonometric functions, and appeared in 1875. It was published in Swedish, German, French and English editions, appearing in 1876, in time to be included among Sweden's contributions to the International "Centennial" Exposition held at Philadelphia that year, where it joined his "bull-dog apparatus" for deep-sea sounding and railway control device.

The Philadelphia Exposition featured another calculator derived from the Scheutz machine. That was the difference engine of G. B. Grant.

George Barnard Grant (1849–1917) was the son of a Maine shipbuilder (Figure 22). Of seventeenth century New England stock, he attended Bridgton Academy in Maine and the Chandler Scientific

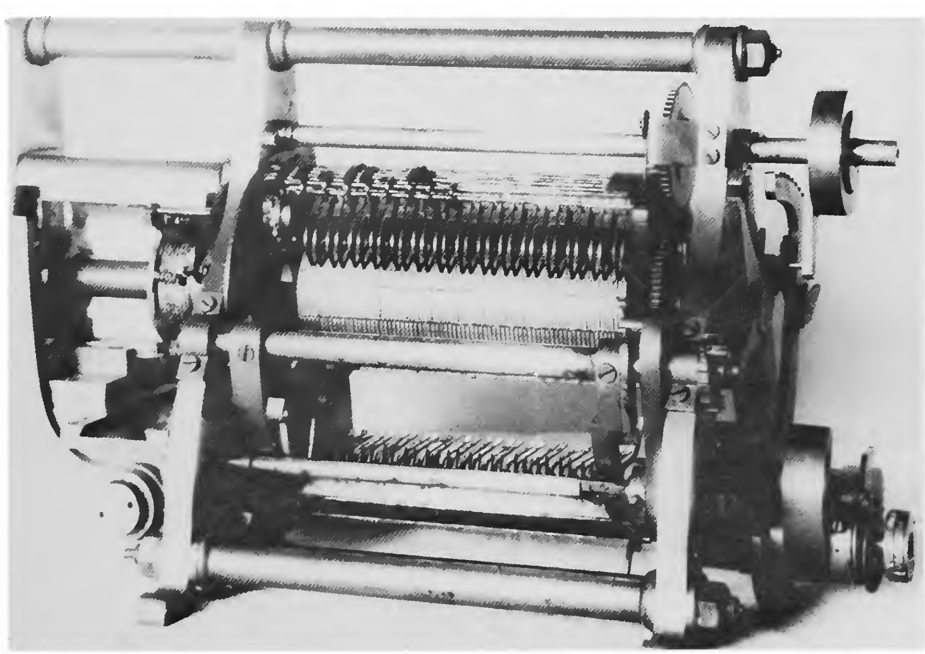


FIGURE 21.—Wiberg difference engine. (Courtesy Tekniska Museet, Stockholm)

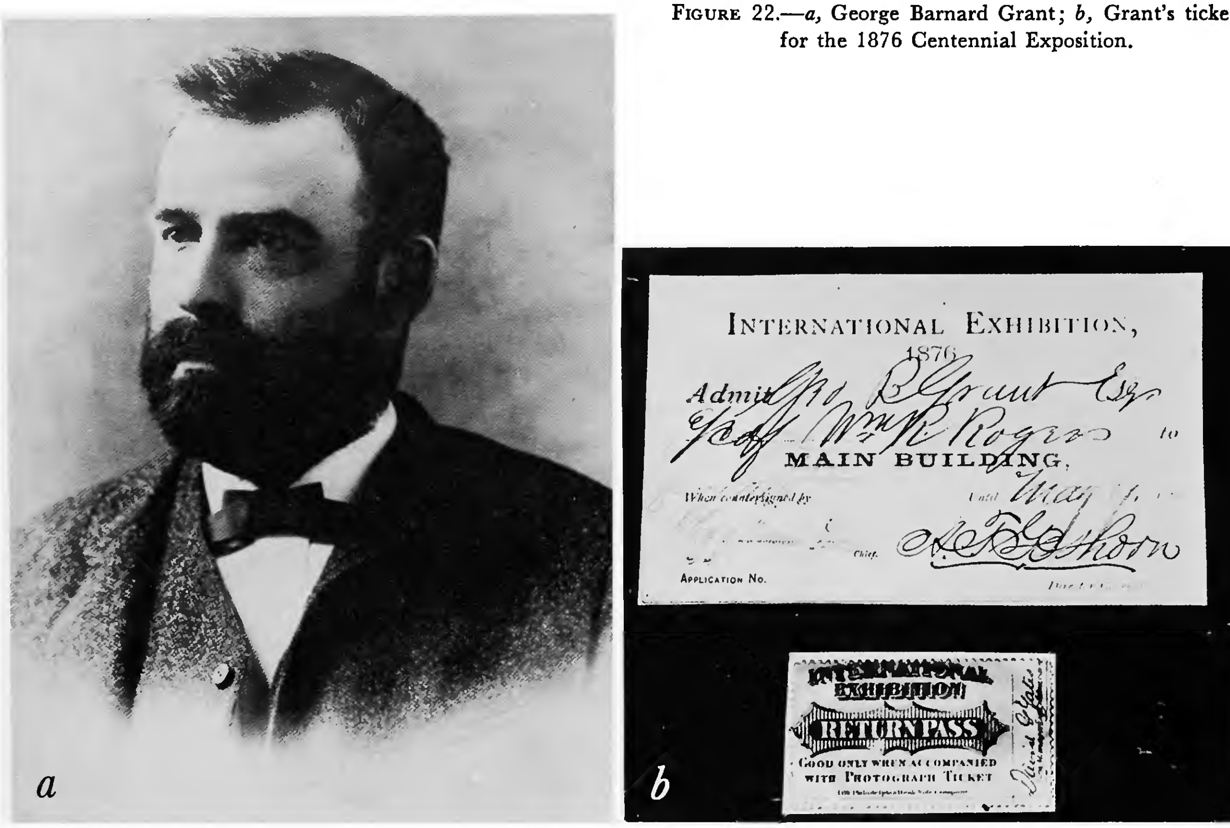


FIGURE 22.—*a*, George Barnard Grant; *b*, Grant's ticket for the 1876 Centennial Exposition.

School at Dartmouth College before entering the Lawrence Scientific School at Harvard, where he obtained his baccalaureate degree in 1873. Grant's first attempts to construct mechanical calculators were made while at the Lawrence Scientific School. According to his own testimony (1871), his interest in the subject was aroused while he was computing a table for excavations and embankments; but he became discouraged with his initial efforts when he realized the subject was more difficult than he had anticipated. In 1870, however, he heard of the Babbage difference engine and proceeded to design one himself. Upon meeting with skepticism concerning the workability of his design, he again laid it aside. He was aroused to resume work on the project when Wolcott Gibbs inquired about his progress and encouraged him to pursue it further. Grant was in the right place: His major supporter, Wolcott Gibbs (1822–1908), since 1863 Rumford Professor of Chemistry at Harvard, was a member of that circle of scientists whose older leaders had supported Gould and his endeavors at Albany. Henry Lawrence Eustis (1819–1885), professor of engineering, who became Dean of the Lawrence School in 1871, approved and helped the project. Another supporter was Joseph Winlock, now director of the Harvard College Observatory, who when head of the Nautical Almanac had approved the work done on the Scheutz machine for that office. John M. Batchelder, who had operated the Scheutz machine at Albany as one of Gould's Coast Survey assistants, was in Cambridge, ready to advise Grant. Benjamin Peirce, now superintendent of the Coast Survey, furnished financial support for the construction of a small model.

Grant described the design represented in this model in the August 1871 issue of the *American Journal of Science*. The publication included references to several accounts of the Babbage and Scheutz difference engines, such as Lardner's detailed 1834 *Edinburgh Review* discussion of the Babbage machine, the 1854 British patent specifications of the Scheutz machine, and some of Babbage's own writings dealing with both machines. The version of the machine described in this 1871 article had numerous features in common with the Scheutz machine. Thus, it too was designed to print by stamping the result on a sheet suitable for stereotyping. Grant did not describe the printing mechanism, beyond observing that "it contains nothing new of importance." Again there was a set of number wheels. As in Wiberg's machine, their arrangement differed from that in the Scheutz machine by being purely linear. For a maximum capacity of n digits per number, there were n sets of these wheels, each using m wheels if the m-1st difference was constant. All these wheels were arranged along a common axis. Again, odd orders of differences were added simultaneously in one operation, even ones in the next.

Following this publication, Grant continued to occupy himself with the problem of mechanical calculation. Aside from reading widely in the existing literature—particularly the patent literature—he worked on desk calculator designs and by the time of his graduation from the Lawrence School had obtained two calculating machine patents. Upon his graduation, his scientific benefactors supported the further development of the difference engine. In 1874 the Boston Thursday Club raised a subscription for the construction of a large-scale model, which was supplemented by a substantial support from Fairman Rogers of Philadelphia. A note dated 3 May 1874 from Rogers to Wolcott Gibbs sheds additional light on the interest taken in the project (Philadelphia, 1874):

> I spent nearly all day yesterday with Mr. Grant, here and at Sellers' place.
>
> We went over the difference engine thoroughly and concluded that the proper thing to do would be for Mr. Grant to make or have made in Boston under his own eye a machine or working model which will suffice to show the working of the apparatus and which would point out what practical changes might have to be made before commencing to make machines on a larger scale—The templates or "jigs" required to make all the pieces alike are the most expensive part of the propositions and the pins should be carefully settled upon by previous experiment before the templates are made.
>
> If, as I understand, the $750 subscribed is applicable to this purpose Mr. Grant could go on immediately with his model. I will very gladly add my share to the amount.

Rogers not only supported construction of the machine, but saw to it that Grant exhibited the machine at the 1876 Centennial International Exhibition at Philadelphia (Figure 23), along with a small general-purpose calculator. The difference machine was approximately 2.5 meters long and 1.5 meters high. It could be manually operated or connected to a power source. It was said to calculate 10 to 12 terms per minute when hand-cranked and to compute more than double that amount when power-driven; small sections of it had been tested at even higher speeds. Grant emphasized the flexibility of the machine, which allowed any number of wheels of the k-th order of differences to be added to any wheel of the k+1-st order. An important distinction between this difference machine and the model described in 1871 lay in the arrangement of the number wheels. It was again linear. But in the 1871 model the wheels had been grouped by place-figures, all the lowest decimal values being grouped together, then the next highest decimal value, etc. Within each such group appeared first the appropriate digit of the tabular value, then the corresponding one of the first order of differences, then that of the second order, and so on. Now the numbers were regrouped: all digits of the tabular value came first, then those of the first difference, then the second, etc. As a result, the carry mechanism, which was closely related to one covered by Grant's general-purpose calculator patents, was simplified. The printing apparatus connected ten of the tabular function wheels with corresponding die-plates holding wax-molds for subsequent electrotyping.

Despite some publicity and favorable notices at the time of the exhibition, the difference machine soon faded into relative obscurity. Grant continued working on mechanical calculators. In the decades that followed, he invented a second small all-purpose calculator, won some awards, and sold a few of his machines. He became best known, however, for establishing a business that was a derivative of his experimentation with mechanical calculators. Just as Babbage's needs had led to advances in precision-tool and parts manufacture in England, and Donkin's requirements for the second Scheutz machine caused him to develop new production techniques, so Grant discovered that, to obtain gears of the accuracy required for his calculators, he had to cut his own gears. Having hand-cut those on his early models, he established a gear-cutting machine shop in Charlestown, Massachusetts, soon after his graduation in 1873. As this business expanded, he moved it to Boston and named it the Grant Gear Works. From this extremely successful establishment sprang the Philadelphia Gear Works and the Cleveland Gear Works. Whereas the Grant Gear Works continued to flourish after Grant's death in 1917, his difference

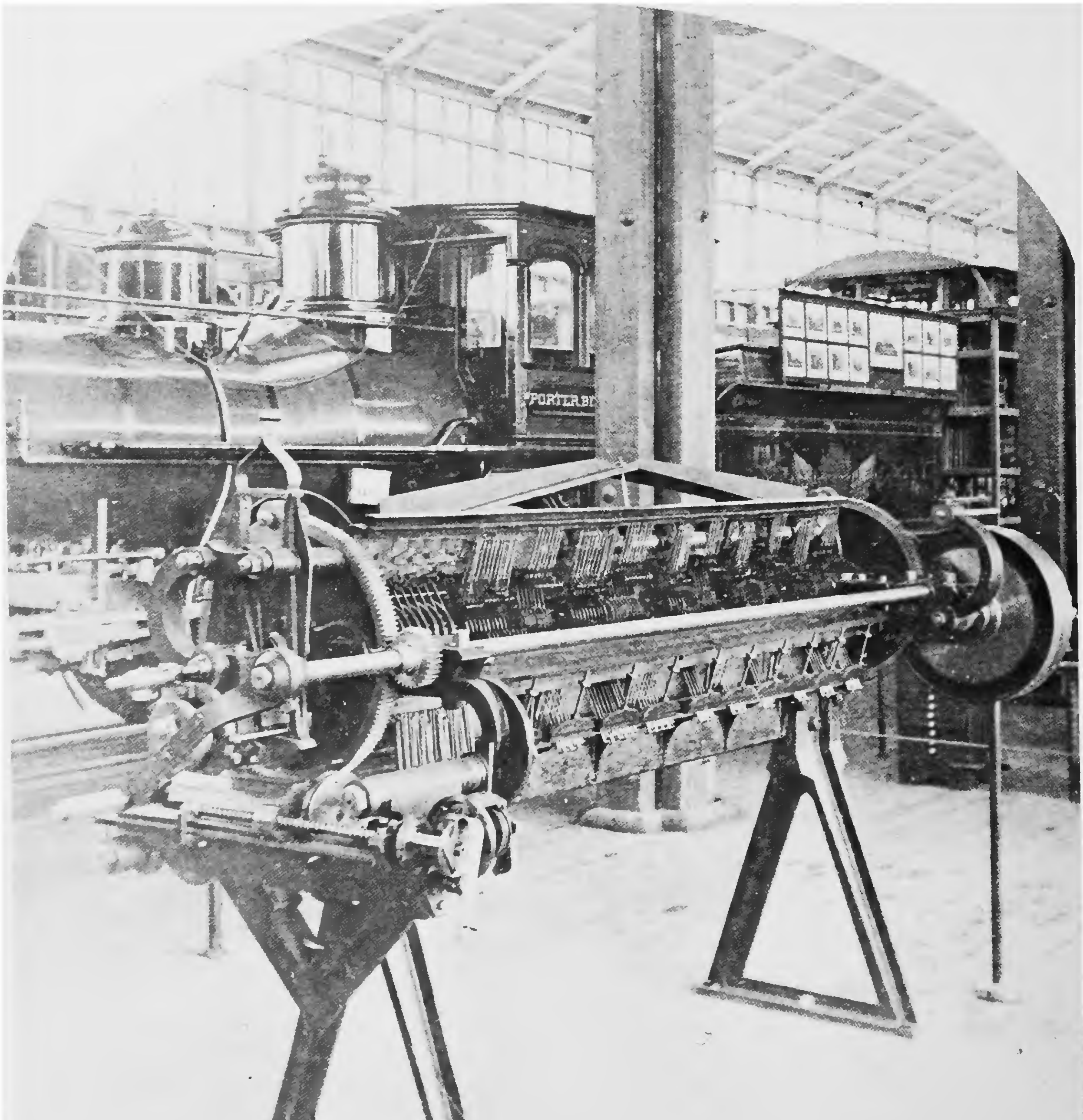


FIGURE 23.—Grant difference machine at the 1876 Centennial Exhibition.
(SI photo 60955-K)

engine, sent back to Philadelphia in the 1890s, had assumed the status of an antiquated curiosity.

General Purpose Machines

In the 1870s, a new trend in calculator design had set in. Attempts to arouse interest in large-scale difference machines in the 1870s and 1880s were unsuccessful. Advances in the design of printing calculators henceforth followed a direction different from that marked by Babbage, Scheutz, Wiberg, and Grant. Their difference machines had been special-purpose scientific calculators. Now a successful series of printing calculators emerged that was designed for more traditional, general-purpose use. Although mechanical desk calculators had been developing slowly ever since the seventeenth century, few had been produced by the time the Scheutz machine was introduced. However, the fine craftsmanship of eighteenth century artisans like Philipp Matthäus Hahn (1739–1790) had shown the technological feasibility of the concepts propagated by Blaise Pascal and Gottfried Wilhelm Leibniz during the seventeenth century. Whereas the adding machines designed by Pascal had entertained heads of state and of scientific societies, the general-purpose calculators of the early nineteenth century were viewed with increasing interest by heads of insurance companies. One of these, Charles Xavier Thomas (1785–1870) developed the first commercially successful calculator in France. By 1876, more than 1200 of his arithmometers had been produced. Though a Thomas arithmometer had lost against the Scheutz machine in the award of medals at the 1855 exposition, these stepped-drum machines, designed to carry out the four basic arithmetic operations, effecting multiplication by repeated addition through the use of a moveable carriage, had the advantage of wide applicability over difference machines.

During the nineteenth century, more and more inventors turned to the design of such machines. By the 1870s, the concepts of the stylus-operated adding machine and the stepped-drum general purpose calculator were supplemented by key-driven adding machines and pinwheel-operated multiplying machines. Emphasis, for the most part, lay in facilitating multiplication and division; the motivation of producing error-free printed records of results was less strong among most inventors than it had been with Babbage, Scheutz, and Wiberg. Concurrently with the development of practicable typewriters, however, a new trend appeared. In 1872 Edmund D. Barbour obtained a U. S. patent for a printing calculator. By 1890, Dorr E. Felt, inventor of the comptometer, had patented and was selling his printing version of that machine, the comptograph (Figure 24). This device, a key-driven full-keyboard machine, recorded results by typing them on a paper roll. It soon gave way to its great competitor, the Burroughs adding machine, which in the twentieth century was to become the most successful full-keyboard listing machine (Figure 25). Banks and insurance companies had led the way in adopting listing machines for daily use; but they soon became a commonplace in businesses of all kinds, and the names of Burroughs, Wales, Universal, Dalton, Ellis, Underwood, and Sundstrand were familiar to business men who, by 1920, could choose among full keyboard, 10-key keyboard, or adding-typewriter combinations.

Once the use of general-purpose listing calculators had become widespread, it was understandable that those interested in building on the Babbage-Scheutz example of aiding the table-maker with a mechanical device should turn to these machines. In a frequently cited early effort to adapt a general-purpose calculator to scientific computation, T. C. Hudson used a Burroughs machine for numerical integration in the British Nautical Almanac Office in 1914. The practices in that office provide a good illustration of changing techniques: Until the 1920s, logarithm tables constituted the chief aid to the human computers employed by the British *Almanac*. During the twenties, mechanical calculators became more common. For computation involving difference methods L. J. Comrie in 1928 used the same machine that had aided Hudson 14 years before. It was then replaced by a similar machine with an additional register, which computed and printed 1,200,000 function values in one year. This in turn was superseded by a multiple-register National accounting machine. With the observation that accounting machines enabled direct transfer of input from any one register to any other register in the machine, these machines soon became a favorite for difference method use, as ordinary listing machines required intermediate steps to effect equivalent transfers. In some places unsuccessful efforts were made to devise difference machines by attaching several like desk calculators to a common drive-shaft.

FIGURE 24.—Comptograph of the 1890s. (SI photo P63-182; NMHT 273036)

FIGURE 25.—Burroughs full keyboard adding machine of the 1890s. (SI photo 58996G; NMHT 292398)

A new opportunity for difference calculations presented itself when, in the early 1930s, punch-card systems incorporated inter-register transfers. With that development, punch-card machines, which had steadily widened their range of application since first being put to major use in the United States Census of 1890, were utilized for differencing in the British Nautical Almanac Office, in the Columbia University Astronomical Computing Laboratory, and in other institutions. One hundred years after Scheutz had read of Babbage's technique for table computation, the same technique—including the trick of simultaneously adding first the even, then the odd differences—was utilized in punch card systems. Scheutz's machine did not involve the use of punch cards, which had been advocated by Babbage for control of his automatic computer, the "Analytical Engine." When, in the 1940s, the analytical engine became a reality with the completion of general-purpose digital automatic computers, the first such machine to become operational (Aiken–IBM Automatic Sequence Controlled Calculator at Harvard University) used techniques of register transfer that owed much to the century-long efforts of machine-aided table computation (Figure 26). The problems besetting the twentieth-century pioneers of automatic computers as their machines calculated and printed mathematical tables were reminiscent of those that had plagued the operators of the Scheutz machine: manual input of initial data and constants, the need for error-checks, periodic "de-bugging," faulty printers. Except for a newly coined expression or two, these complaints had been familiar to Scheutz, Gravatt, Donkin, Gould, and Farr. Their twentieth-century successors had the benefit of continuity of effort. In part, at least, this gave them a better chance to overcome the problems of the past.

Epilogue

Only one of the men who collaborated in creating and promoting the Scheutz machine lived to see the concept of a printing calculator translated into commercial reality. None participated in the subsequent events that led to the establishment of a worldwide industry. How did they conclude their lives?

Georg Scheutz was 70 years old when he received the gold medal of the Paris Exposition; but he had not come home to retire. In December 1854, Per

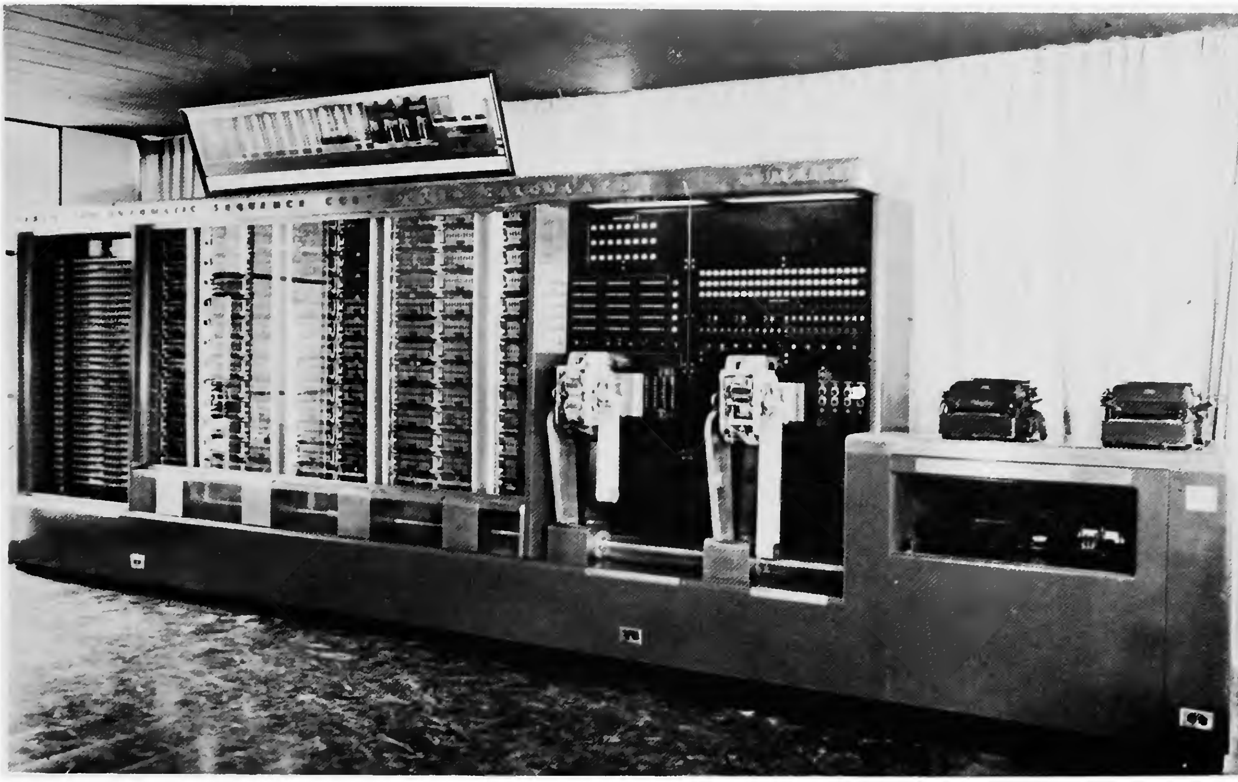


FIGURE 26.—The Aiken-IBM Automatic Sequence Controlled Calculator, Mark I. (SI photo 55754)

Ambjörn Sparre had been awarded the contract to print Sweden's first postage stamps. He supervised this operation for only a short time, asking Georg Scheutz in 1856 to take charge of the postage stamp production. This was to provide Sparre with an opportunity to travel abroad. Sparre's travels became more frequent, however, as his business interests spread, so that for practical purposes Georg Scheutz was in charge of the printing establishment. From then until his retirement in 1870, when he was 84, it was Scheutz who was responsible for the design and production of Sweden's stamp issues. This did not occupy him exclusively, however. He never ceased his writing activities. In 1853, the year that the machine had been completed, his translation of Liebig's *Chemical Correspondence* had appeared. In 1854, he produced a translation of Arago's writings, with an introduction by Alexander von Humboldt. During the next decade Scheutz issued editions and translations of handbooks for distillers, merchants, manufacturers, artisans, and industrialists. At this time, he also authored a rather popular work on natural history, and translations of several novels by M. E. Braddon. In 1864, 55 years after his translation of Zimmermann's work, he produced a translation of the English traveler Thomas Woodbine Hinchliff's account of Brazil. In the last year of his life appeared the last volume of his translation of Wägner's *Rom,* published by L. J. Hierta. It was an appropriate conclusion to a publishing career that had been inspired by tales of Mediterranean lands heard as a boy.

His countrymen had not neglected to honor the energetic old man. In 1860 the Riksdag voted him a lifelong pension of 1200 riksdollar. In December 1872, less than five months before his death, the Swedish Academy of Sciences awarded him the Carl Johan Prize, citing his contributions to literature, in particular his success in "clothing Shakespeare in Swedish dress," as well as his lifelong publishing activities, "not to be negated by his having made a respected name for himself in a field that lies outside the limits of belles-lettres" (Bergstedt, 1878:172–173).

Edvard Scheutz, who had worked closely with Donkin during the construction of the second machine and the search for additional buyers, nevertheless did not pursue the subject after his return to Sweden. Instead, he established himself as a civil engineer. He ran the printing establishment for two years after his father's retirement, until Sparre's government contract expired; but he is best known as inventor of a steam engine that proved useful in steamboat construction. Not having inherited his father's constitution, he died in January 1881, aged 59.

Sparre and Bergström likewise pursued courses that led them away from calculating and printing mechanisms. Sparre, who continued to concern himself with postage stamp production for some years, found an invention dealing with cardboard cartridge production more profitable during the Franco-Prussian War. Having been received into the Legion of Honor, he subsequently lost most of his earnings in trials at which he was accused of being a German spy. Though exonerated, the experience seems to have cast a shadow on his later career. He spent the rest of his life primarily in Italy and France, dying in Paris in 1921 at age 92. Sparre was perhaps the only one of the promoters of the Scheutz machine who knew at the time of his death that printing calculators had become a familiar and accepted product of twentieth-century technology. Bergström saw his works become solidly established in a successful and productive period of industrial expansion. He, too, turned to the manufacture of weapons, after initial successes with gas lighting and conduit fabrication. He continued his leadership in the construction of municipal gas and waterworks and died a few months after Edvard Scheutz, in April 1881, aged 69, respected as one of Stockholm's leading citizens.

Of the English promoters of the Scheutz machine only Charles Babbage continued to devote his attention to the furtherance of mechanical calculation, particularly through his analytical engine. Despite exchanges on the subject with correspondents ranging from Napoleon III to interested inquirers in the United States, little new progress had been made on the machine when Babbage died on 18 October 1871. By that time, the firm of Donkin, under the direction of Bryan Donkin and his brother Thomas, had turned to the manufacture of steam engines after completion of a large contract obtained in 1858 for building a paper mill in St. Petersburg. In addition, the company manufactured valves, exhausts, and other items pertaining to the gas industry. William F. Gravatt, honored by membership in the Swedish Academy of Sciences in 1858, did not live long after his collaboration with the Donkins on the second Scheutz machine. He died in May 1866 of an accidentally administered overdose of morphine.

What, finally, became of the Scheutz calculator at the Dudley Observatory? After Gould had left Albany and gained fame through his work at the Cordoba Observatory in Argentina, where he prepared a large star catalogue of the southern sky, the machine appeared to lie forgotten for a number of years. In his annual report dated 1 February 1864 (Albany, 1871:42) George Washington Hough (1836–1909), who had become director of the observatory in 1862, told of his attempts to revive it:

> The entire absence of plans, explanations, and directions which might have been expected to accompany an instrument of this character, as also the pressure of other duties, had, until quite recently, deterred us from any attempt to investigate the mode of its operation. A few days of leisure during the past winter afforded an opportunity, which was improved, of examining its condition, mastering the details of its mechanism and the relation of its parts, discovering the theory of its action, restoring it to good working condition, and obtaining results to the full measurement of its capacity.
>
> It was found to be in a very disordered condition, and the greater part of the labor expended upon it was required by adjustments and repairs.

Hough (Albany, 1864:42) too, referred to the accidental error noted by Gould and his assistants. He appeared more confident of remedying it than they had been:

> The thorough examination of the source and cause of the difficulty leads us to conclude that by a slight addition to the mechanism, the possibility of accidental error from this source may be reduced to so small a limit as to make the machine perfectly reliable for any computations included within its capacity. The success of our improvements has been satisfactorily demonstrated in the use of temporary mechanism constructed for that purpose. It was found that those wheels which were before frequently liable to error, worked perfectly after the proper mechanism was applied.
>
> We propose to apply motive power to the machine, so that when once set, it shall be a complete automaton, making its computations without the assistance of any person. As soon as one set of constants are exhausted, the machine will stop, and will also be made to give notice of the fact by ringing a bell; upon which, a new set of constants may be introduced, and the computations continued.

Hough reported that he had used the machine for computing approximate planetary ephemerides the following year, and reported new modifications in 1867. After Lewis Boss became director of the Observatory in July 1876, however, he noted in his report that the instruments and building were in need of repair, and included the Scheutz machine in a list of items unused and "out of repair" (Albany, 1878).

Little interest was shown in the machine for several decades, until 1924, when it was offered for sale to Dorr E. Felt, of comptometer fame, who procured it for his calculator collection. This brought it to the attention of several calculating machine aficionados. Felt and J. A. V. Turck, Felt's assistant and chief adviser on historical matters, put it back into operation and demonstrated it to interested visitors. Thus, Carl Beust, head of the patent department of the National Cash Register Company, could report in 1926 that Felt and Turck had demonstrated the machine to him in October of that year and that it was "in rather good condition considering its age" (Washington, 1871–1940).

The machine remained in the Felt collection until 1963. Victor Comptometer Corporation, which had absorbed Felt and Tarrant Company, and the Felt collection, exhibited and demonstrated the calculator in Chicago during the preceding decade. That appears to have been its last public exposure until it was donated to the National Collections in 1963, and placed in the National Museum of History and Technology, Smithsonian Institution, at Washington where it has been on exhibit since 1966 (Figure 27).

FIGURE 27.—The Scheutz calculator (right) and a replica of a portion of the Babbage difference machine (left) in the National Museum of History and Technology, Smithsonian Institution. (SI photo X4723)

As is true with most major events, the history of the Scheutz difference engine. allows for various interpretations and conclusions. Those who uphold the utility of wide learning in times of increasing specialization can point to Georg Scheutz to support their view. Those who support the idea that creativity results from the confluence of previously separate streams of thought can point to Scheutz for confirmation. Those who stress the importance of government support for scientific and technological enterprises can point with pride to the support Scheutz received from the Swedish parliament for "the Swedish Tabulating Machine."

The discussions surrounding the Scheutz calculator illustrate another issue of interest to many: the relationship of a scientist's attitude towards innovation to the nature of his institutional surroundings. Leverrier's position vis-à-vis machine calculation provides a classical example of the essential conservatism of one responsible for a successfully established scientific enterprise—especially an enterprise that must produce periodic results. The Dudley Observatory's Scientific Council, on the other hand, demonstrates the willingness of reputable scientists engaged in forming new institutions to take greater risks, including some not scientifically motivated.

The story of Scheutz's life suggests quite clearly that his calculator came into being not primarily because of the scientific or technological expertise of its chief creator but rather because of the support this man ultimately commanded within his country's political, scientific, and economic power structure. This support was based on respect for his contributions to a broad range of fields. Joined with this was the fortuitous proximity of scientists and engineers, who, for motives of their own, had an interest in seeing the venture succeed. More generally, Georg Scheutz's story forces upon us a recognition of the common conceptual currents and the close intertwining of human activities that shaped the monumental sequence of events making up the intellectual and technological history of the nineteenth-century Western world.

One interest group stands out from these interlocking activities: it consists of men who were concerned with specialized printing and recording processes. The study and advancement of printing and recording techniques—whether applied to the production of banknotes, postage stamps, or mathematical tables—provided the chief bond among Scheutz, Sparre, and Bergström in Sweden, the Donkins and Babbage in England, and Gavit in the United States of America. It relates directly to the significance of the Scheutz difference machine.

In establishing Georg Scheutz's place in the history of computation, we must credit him—and his son—with the first complete construction of a printing calculator. His contribution lies not in the fact that his work resulted in a specialized computing device, the significance and advantage of which were not accepted by the majority of those for whose benefit it was designed. Rather, his contribution lies in having shown the feasibility of constructing *any* kind of calculator that would produce results in a retainable—printed—format.

Appendix I

BRITISH PATENT A.D. 1854, NO. 2216

Provisional Specifications

(filed 17 October 1854)

This Invention relates to the effecting of calculation by mechanical agency, and consists principally in the employment of a set of *calculating wheels,* each of which can be turned backwards or forwards at pleasure independantly [sic] of the others.

Figure 1 [Figure 28] of the annexed Drawings is an end elevation of the apparatus; Figure 2 [Figure 29*a*] is a plan of the same; and Figure 3 [Figure 29*b*], a corresponding side elevation.

The calculating wheels A, A^1, are arranged in rows, in such a manner that all the wheels which, during the movements of the machine, represent terms in a series of the same order are arranged in the same plane.

When the machine is working, all the calculating wheels A which represent *even* differences turn in one direction, and the calculating wheels A^1, which represent odd differences, are stationary, and vice versa. When the calculating wheels which represent *odd* differences are in motion, they turn in an opposite direction to the former, while all the wheels representing even differences are then at rest or station-

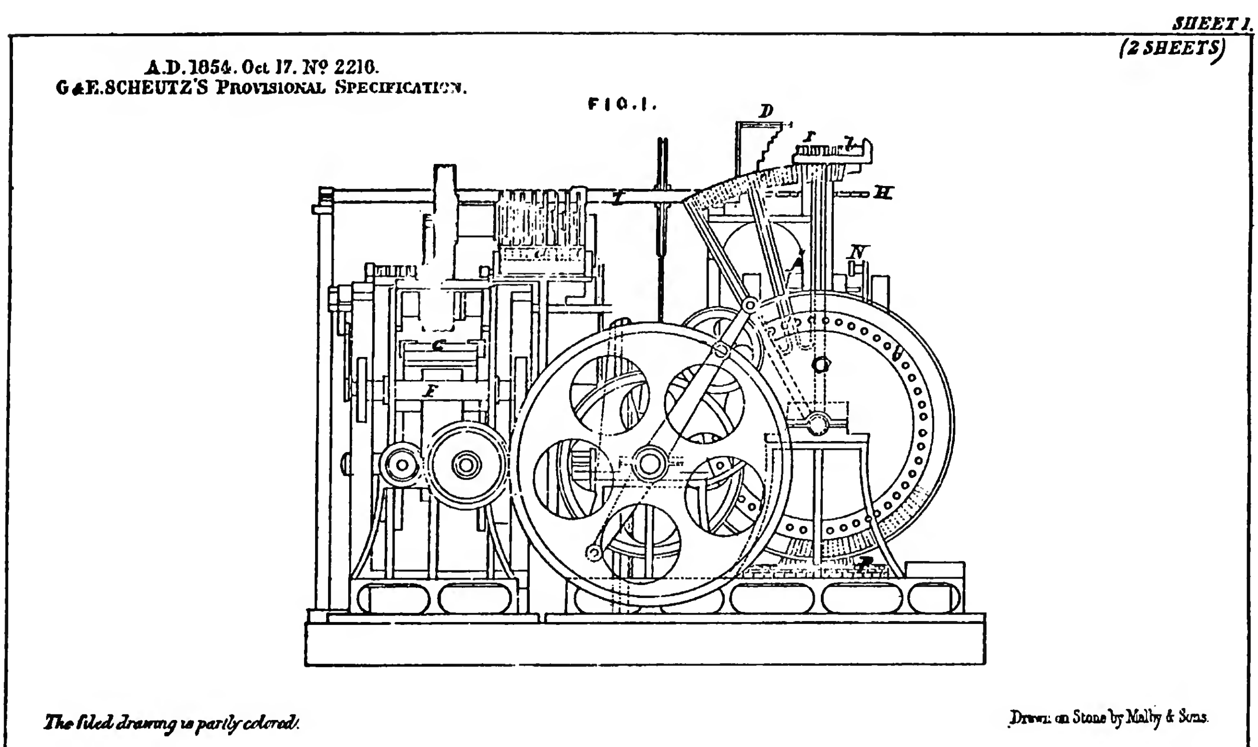


FIGURE 28.—Provisional patent specifications of Scheutz calculator, end elevation.

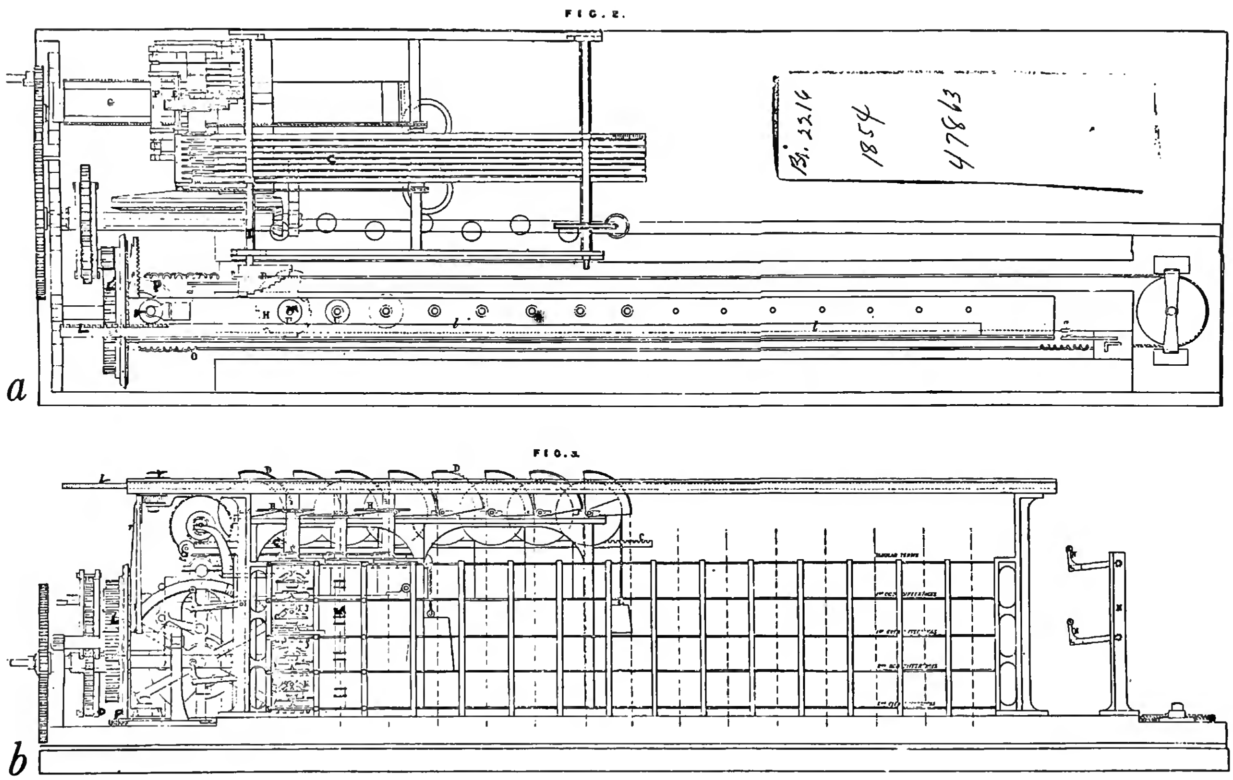


FIGURE 29.—Provisional patent specifications of Scheutz calculator: *a*, top plan; *b*, side elevation.

ary; whilst the calculating Wheels A^{11}, which represent the tabular numbers, or, in other words, which represent the zero differences, are at rest. The figures thereon which express a given tabular term are reproduced by type wheels B, actuated by racks C and toothed cams D. The type wheels are adjusted to print straight by means of a suitable ruler E, working on a fixed centre F. The adjusted type wheels impress the tabular terms in lead, or any other material suitable as a matrix for stereotypes, placed on the table G, which is pushed up to give the impression.

The mechanical means by which the herein-before described motions are performed may be made in various ways, some of which, viz., those for the printing, for thrusting in the rule and for removing the printed lines, contain nothing new or unknown; whereas others are either entirely new, or are new combinations, and of which the following are to be named:—Every one of the calculating wheels representing the tabular numbers which are to be printed is combined with a toothed volute cam or Snail H, on which bears a spiral toothed cam, or the portion of a toothed cylinder D. The second spiral toothed cam or portion of cylinder is fixed on an horizontal axle I, which, by suitable gearings and the rack C, is combined with the type wheel B, and in such a manner transmits the movements of the calculating wheel to the type wheel. Each calculating wheel is provided with as many teeth J as there are figures in the numerical system which the wheel is made to represent; consequently it contains *six* teeth for the figures 0, 1, 2, 3, 4, and 5 in the *sixial* system, ten teeth for the figures 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 in the decimal system, twelve teeth for the figures 0, 1, 2, ... 11 in the duodecimal system, and in the like manner for any other system. Each calculating wheel, excepting the wheels A^{11}, which represent the tabular numbers, is, moreover, provided with a catch K, working on a trap L, which turns together with a vertical axle M, on which it is fixed, and the calculating wheel can thereby set the trap to work. When the trap is working, it catches one of the teeth J of the calculating wheel, which is placed in the next row immediately above, and represents any of the figures corresponding to the same vertical column, as in ordinary numerical expressions, that the wheel expresses, thus setting the trap to work; that is to say, that any wheel that represents units, and can set a trap to work, can also by means of that trap turn another wheel which represents units; that any wheel which represents tens, and can get a trap to work, can also by means of that trap turn another wheel which represents tens; that any wheel which represents hundreds, and can get a trap to work, can also by means of that trap turn another wheel which represents hundreds; that any wheel which represents thousands, and can get a trap to work, can also by means of that trap turn another wheel which represents thousands; and so on, according to the extent of the numbers which the machine is required to calculate. The vertical axles are turned by means of the pinions (u), which are simultaneously acted on by the rack (l), which is put in motion by the pinion (r), which is driven by the toothed segment (r^1), which is moved in alternate directions by means of the mangle wheel (l^1), which is turned by any convenient means. When any of the calculating wheels turns to or beyond the tooth which corresponds to its zero, it works on a lever between that wheel and the next wheel in the same row, in such a manner that the latter wheel may be carried forward a single step, corresponding to a single unit. By these means the figures representing 6, 10, or 12, &c., according to the numerical system in use, may be carried, the number of teeth corresponding always to the number of figures in each calculating wheel. In the operation of carrying, the calculating wheels are brought into action by arms or levers, affixed to each of the two traversing upright arms N, which are driven by a chain O and chain pulley P. In Figures 2 and 3 [Figure 29 *a,b*] the several calculating wheels and mechanism connected therewith is not repeated, in order to avoid complication in the Drawings, ...

Final Specifications

(filed 17 April 1855)

The Invention consists of three distinct but cooperating apparatus, viz:—1. A calculating apparatus. 2. A printing apparatus. 3. A numerator.

1. The Calculating Apparatus.

The principal parts of the calculating apparatus are the calculating wheels D, d. Each calculating wheel is provided with as many teeth J, J, as there are figures in the numerating system which the wheel is made to use in calculating; consequently it contains six teeth for the figures 0, 1, 2, 3, 4, & 5 in the sexial system, ten teeth for the figures 0, 1, 2, 3, 4, 5, 6, 7, 8, & 9 in the decimal system, and would contain twelve teeth for figures representing 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, & 11 in the duodecimal system, if reckoning by means of that system should come in question. The calculating wheels are, moreover, marked with the figures for which they contain teeth.

The calculating wheels have a wide central opening, no axles touching them anywhere. Nevertheless they are centrally moveable, each wheel being inclosed in a ring, or in portions of a ring, or in any other bearings which are concentric to the wheels, and fixed on shelves, which form a part of the frame. In these rings or portions of rings or bearings the calculating wheels are moveable backwards and forwards by the hand, and can be set in every circumferential position, or with any of their figures pointing directly to the front or to the back of the frame.

The calculating wheels are arranged in rows in such a manner that the ends or butts of the teeth of all the wheels which, during the movements of the machine represent terms in a series of the same order, lie in the same horizontal planes, consequently in the same order as the figures, which in writing or print express a number.

When the machine is working, all the calculating wheels which represent *even* differences turn in one direction, and the calculating wheels which represent *odd* differences are stationary, and vice versa. When the calculating wheels which represent odd differences are in motion, they turn in an opposite direction to the former, while all the wheels representing even differences are then at rest or stationary. Thus every other row of wheels is alternately in motion and at rest, and when they are in motion they alternately turn in opposite directions.

Each calculating wheel, excepting the wheels in the uppermost row, which represent the tabular numbers, is provided with a catch K, working on a trap L. All the traps turn simultaneously with a vertical spindle M, revolving within the calculating wheels without touching them, and on which spindles the traps are fixed. A part p of the catch K touches a

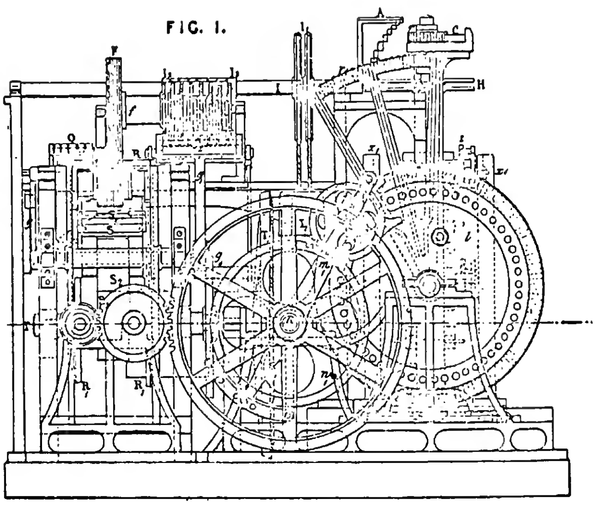


FIGURE 30.—Final patent specifications, end elevation.

descending arm of the trap as the arm passes the catch, and when the movements go in the one direction, the descending arm of the trap depresses the said part *p* of the catch, and passes it without further effect; but when the trap moves in the opposite direction, the catch in touching the arm of the trap causes the trap to rise and rest on a stud L_1. The catch K is free to work or cause the erection of the trap whenever the calculating wheel during the movement of the trap represents a valid figure, or 1, 2, 3, 4, 5, 6, 7, 8, or 9; but when the wheel represents zero, the catch is pressed down by an arm n_2, fixed on the frame, and in that position the catch cannot reach the trap or work upon it.

When a trap is raised, the small pin of it inserts itself in the space above it, existing between two teeth J, J, of the calculating wheel, catches the tooth which

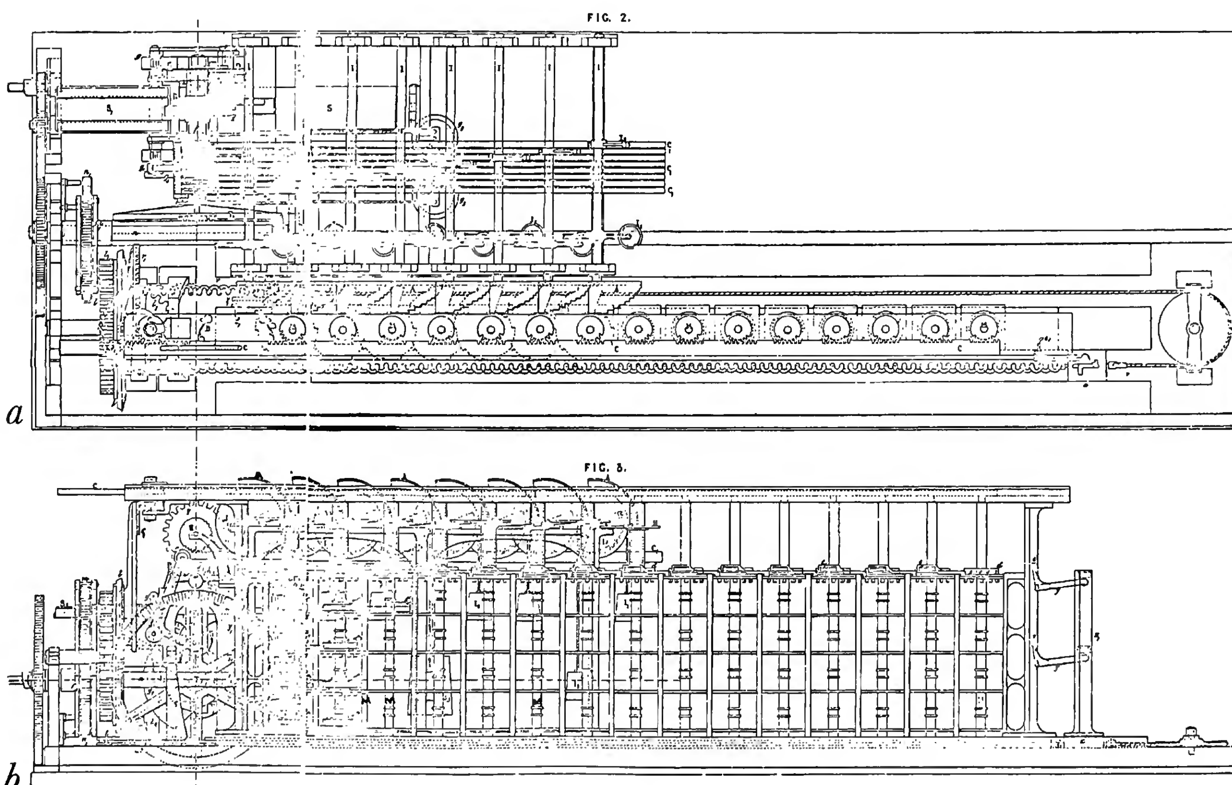


FIGURE 31.—Final patent specifications: *a*, top plan; *b*, side elevation.

it reaches in its revolution, and turns the wheel, but releases it when the revolution ceases, at which moment all raised traps are at once restored to their former inactive position. The simultaneous release of the catched [sic] and turned calculating wheels, as well as the cause thereof, viz., simultaneous restoration of the traps from activity to inactivity, is effected by means of the inclined planes L_2, over which the one arm of the trap studs L_1 passes, and which inclined planes thereby lift the stud arms, and let each trap free to fall down in the angle between the stud and its arm, in which position the traps do not reach any tooth of the calculating wheels above them. To insure the fall of the traps, two springs, B, B, are placed beside the rack C, each of which resists the rack when it completes its motion forwards or backwards, and causes it to move the traps a little backwards, so as to come out of contact with the teeth of the calculating wheels. The rotation of the vertical spindles M, M, together with their traps, is effected by the said rack C. The rack is put in motion by a pinion r, which is driven by a toothed segment r_1, which is pushed in alternate directions by means of a mangle wheel l. The mangle wheel l is driven by a spur pinion l_1, fixed on an axle bearing another spur pinion m, which rotates between two parallel arms m_1, in which arms are holes for the common axle of the pinions l_1 and n [m]. These arms m_1 are moveable around the axle n of a spur wheel n_1 which is in gear with the pinion m, to which it transfers the movement from any moving power.

Each calculating wheel, excepting those in the last column to the left and those in the lowest row, is provided with a single cog or tooth q, besides the teeth for the figures; that cog or tooth q is so placed that it can actuate the one arm s of a horizontal lever s, t, turning on a pin fixed on the shelf beside the wheel, and push it aside whenever a zero is expressed by the wheel. The other arm t of the lever s, t, reaches over part of the shelf to the left on the former shelf, and bears two inclined planes, a vertically inclined plane t^1 [sic] and a horizontally inclined plane u. When the lever arm s is pushed aside by the cog q, the lever arm t brings the vertically inclined plane t_1 nearer to the edge of the shelf, and in that position the horizontally inclined plane u leans out over the said edge.

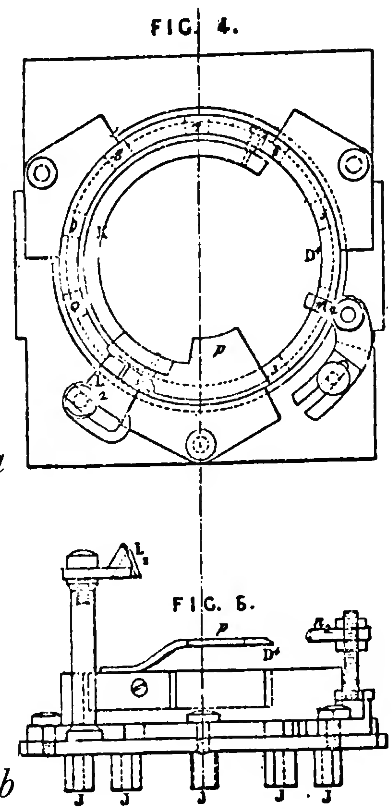
Before and behind the pillars of the frame which bears the calculating wheels are guides or grooves v, parallel to each other and to the rows of calculating wheels; and in these guides or grooves slide glands x, connected with pillars x_1, which move backwards and forwards, one pillar before and one pillar behind the rows of calculating wheels. The backward and forward motion of the pillars is effected by a toothed chain, the ends of which are fixed on the glands. On the same glands, but at their opposite sides, a rope or common chain is fixed, going around a guide pulley, which is fixed on the frame, and holds the toothed chain stretched. The toothed chain gears with a spur pinion l_2, connected with a bevel pinion l_3, which is driven by a bevel wheel connected to, and rotating backwards and forwards with, the mangle wheel l.

For each *odd* row of calculating wheels the one of the pillars x_1 bears a latch y_1 & y_3, and for each *even* row the other of the pillars x_1 bears a latch y & y_2, the lowest wheel row excepted. These latches can be lifted vertically at pleasure, each latch turning on axles or pins, fixed on the pillar, and leaning when at rest on supports, also fixed on the pillar. The free end of each latch bears a friction roller z, so placed that it meets any of the vertically inclined planes t_1 during the passage of the pillar forwards to the left, if any such plane is pushed out nearer to the edge of its shelf. In that case the friction roller z rolls over the plane t_1 thereby lifting the latch from its resting position, but allowing it to resume the resting position when the plane is passed over. Beneath the roller z the latch bears also a tooth z_1, which passes under the teeth of the calculating wheels without touching them when the latch retains its resting position. But the tooth z_1 catches a tooth of the wheel behind the inclined plane t_1, and causes the wheel to advance a single step, corresponding to an unity, whenever the latch is lifted, by its roller passing over the inclined plane. The pillars x_1 bear also horizontally inclined planes u_1, which actuate the horizontally inclined planes u on the levers s, t, and thereby push the arms t inwards on the shelves, thus restoring the horizontal levers s, t, to their former position, in which they are ready for a new similar movement.

When all the figures of a tabular term which are used in calculating it are not to be expressed in print, and when the last figure retained for print is as usual to undergo corrections, the corrections will be performed if the zero cog q of the calculating wheel next to the right of the wheel which expresses the last figures subjected to corrections is removed from its usual circumferential place to another, so chosen that the arms of its lever *s, t,* are not touched by the cog *q* when the wheel bearing the latter exhibits *zero,* but when it exhibits *five.* The removing of the cog is done by hand when the calculating apparatus is set to calculate tabular terms containing such corrections, and afterwards it works continuously for all the terms which require corrections. When no corrections are intended, the cog is left in its usual place.

In order that the latches *y* may also work wheels for the sexial system, such wheels being inserted between decimal wheels (as for reducing sexagesimal quantities), the teeth of the sexial wheels are made longer than the teeth of the decimal wheels, and a prolongation under the tooth z_1 is adapted to reach the teeth of the sexial wheels, and carry them forwards a single step, when the friction roller *z* passes over the inclined plane t_1 before a sexial wheel.

In effecting a faster movement of the machine (in which case the momentum of the calculating wheels should be moderated, as they must not be permitted to exceed their point of release), small clicks *b* with inclined planes falling into the clearence [sic] between two teeth may be applied, and forced into the clearences by springs.



a

b

FIGURE 32.—Final patent specifications, catch mechanism: *a,* top plan; *b,* side elevation.

2. THE PRINTING APPARATUS.

Each calculating wheel representing figures for print is combined with a toothed volute cam or snail H, on which leans a similar snail or portion of a toothed screw thread A. The second snail or portion of toothed screw thread A, fixed on the horizontal axle I. On the axle I is also fixed a pulley I_1, bearing a weight I_2; and on the same axle is moreover fixed a toothed sector I_3, gearing with a rack C_1.

The toothed volute cam or snail H can be considered as a composition of sectors 0, 1, 2, 3, 4, 5, &c., one sector for every figure of the calculating wheel to which the snail belongs; and each sector regularly differing from its neighbour by an equal part of the radius, in such order that the greatest sector 0 corresponds with the zero on the wheel; the next in size 1, with the [numeral] 1 on the wheel; the next in size 2, with the [numeral] 2 on the wheel; and so on to 9, (or to 5, if the wheel is adapted to the sexial system.) The second volute cam or portion of toothed screw thread A is so placed that its teeth or steps concide with the respective sectors of the first volute cam or snail H.

The weights T_2 [$=I_2$] on the pulleys T [$=I_1$], working on the horizontal axles I, tend to lower the steps of the second snails or toothed screw thread A down to the various sectors of the horizontal snails, in such order that if a step o leans on a sector O, and the calculating wheel turns from 0 to 9, (or to 5, if a sexial wheel,) the second snail or toothed screw thread A in question will sink successively, step after step, from 0 to 9 (or to 5).

The toothed sectors T_3 [$=I_3$], which are fixed on the horizontal axles I, and gearing with the racks C_1, propel these racks more or less in their gearing direction, according to the greater or lesser sinking of the toothed screw thread A and of the weights T_2.

The racks C_1 are in gear with spur wheels E, which, together with corresponding spur wheels F, are fixed on opposite ends of tubes *f,* thrusted one over the other, in the same manner as the tubes of

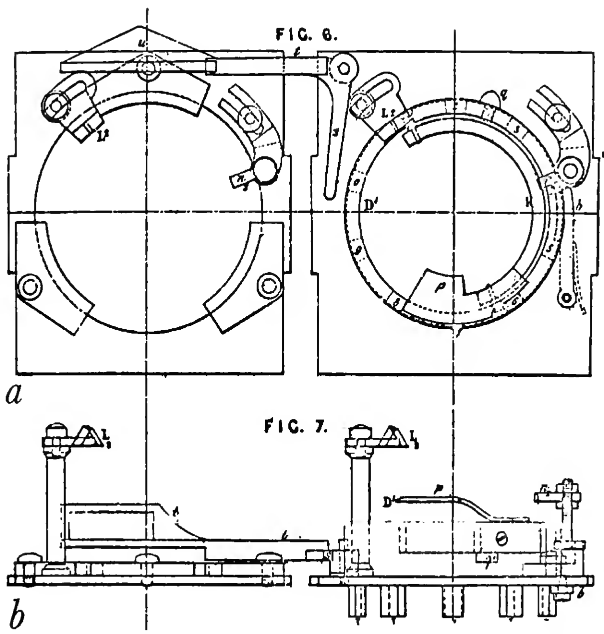


FIGURE 33.—Final patent specifications, carry mechanism: *a*, shelf surrounding number wheel, top plan; *b*, side elevation.

a telescope. Each wheel F gears with a type wheel G, provided with eleven teeth, the ten teeth bearing types for the [numerals] 0, 1, 2, 3, 4, 5, 6, 7, 8, & 9; but the eleventh is used where no impressions but only blanks are to appear in the print, or for interspersing types of signs or lines between the types of figures, in order to be reproduced in print simultaneously with the figures themselves.

Underneath the type wheels is a printing table S, moveable up and down or to and from the type wheels. On the table S glides a slide S_1, on which paper or a plate can be fixed to receive impressions from the types. The table S rests on a frame, provided with a friction roller S_2 and this friction roller rests on an eccentric S_3. When rotating, the eccentric S_3 lifts and lowers alternately the friction roller S_2, the table S, the slide S_1 and the paper or plate, during the lifting movement, pressing the paper or plate against the types.

The toothed sectors T_3, the rack C_1, and the wheels E, F, and G, are geared together in such an order that the figures, which by the calculating apparatus are exhibited for print, are also pointed down by the type wheels directly towards the paper or plate. When a tabular term consists of decimals beginning with one or more zeros, the printing apparatus repeats as usual these zeros on the paper or plate; but when tabular terms, not being decimals, increase successively in a table, the valid figures (as 1, 2, 3, 4, 5, 6, 7, 8, & 9,) ought not to be preceded by any zero. To obviate the appearance of zeros in the latter case, the type wheels are provided with the eleventh tooth, on which no type exists, and which, when pointed down towards the paper or plate, leaves no impression, but a blank. To effect the pointing down of the eleventh tooth in such cases, a bolt o_1, inserted in the zero sector 0 of the snail H is pushed out by hand, and caught by a pin, which descends from the frame above, on which the pin is fixed; and when the zero sector is thus lengthened (or rather provided also with an eleventh tooth, though but provisionally), the lowest edge of the second snail or toothed screw thread A reaches the bolt o_1 and rests on it, preventing thereby the zero step o from sinking down and resting on the zero sector 0, consequently preventing also the zero type of the respective type wheels G from pointing down towards the paper or plate, but presenting in its place the blank tooth; but when the snail moves, its bolt o_1 leaves the pin and is pushed in by a spring. When a tabular term is impressed on the paper or plate, and the printing table S is left free to sink down by the subsequent rotation of the excentric S_3, the sledge S_1 is trust [sic] along the table S by means of a ratchet. By the ratched movement the paper or plate is removed from the place on which it lay when receiving the last line of numbers, and brought to another place, in which it presents a blank ready to receive a new line, and so on, line after line.

3. THE NUMERATOR.

The numerator, the object of which is to count, and to present for printing the indices of other tabular terms, is, properly speaking, no integral part of a calculating machine, the calculating apparatus being itself also capable of counting and presenting for print the indices. The present machine is, however, provided with a numerator Q, by means of which the whole of the calculating apparatus may be reserved exclusively for such tabular terms which increase by more than unities.

The numerator is put in motion by an arm g, fixed on the same axle with another arm g_1, bearing a fork, and in it a friction roller g_2. The friction roller

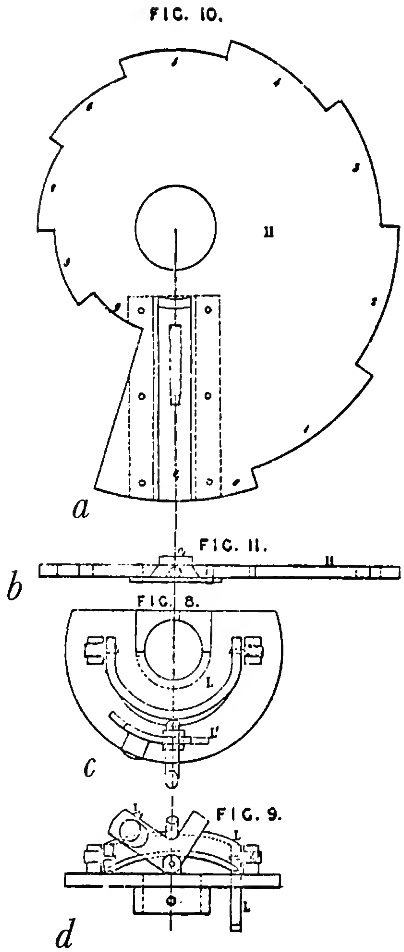


FIGURE 34.—Final patent specifications: *a*, snail, top plan; *b*, snail, side elevation; *c*, trap mechanism, top plan; *d*, trap mechanism, side elevation.

g_2 works on the ends of the racks C_1, and is forced against them by weights g_3, sufficiently heavy to lift, by means of the rack C_1 the toothed screw threads, as well as the weight T_2 and also to turn the wheels E, F, and G. The weights g_3 and T_2 are so arranged that the small weights push these combined parts in the one direction, and the great weights push them in the opposite direction, the alternate movements being determined by an excentric g_4, which works on the arm g_5.

The rule R is, by the working of two uniform excentrics R_1, brought into an alternating movement to and from the type wheels, and to insert itself in the clearing between two rows of teeth of all the type wheels G; it brings thus all the printing types into a straight line, thereby securing the straightness of the printed lines. During the revolution of the two last-named excentrics R_1, the rule R receeds from the type wheels, leaving them free to change their position for a new line. Two springs push the rule from the type wheels, when the position of the excentrics R_1 allows that movement to take place.

The axle T bears all the excentrics fixed on it, and is brought into a permanent revolving motion by a bevel wheel T_1 in gearing with a bevel-pinion T_2, which is fixed on the axle n, this axle bearing also fixed on it the spur wheel n_1, between the two arms m_1. By the respective positions of the excentrics, and by their relative excentricity, as well as by the respective proportions of the wheels relative to their pinions, the machine is brought to effect its various movements at fixed times; no movements presenting any hindrance to other simultaneous movements, nor any parts which can work simultaneously being permitted to rest when other parts of the same category are in motion. Hence these proportions ought to be different for machines of various sizes, that is to say, according to the greater or smaller number of calculating wheels, by means of which they are intended to execute their work. The impressions from the types can be taken on paper, and also on lead, or any other metal or material proper as matrices for stereotypes or electrotypes.

The mechanical means by which the herein-before described motions are performed may be made in various ways, some of which, viz., those for printing, for thrusting the rule, and for removing the printed lines, contain nothing new or unknown; whereas

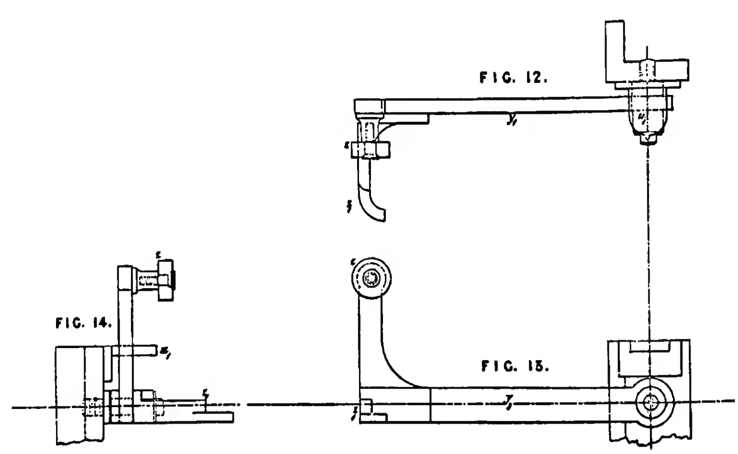


FIGURE 35.—Final patent specifications, latch mechanism.

others are either entirely new, or are new combinations, and of which the following are named as the chief objects of the Patent. What we claim as our Invention is—

1^0, calculating wheels so constructed that no axle touches or bears against them, but rotating in rings or in portions of rings, or between circumferential bearings of any form fixed on the frame, the wheel being centrally open for the free and untouching passage and revolution of the axles for the adding contrivance.

2^0, the arrangement of the calculating wheels in rows, each row in a separate plane, and each plane containing the wheels for figures which belong to terms of the same difference.

3^0, the arrangement of the calculating wheels in columns perpendicular to the same planes, and each column containing the wheels for figures which belong to terms of various differences.

4^0, the use of sexial wheels, as above described, for reducing sexagesimal quantities, as seconds to minutes, and minutes to degrees or hours, and vice versa.

5^0, the adding contrivance, consisting principally of the catches K, the traps L, the studs L_1, the inclined planes L_2, and springs B. B.

6^0, the carrying contrivance, consisting principally of the cogs or teeth q, the levers s, t, the inclined planes t_1, u, and u_1, the friction rollers z and the teeth z_1.

7^0, the term transporting or compositing contrivance, consisting principally of the snails H, the second snails or toothed screw threads A, revolving at right angles to the other snails H, and of the combination between the second snails or toothed screw threads A and the type wheels.

8^0, the mode of effecting corrections of the last figures of tabular terms when required.

9^0, the combination of the whole machine as above specified, and in the annexed Drawings delineated.

In witness whereof, we the said George Scheutz and Edward Scheutz, have hereunto set our hands and seals, this Ninth day of March, One thousand eight hundred and fifty-five.

Appendix II

GRAVATT ON THE OPERATION OF THE CALCULATOR

(Extract from the *Specimen Tables Calculated and Stereomoulded by The Swedish Calculating Machine*)

The following is an abstract kindly furnished by Mr. Gravatt of his own manner of considering and of working this machine.

If u be any function of x, and we set in the machine its initial value u_0 and the finite differences Δ^1u_{-1} Δ^2u_{-1} Δ^3u_{-2} Δ^4u_{-2} in the order shown in the left-hand column below:—

u_0	u_1	u_2	u_3	. . &c.
Δ^1u_{-1}	Δ^1u_0	Δ^1u_1	Δ^1u_2	. &c.
Δ^2u_{-1}	Δ^2u_0	Δ^2u_1	Δ^2u_2	. &c.
Δ^3u_{-2}	Δ^3u_{-1}	Δ^3u_0	Δ^3u_1	. &c.
Δ^4u_{-2}	Δ^4u_{-1}	Δ^4u_0	Δ^4u_1	. &c.

Then in the first half-stroke the machine will simultaneously add the even differences to the odd differences immediately above them, giving the new odd differences Δ^3u_{-1} and Δ^1u_0. At the next half-stroke it will add these new odd differences to the old even differences, thereby forming Δ^2u_0 and u_1 and the machine will appear arranged as shown in the second column. In like manner will be formed the third, fourth, &c., columns, and if $\Delta^4u_{-2}=\Delta^4u_{-1}=\Delta^4u_0=$&c., that is if the fourth difference is constant, the machine will go on calculating the successive values of u as long as we please to turn the handle.

We see, therefore, that this machine is at least capable of tabulating any function of x in which the fourth difference is constant.

As an example, let us take $u_0=1$ $\Delta^1u_{-1}=1$ $\Delta^2u_{-1}=2$ $\Delta^3u_{-2}=0$ $\Delta^4u_{-2}=0$; the machine when set would appear as in the left-hand column below, where the third and fourth differences being zero, are, for the sake of simplicity, omitted.

1	4	9	16	25	36	. . . &c
1	3	5	7	9	11	. . . &c.
2	2	2	2	2	2	. . . &c.

Here at the first half-stroke 2 is added to 1 giving 3, and at the second half-stroke this 3 is added to 1 giving 4. Again, 2 is added to 3 giving 5, and this 5 is added to 4 giving 9, and so on; the machine as thus set producing the squares of the natural numbers for ever.

Again, if we set the machine to the number shown in the left-hand column below,

1	16	81	
1	15	65	175
14	50	110	
12	36	60	84
24	24	24	

24 will be added to 12 and *simultaneously* 14 to 1, giving respectively 36 and 15, and then 36 will be added to 14 and *simultaneously* 15 to 1, giving respectively 50 and 16, and so on; the machine as thus set producing the squares of the squares, or the fourth powers of the natural numbers as long as we please to turn the handle.

In the last example the machine is supposed to be stopped at a half-stroke, with only the *odd differences* 84 and 175 in the fourth column. Now, if we re-set the machine (changing the sign of these odd differences) as shown in the left-hand column below,

81	16	1	
−175	−65	−15	−1
110	50	14	
−84	−60	−36	−12
24	24	24	

we shall have $24 + -84 = -60$, and simultaneously $110 + -175 = -65$ for the first half stroke, and $-60 + 110 = 50$, and simultaneously $-65 + 81 = 16$ for the second half-stroke, and so on. That is, if we in this way change the signs of the odd differences, the machine will, so to speak, go backwards, and that as long as we please to turn the handle.*

A negative number is expressed in the machine by its complement; thus, if to 56789, we wish to add, say minus 67 (that is, in fact, to subtract 67), we set the machine to add 99933 to 56789, thus:—

	56789		56789
less	67	added to	99933
gives	56722	gives	156722

but as in the machine there is purposely no figure-wheel to receive the left-hand 1, it is thrown (so to speak) into the air, and the machine shows and stereomoulds 56722 as it ought to do.

This particular machine is capable of expressing u and its differences as far as the fourth order, to fifteen places of figures; but we may have to deal with differences of more than fifteen places, although we only require four, five, six, seven, or at most eight places of figures, to be printed as the tabular value of u.

Now if the machine be worked, so as to give very many values of u, it is evident that the omission of the 16th, &c., places of figures might begin to tell in the tabulated result.

To avoid this, it is necessary to know how many values of u we may obtain without an error, in the lowest figure of the printed result.

For this purpose, if we, considering what has gone before, imagine the machine set, as shown in the first column below, putting in only one value Δ, and that in the fourth order of differences,

1st	2d	3d	4th	5th	nth Terms
0	0	1Δ	5Δ	15Δ	$\ldots \frac{n-2}{1}\cdot\frac{n-1}{2}\cdot\frac{n}{3}\cdot\frac{n+1}{4}\,\Delta$
0	0	1Δ	4Δ	10Δ	$\ldots \frac{n-2}{1}\cdot\frac{n-1}{2}\cdot\frac{n}{3}\cdot\Delta$
0	1Δ	3Δ	6Δ	10Δ	$\ldots \frac{n-1}{1}\cdot\frac{n}{2}\quad\Delta$
0	1Δ	2Δ	3Δ	4Δ	$\ldots \frac{n-1}{1}\quad\Delta$
Δ	Δ	Δ	Δ	Δ	Δ

we should, in the manner in which the machine combines the differences (that is, always in *simultaneously formed couples*), obtain the 2nd, 3rd, 4th, 5th, and nth columns, the coefficients of Δ being necessarily and obviously *figurate numbers* of the various orders (in this case up to the 5th order) but with the 2nd and 3rd figurate numbers *set forward one term,* and the 4th and 5th figurate numbers *set forward two terms*—the law for any machine taking in any order of differences being evident. We immediately see that if we were to set in such a machine Δ^0 Δ^1 Δ^2 Δ^3 Δ^4, putting P_n for the n^{th} *printed* number we shall get

$$P_n=\Delta^0+\frac{n-1}{1}\Delta^1+\frac{n-1}{1}\,\frac{n}{2}\Delta^2$$

$$+\frac{n-2}{1}\,\frac{n-1}{2}\,\frac{n}{3}\,\Delta^3+\frac{n-2}{1}\,\frac{n-1}{2}\,\frac{n}{3}\,\frac{n+1}{4}\,\Delta^4$$

Whence we see that if the error from leaving out the 16th, &c., figures, be α in the first difference, and β, γ, δ, respectively, in the 2nd, 3rd, and 4th differences (putting e the error in P_n), we should have e always less than

$$n\alpha+\frac{n^2}{2}\beta+\frac{n^3}{6}\gamma+\frac{n^4}{24}\delta.$$

Now as we may always set the machine to $u_0\pm\frac{1}{2}e$ instead of u_0, (thereby halving the effect of any error) we may, even when working with all the four differences, put practically

$$e=\frac{n^4}{48}\delta.*$$

If m be the number of places required in the table, it is usual not to allow a greater error than ±5 in the $m+1^{th}$ place. Now, the *greatest value* δ can have is (less than) 5×10^{-16}, whence we readily see that we may put $n^4=48\times10^{15-m}$. So that if, for instance, we required the machine to print 8 places correctly, we have $n^4=48\times10^7=480\ 000\ 000$ or $n=148$ for the number of values of u that we can print in each direction.

If we wish to print only 7 places correctly, we have $n^4=48\times10^8$ or $n=263$.

If we wish to print only 5 places correctly, we have $n^4=48\times10^{10}$ or $n=832$, so that in this case we may print about 800 terms for each forward and for each backward working of the machine, or together about 1600 terms.

* In this way we can always make the machine itself show us the differences with which it was set.

* Instead of $\frac{n^4}{48}$ we really use $\frac{n^4-2n^3-n^2+2n}{48}$

The following method of finding proper differences with which to set the machine (founded on the 5th lemma of the 3rd book of the Principia) is general, and extremely easy in practice. Let $u_x = u_0 + ax + bx^2 + cx^3 + dx^4$ now putting x successively $= 0 \pm 1$ and ± 2 we get

$$\begin{array}{ll} & \text{1st Differences.} \\ u_{-2} = u_0 - 2a + 4b - 8c + 16d & \\ & a - 3b + 7c - 15d \\ u_{-1} = u_0 - a + b - c + d & \\ & a - b + c - d \\ u_0 = u_0 & \\ & a + b + c + d \\ u_1 = u_0 + a + b + c + d & \\ & a + 3b + 7c + 15d \\ u_2 = u_0 + 2a + 4b + 8c + 16d & \end{array}$$

2nd Differences.	3rd Differences.	4th Difference.
$2b - 6c + 14d$		
	$6c - 12d$	
$2b + 2d$		$24d$
	$6c + 12d$	
$2b + 6c + 14d$		

Whence $d = \frac{1}{24}\Delta^4 u_{-2}$ $\quad c = \frac{1}{6}\Delta^3 u_{-2} + 2d$

$b = \frac{1}{2}\Delta^2 u_{-1} - d$ and $a = \Delta^1 u_{-1} + \frac{1}{2}\Delta^2 u_{-1} - c.$

Now, if N $-$ 1 be the number of terms to be interpolated between u_0 and $u_{\pm 1}$, $u_{\pm 1}$ and $u_{\pm 2}$, &c.;

putting $\frac{1}{\text{N}} = x$ we get immediately

$$\begin{aligned} \Delta^4 u_{-2x} &= 24dx^4 \\ \Delta^3 u_{-2x} &= 6(cx^3 - 2dx^4) \\ \Delta^2 u_{-x} &= 2(bx^2 + dx^4) \\ \Delta^1 u_{-x} &= ax - bx^2 + cx^3 - dx^4 \end{aligned}$$

With which differences we can set the machine and tabulate forwards from u_0 through u_1 to u_2, and by changing the sign of the odd differences in the manner before shown, we can tabulate backwards from u_{-0} through u_{-1} to u_{-2}, and this without knowing even the form of the function we are tabulating, it being sufficient that we have five values taken at equal intervals.*

* The way I use the above formula in practice, is to begin, at the right-hand side of properly ruled paper, with the 4th differences, performing the calculations line by line in the order shown in the example given in page 8. In order to enable us to work always forwards from u_{-1} through u_0 to u_1 (which may sometimes be convenient) I have arranged a formula and given under it an example in page 9 . . .

Now u (the function of x, we may have to consider), may not have the 4th, nor indeed any order of differences constant, and to see the consequences of this let us compare (as in most cases will be amply sufficient) the value of the u_x derived from four orders of differences (which I write ${}^4u_x$) with the value of u_x derived from six orders of differences (which I write ${}^6u_x$).

In the equation $u_x = u_0 + a\,x^1 + b\,x^2 + c\,x^3 + d\,x^4 + e\,x^5 + f\,x^6$, putting x successively $0 + 1$, ± 2, ± 3, in the manner before shown, we get

$$f = \frac{1}{720}\Delta^6 u_{-3}$$

$$e = \frac{1}{120}\Delta^5 u_{-3} + \frac{1}{240}\Delta^6 u_{-3}$$

$$d = \frac{1}{24}\Delta^4 u_{-2} - \frac{1}{144}\Delta^6 u_{-3}$$

$$c = \frac{1}{6}\Delta^3 u_{-2} + \frac{1}{12}\Delta^4 u_{-2} - \frac{1}{24}\Delta^5 u_{-3} - \frac{1}{48}\Delta^6 u_{-3}$$

$$b = \frac{1}{2}\Delta^2 u_{-1} - \frac{1}{24}\Delta^4 u_{-2} + \frac{1}{180}\Delta^6 u_{-3}$$

$$a = \Delta^1 u_{-1} + \frac{1}{2}\Delta^2 u_{-1} - \frac{1}{6}\Delta^3 u_{-2} - \frac{1}{12}\Delta^4 u_{-2} + \frac{1}{30}\Delta^5 u_{-3} + \frac{1}{60}\Delta^6 u_{-3}$$

Now suppose we put $u_0 + ax + bx^2 + cx^3 + dx^4 + ex^5 + fx^6 = u_0 + \alpha x + \beta x^2 + \gamma x^3 + \delta x^4$ rigidly only when $x = 0 \pm 1$ and ± 2, but within a certain degree of approximation only when x has any other values; we get directly

$$\delta = \frac{1}{24}\Delta^4 u_{-2} \qquad \gamma = \frac{1}{6}\Delta^3 u_{-2} + \frac{1}{12}\Delta^4 u_{-2}$$

$$\beta = \frac{1}{2}\Delta^2 u_{-1} - \frac{1}{24}\Delta^4 u_{-2}$$

$$\alpha = \Delta^1 u_{-1} + \frac{1}{2}\Delta^2 u_{-2} - \frac{1}{6}\Delta^3 u_{-2} - \frac{1}{12}\Delta^4 u_{-2}$$

Whence $${}^6u_x - {}^4u_x = \frac{1}{720}\Delta^6 u_{-3}\, x^6 + \left(\frac{1}{120}\Delta^5 u_{-3} + \frac{1}{240}\Delta^6 u_{-3}\right) x^5 - \frac{1}{144}\Delta^6 u_{-3}\, x^4 + \left(\frac{1}{24}\Delta^5 u_{-3} + \frac{1}{48}\Delta^6 u_{-3}\right) x_3$$

$$+\frac{1}{180}\Delta^6 u_{-3}\, x^2$$
$$+\left(\frac{1}{30}\Delta^5 u_{-3} + \frac{1}{60}\Delta^6 u_{-3}\right) x$$
$$= \frac{1}{720}\Delta^6 u_{-3}\{x^6 + 3x^5 - 5x^4$$
$$- 15x^3 + 4x^2 + 12x\}$$
$$+\frac{1}{120}\Delta^5 u_{-3}\{x^5 - 5x^3 + 4x\}$$

Now if we attend to the spirit of Newton's lemma, we see that the errors arising from the use of four differences, when we ought to use six differences, must be nearly maximums when $x = \pm\frac{1}{2} \pm \frac{3}{2}$, and putting in our equation these values of x, we have rigidly

$${}^6u_{1/2} - {}^4u_{1/2} = \Delta^5 u_{-3} + \frac{3}{256} - \frac{7}{1024}\Delta^6 u_{-3}$$
$${}^6u_{-1/2} - {}^4u_{-1/2} = \frac{3}{256}\Delta^5 u_{-3} - \frac{5}{1024}\Delta^6 u_{-3}$$
$${}^6u_{3/2} - {}^4u_{3/2} = -\frac{7}{256}\Delta^5 u_{-3} - \frac{21}{1024}\Delta^6 u_{-3}$$
$${}^6u_{-3/2} - {}^4u_{-3/2} = \frac{7}{256}\Delta^5 u_{-3} + \frac{7}{1024}\Delta^6 u_{-3}$$

Or, in practice, the maximum *half error* may be taken as

.001 ($6\,\Delta^5 u_{-3} + 3\tfrac{1}{2}.\ \Delta^6 u_{-3}$) between u_0 and u_{-1}
.001 ($-6\,\Delta^5 u_{-3} - 2\tfrac{1}{2}.\ \Delta^6 u_{-3}$) between u_0 and u_1
.001 ($-14\,\Delta^5 u_{-3} - 10\tfrac{1}{2}.\ \Delta^6 u_{-3}$) between u and u_2
.001 ($14\,\Delta^5 u_{-3} + 3\tfrac{1}{2}.\ \Delta^6 u_{-3}$) between u_{-1} and u_{-2}

and these errors will of course be kept out of our tables; that is, we shall use one place of figures less than that which would be affected.

As an easy (and certainly a very favourable) example of the power of the machine, let us with it calculate a table of the Logarithms of the natural numbers up to 10,000, to five places of decimals. We must first actually calculate by any of the known methods the logarithms of 2, 3, 7, 11, 17, and 19, to seven places of decimals, from which we shall immediately obtain the logarithms of

10	20	40	80
11	22	44	84
12	24	48	88
13	26	52	92
14	28	56	96
15	30	60	100
16	32	64	
17	34	68	
18	36	72	
19	38	76	

To which, applying the formulae just given, we, by ten easy calculations, and by ten forward and ten backward settings of the machine, shall obtain a stereomoulded table up to 10,000.

The time occupied by the machine at its ordinary rate of working (namely, 120 numbers per hour), would be seventy-five hours; the ten plus and minus (say twenty) settings would not take up quite two hours; the calculations by the fomulae given of the proper differences to be set in the machine, could not cause a delay of two hours, the time taken (exclusive of the preliminary calculation of the logarithms of 2, 3, 7, 11, 17, and 19) being altogether about seventy-nine, or say eighty hours.

Appendix III

DISCUSSION AT THE ACADEMY OF SCIENCES, PARIS

(reported in *Cosmos* 13, 1858; translated by the author)

Mr. Babinet, in the name of the Messrs. Scheutz, father and son, made a gift of a small volume of immense compass, which has for its title: Specimens of various Tables, calculated, stereotyped and printed by means of the celebrated machine for calculating differences. These specimens of tables, 15 in number, give the logarithms of numbers from 1 to 10,000, with five decimals; the successive values which two fourth order polynomials in x take when by and by one sets x equal to 1, 2, 30, 50, etc.; the logarithms of two series of numbers and of trigonometric lines to seven decimals; the arcs in degrees, minutes, seconds and tens of seconds which correspond to given natural sines; the ranges of shot for various powder charges; the logarithms of male life in London; the heliocentric coordinates of Venus, the Earth, Mars, and the logarithms of radius vectors of these stars at noon, for the months of January, February, March, and April 1858. These are only very feeble samples of all that one can ask of this admirable instrument, the appearance of which on our European continents *Cosmos* was the first to signalize.

[Babinet next gave a brief description of the history and status of the machine, based on the introduction in the *Specimens,* 1857.]

After the presentation of Mr. Babinet, Mr. Leverrier asked for the floor, believing he must make some critical observations. He saw, studied and discussed the machine in 1855; it had been deposited at the Imperial Observatory, and the learned director had been asked whether it presented enough interest and utility that the French government should acquire it. Mr. Leverrier reserved for himself the judgment of the calculating mechanism, and asked Mr. Bailleul to judge the printing mechanism; both recognized that the invention was extremely ingenious, that it functioned regularly, but that, in practice, it presented no advantage that would compensate for the considerable expense of its purchase. One asked 50 000 francs at that time, today the machine would cost at the most 25 000 francs. Accordingly, Mr. Leverrier certified to the government that there was no need to accept the proposal of the inventors, to which, fortunately, Mr. Gould has extended a friendly and helping hand. Mr. Leverrier has not changed his mind: he still finds the machine very ingenious, but he does not perceive any practical utility in it; according to him, it does only a fifth of the work necessary for the definitive calculation of tables, and it does this fifth less quickly than an ordinary calculator. Mr. Leverrier despite the opinion solemnly formulated by the Davys, the Brandes, the Brunels, the Baylies, the Herschels, the Katers, the Pounds, the Wollastons, the Sabines, the Donkins, the Rennies, etc., etc., expects nothing of calculating machines.

When we see opposed to a magnificent invention an inopportune motion to have its merits denied, we too much mistrust ourselves and the sentiments of sadness, we should almost say of humor, which agitate us to try to refute directly the assertions and objections of Mr. Leverrier. To his personal judgment we would oppose that of a greatly esteemed English mathematician, member of the council of the Royal Astronomical Society of London, professor De Morgan; we would combat the testimony of Mr. Bailleul, concerning the printing mechanism of the calculating machine, with the appreciation issuing from one of the masters of English typography; finally, enough will soon be given, when the American astronomical savant, Mr. Gould, will have published his first astronomical tables, calculated and stereotyped by the Scheutz apparatus, to proclaim that the hour of repentance and reparation has sounded. First let us listen to Mr. De Morgan: "A large part of the scientific world looks very coldly on this invention. They say it is of *no use;* that tables could be constructed for a small part of the money, as many and as good as with the machine.

Dr. Young thought, we believe, that the sums expended for the construction of Mr. Babbage's machine, invested in State funds, would keep computers enough at work to supply the place of the machine. This argument is not absolutely false. Mr. Weller, senior, made use of it so ably that he might have stopped the great invention of railroads, if it had been duly weighed at the time when Stephenson passed for a fool for talking of 15 kilometers an hour, and was obliged to keep the possibility of 90 kilometers to himself. What rate could I keep a coach at, said the veteran whip, if one gave me a million per kilometer payed in advance? The event has shown that the argument was wrong: the railroad is what it is, and there is much reason to think that the electric telegraph would never have been thought of in our day if the railroad had not existed. On with the work then! let every development of a new scientific idea and every new application of the idea, be encouraged and welcomed, even though its ultimate uses, we mean those uses which the man of the day can *see,* were as distant as universal gravitation and the lunar orbit from the old conic sections of the Platonic school of geometers, curves which one was happy to find had been studied when they appeared in the sky. Those who decry the highest stone because it supports nothing are fortunate in one point that no one will envy them, that they will always have something to decry. Those who are busy in raising the next stone do not bother them, because they know that a new job awaits them at the instant the old one is finished. Machines will one day do all that which symbolic calculation will do, whether simply numerical or algebraical. And the recent developments of algebra seem to point to a time when the details of the operations will be the work of mechanical machines, when ever one wishes to exhibit definitive results."

This is what the learned author of the Lectures on the Differential and Integral Calculus wrote nearly a year ago, on introducing to the scientific world these same *Specimens* of diverse Tables calculated, stereotyped and printed by the Scheutz machine, specimens the sight of which alone confounds us, it is so astonishing a triumph of mankind which gave birth to them. Mr. De Morgan added:

"Our readers understand without difficulty that the machine is not fully automatic. It does not give logarithms, for example, merely for saying, Good machine, we want logarithms. It must be fed both with mechanical force and with calculations. The seed which one plants must be according to the harvest wanted: who could claim to grow figs of thistles without laborious culture? Similarly, the machine must be cultivated, but the return that it gives surpasses nearly all known harvests. A VERY LITTLE CALCULATION DEPOSITED IN ITS WOMB makes it produce an enormous quantity of results without any effort other than that needed to make a barrel-organ sing. It may fail sometimes because it has been fed badly, but the error will always be discovered; labor and lead may have been spent in vain, but bad merchandise will never issue from good."

It is the turn of Mr. Alfred Deacon, director of the great printing establishment of Beaufort-House, on the Strand, to combat by figures the opinion of Mr. Bailleul. The characters can be as beautiful as one wishes them to be; the justification is perfect, the impression very neat; hence there can be a question only about the net cost, of the expense of the work, and of the time; now listen to the English printer: "As an example let us take the logarithm tables of the Specimen: each folio has sixteen pages, each page six double columns, each column has fifty lines; it is no exaggeration to evaluate the work of the calculator at 20 pounds. Now it is necessary to send the sixteen pages to the press and to set them in movable type; the price of composition, including reading of several proofs and corrections, will be at least 5 pounds; hence the total is 25 pounds. Let us compare this expense with that of the tables calculated with the aid of the machine. This time one does not need an experienced calculator, for the principal operation is reduced to writing differences on the cylinders; then the only questions is that of turning a crank until the table is terminated, as does the barrel-organ grinder as long as his air lasts. This work will certainly cost no more than 2 pounds; and there will be no errors to remark, no proofs to read, no corrections. Instead of having to reproduce the page of calculations in movable type, it will suffice to take its imprint or stereotype plate in metal, gutta-percha or any other material, by known procedures; stereotype and electrotype will produce them in relief, so it remains only to affix the pages on wooden forms so that they are ready to be printed. The expense of this sequence of operations for a folio of sixteen pages is 4 pounds, 16 shillings, no more no less; the next cost of each folio is therefore 6 pounds 16 shillings instead of

25 pounds. Hence, a difference in favor of the machine of 18 pounds 4 shillings or 445 franc per folio! And the logarithm tables of the machine will be safe from the errors of the tables calculated and composed by hand! There is the expenditure in money. Now let us arrive at the expenditure in time. The composition of each folio will demand 96 hours, and perhaps more; while the machine will calculate and print this same folio in 32 hours, more or less, that is in a time three times smaller." Here is the truth: a monetary saving of three-fourths, a time saving of more than one-third. One can sell it cheaply at its birth, but it will triumph sooner or later.

Bibliography

Introduction

The following bibliography serves a twofold purpose. First, it is intended to document the present work and to note the chief sources of information and citations. Secondly, it is meant to serve as an introductory aid to the scholar who wishes to pursue further some aspect of our topic.

The "Location of Sources," while expressing my indebtedness to certain institutions, indicates some of the major depositories of Scheutz-related materials outside of Sweden. The "Bibliographic Guide," arranged to follow the sequence of the text, also comments on the literature in the "References." The latter, arranged by author, contains titles of general works pertinent to this study and to works published prior to 1947 that refer to Scheutz or the Scheutz calculator. Not included are numerous articles from encyclopedias derived from the representative selection listed under "Calculating Machine." Entries that do not explicitly mention Scheutz or one of the two Scheutz calculators are preceded by an asterisk (*). Entries that are cited elsewhere as being relevant to Georg Scheutz or his calculator but that I have not seen are preceded by a dagger (†). The final section of this bibliography is intended as a preliminary checklist of Scheutz's publications. It is arranged by author; journals edited by Georg Scheutz are listed under the title of the journal. All the items included were written, translated, or published by Georg Scheutz; newspaper or journal articles were not included. Only a few of the works in this section have been inspected; the list has been compiled with the aid of some of Scheutz's own publications, of which the following are in the "References": Almquist 1904, Bygden 1898–1915, Klemming 1879, Linnström 1961, and *Svensk bokkatalog för 1866-1875.* Bergstedt 1878, which was used for the list in Archibald 1947, served as the starting point for the present checklist. Particular effort was made to identify anonymous authors and translators; the results are given in brackets.

It is hoped that this first comprehensive bibliographic checklist of Scheutz's work, will encourage further study of his publications. It may be fruitful to examine more closely his political and technological writings, as well as his other journalistic contributions, especially those to *Aftonbladet.* Additional topics that should be treated include an analysis of works that he translated or whose translations he published. His editions of James Fenimore Cooper and Sir Walter Scott have been almost entirely ignored in bibliographies of these authors. His interest in North American life and literature, evidenced by Birckbeck 1818, Cooper 1825–1826, 1826, 1827, 1828, and Wright 1826, may be worth considering at least in the context of his penchant for tales of travel and adventure, if not as part of a study dealing with nineteenth-century Swedish accounts of life in the New World. Any student of Scheutz's publications should examine more closely the validity of the claim that he rewrote much of that which he translated or published. If he did so, an in-depth analysis of his overall role in the history of Swedish letters becomes even more rewarding.

Location of Sources

Most of the material for this study can be found at the Library of Congress, where the major part of my research was performed. In addition, the United States Naval Observatory Library and the library of the Dudley Observatory were consulted for materials pertaining to the history of the machine at Albany; the Folger Shakespeare Library for materials pertaining to Shakespeare in Sweden and to Scheutz's work on Shakespeare; the library of the University of Texas, especially items from the Svante Palm Bequest, for general and biographical Swedish references and for a copy of Scheutz's *Journal för manufakturer och hushållning;* the Boston Public Library for a copy of Wiberg's logarithm tables; the Bibliothèque Nationale for French newspapers and periodical references to the calculator in the 1850s; and the New York Public Library for various references not located elsewhere. The holdings of the Science Museum in London, the Tekniska Museet in Stockholm and the National Museum of History and Technology in Washington, D.C., provided important related documentation. As shown in the bibliography, the United States National Archives, the British Museum, and the Franklin Institute contain manuscript material most valuable to this study and not previously noted.

Bibliographic Guide

Georg Scheutz

Among numerous English-language histories of Sweden, Oakley 1966 provides an especially useful introduction to the political movements that affected Georg Scheutz's career most closely. A splendidly illustrated general history which emphasizes cultural aspects is *Den svenska historien* 1968; volumes 7 and 8 cover the period 1772—1865. Aside from the brief but revealing account in Thomson 1813, good descriptions of Jönköping at the time of Georg Scheutz's childhood and youth are found in Jönköping 1921 and Sallnäs 1965. Jönköping 1921 includes plans and references to the Scheutz inn. Sweden, Statistiska centralbyran 1969 presents enlightening statistical figures.

Gustafson 1961 gives a valuable English-language introduction to the history of Swedish literature. For detailed study of literary activities involving Scheutz, Schück and Warburg 1929 appears indispensable. A wealth of facts concerning Scheutz's various journals and other periodicals can be found in Lundstedt 1969, which is a reprint of a work that appeared at the turn of the century (1895–1902); information concerning the publications includes names of chief participants, dates and frequency of publication, price, type style, size, and the like. Bernström 1958 remarks on Scheutz's publishing of Crusenstolpe and has useful related material. Göransson 1937 points to the relationship between Scheutz's *Argus* and Hierta's *Aftonbladet*.

The most extensive available biographical sketch of Georg Scheutz has been Bergstedt 1878, which includes details concerning his life prior to 1832. It is supplemented by some anecdotes in Johnson 1932 and personal recollections in Borgström 1836. Almqvist 1909 was checked in connection with the question of Scheutz's having taken the *Bergexamen*. Kihlberg 1968, a fine biography of Lars Hierta, leads to many interesting details about the long collaboration between Scheutz and Hierta. Gottlieb 1956 also refers to Scheutz and *Aftonbladet*. Scheutz's other publishing activities are documented in Almqvist 1904 and Linnström 1961.

The technological growth in Sweden between the 1820s and the 1860s is discussed in the general histories above, and reflected in Scheutz's *Journal för manufakturer* as well as his other publications. Sidenbladh 1873 and 1876 furnish useful statistics concerning developments in printing and publishing. Bjoerkbom 1948 gives a history of Swedish printing from its inception to the 1930s. The masterful history of Swedish book printing, Klemming and Nordin 1883, provides information about a multitude of significant events related to Scheutz and his contemporaries. Henriques 1917 and 1927 publications present not only a history of the Stockholm Technological Institute but a wealth of related facts. By providing a list of library holdings, Stockholm, Tekniska Högskola 1849 sheds light on the diffusion of technical and scientific information at the time.

The literature on Babbage is growing. Most biographical accounts are based on C. Babbage 1864. They either parrot his biases or overreact against them. Therefore, it is just as well to return to the primary source, which includes a host of facts as well as anecdotes. The papers included in H. P. Babbage 1889, along with the correspondence in the British Museum (London, British 1854–1858) and the holdings of the Science Museum in London 1926, provide a wealth of material for the student of Babbage's machines. Lardner 1834 is as readable today as it was in Scheutz's time. Copley 1923 and Thompson 1914 deal with Babbage in the context of scientific management, which interested Scheutz.

Creation of the Calculator

Information about Edvard Scheutz is based on standard Swedish biographical sources, *Specimens* 1857, Bergstedt 1878, and Klemming and Nordin 1883. Edvard's play is referenced in "Titles Published by Georg Scheutz" (Scheutz 1836).

The names of the machine's underwriters are given in *Specimens* 1857. A number could be identified easily through their association with Scheutz and through standard biographical sources. The identity of others remains uncertain because of the lack of given names and because of possible misspellings.

Dahlgren 1915 is a useful guide to members of the Swedish Academy of Sciences. It should be supplemented with standard biographical references such as Hofberg 1876 and 1906, *Svensk uppslagbok* 1937, *Svenskt biografiskt lexicon* 1857–1907, *Svenskt porträttgalleri* 1903 and *Svenska män och kvinnor* 1942–1955. Söderbaum 1929 contains relevant observations concerning Berzelius' political orientation.

Sweden, Riksdagen 1851 and the associated protocols of the four chambers for the years 1851 and 1853/54 document the Swedish parliament's discussion of the Scheutz calculator and reflect the position of the leading members; this fascinating primary source has been totally ignored in previous discussions and bibliographies of the calculator. Biographical background concerning most of the participants in the discussion can be obtained from *Svenskt biografiskt lexicon* 1857–1907 and the earlier *Biografiskt lexicon* 1835–1857. Kjellander 1953 gives an informative biographical account of J. W. Bergström.

Structure and Operation of the Scheutz Calculator

The description of the machine is based on a comparison of the patent description, reprinted as Appendix I, and the actual present-day (1972) appearance of the machine.

Promotion of the Calculator

Per Ambjörn Sparre's career is described in Akerstedt 1964. Lindgren 1968 and Platbarzdis 1963 have references to Sparre in relation to the production of bank note paper and the history of the Riksbank. Of particular interest, recalling the association with Donkin, are references to the printing of serial numbers. The activities of the Tumba paper mill are elucidated in Castegren 1955. Stockholm, Postmuseum 1930 preceded Åkerstedt 1964 in describing Sparre's and Scheutz's contributions to Swedish philately.

Aside from standard biographies and obituaries such as the *Dictionary of National Biography* or Royal Society of London 1854, Donkin 1925 is the best guide to the history of the Donkin firm. Oldham 1842 and Mackenzie 1953, which describe some of the activities that brought Babbage and Donkin together, help nicely to bring out the parallelism between these endeavors and those involving Sparre in Sweden. Biographical information about Gravatt is based on obituaries in Royal Society of London 1867 and Institution of Civil Engineers 1867.

The report of the committee of the Royal Society appointed to study the calculator appeared in two widely read publications: Royal Society *Proceedings* and *Philosophical Magazine* (1856a). Related material, such as Babbage's correspondence with Stokes about the report, can be found in London, British Museum 1854–1858 (Add. Mss. 37196). This also contains considerable information about the machine and its journey to and stay at the Paris Exposition. Published accounts of the machine and its surroundings at the exposition can be found in the leading Parisian newspapers for 1855, as well as the *London Daily News* for 1855, Brisse 1857, Paris, Exposition 1855, and Pascal 1855. The documentation of Babbage's efforts on behalf of the machine found in London, British Museum 1854–1858 (Add. Mss. 37196 and 37197) is supplemented in Academie des Sciences 1855, C. Babbage 1855a, 1855b, 1856, and H. P. Babbage 1855. *Cosmos* 1856a and 1856b should be consulted in this connection, along with Chasles 1856 and Dupin 1856, which, together with Academie des Sciences 1858, reflect the divergence of views among French scientists.

Sentiments in the American scientific community towards Babbage are documented in American Association 1856 and in London, British Museum 1854–1858 (Add Mss. 37196). The latter also contains many details concerning the negotiations for purchase of the machine. Of the numerous pamphlets and broadsides relating to the early history and controversy at the Dudley Observatory, only the major ones are listed below. Albany, Dudley 1864, 1866, 1871, 1878 and Albany . . . Scientific Council 1858 as well as Albany . . . Trustees 1858 all mention the Scheutz tabulating machine, as does Gould 1859, Thacher 1858 and Albany, Committee 1858. Boss 1968 contains a helpful summary of the complex sequence of events. Bailey 1931 gives information about Searle, who ran the machine in Albany.

One of the interesting, forgotten aspects of the machine's history is the interest and financial commitment on the part of the United States Department of Navy—or, at least, the Office of the Nautical Almanac. This is documented in U. S. Navy Department 1857 and 1858, and Washington, U.S. National

Archives 1856–1858 (Record Group 78). The manuscript material at the National Archives contains not only copies of the letters published in the official Annual Reports of the Navy, but also of those sent to Albany dealing with the progress of computations, requests for vouchers, and the like. A copy of Davis' initial inquiry about the machine, which first came to my attention in London, British Museum 1854–1858 (Add. Mss. 37196), can also be found in Record Group 78 in The National Archives, Washington. Weber 1926 provides a chronology pertinent to the history of the Naval Observatory and the Nautical Almanac office.

Propagation of Recording Calculators

Great Britain, General Register Office 1864 has an extensive account of the Scheutz-Donkin machine (Scheutz No. 2), with special reference to Farr's work on it; it includes the classic results of this work. Gravatt 1859 and 1862 contain certain examples of work done on the Scheutz-Donkin calculator. London, Science Museum 1926 contains pertinent information concerning the machine and associated items transferred to the museum.

Numerous references given below under "Calculating Machine" furnish a sampling of the appearance of the Scheutz calculator in standard encyclopedia articles. Of these, those devoting major space to the Babbage machines are derived from an article in *Chambers' Encyclopedia* by Major-General Babbage (1861). Others tend to perpetrate and perpetuate a variety of erroneous statements, including one that makes brothers of Georg and Edvard Scheutz. It is significant, however, that prominent mention of the machine is so frequent in these works in the latter part of the nineteenth century; still undetermined is the impact of such information on budding inventors for some of whom home encyclopedias constituted a chief source of reading material.

Information about Martin Wiberg is given in *Svenska män och kvinnor.* It should be supplemented by H. Wiberg 1955. Anderson 1933 discusses his calculator in more detail. M. Wiberg 1860 is a version of the early interest tables, M. Wiberg 1876 of the more widely distributed logarithm tables computed on his difference machine. Academie des Sciences 1863 gives the rather detailed account of the study Mathieu, Chasles, and Delaunay made of Wiberg's machine. My description of his machine is based on this study.

Pertinent information about Grant and his machine is found in standard American biographical encyclopedias and in Grant 1871. The Locke papers in Washington . . . National Museum of History and Technology 1871–1940 supplement this with copies of his patents, selected correspondence, Centennial-related description of the difference machine and the like; this collection also documents, in part, L. Leland Locke's efforts in the twentieth century to locate Grant's difference machine. Grant's supporters, mentioned in Grant 1871, are readily identifiable and linked to the Scheutz machine's history in America. The least known of these, John M. Batchelder, repeatedly appears in the 1858 letters in the Washington, D.C., National Archives 1856–1858 as the operator submitting vouchers for work done on the Scheutz machine at Albany. The 1874 letter from Fairman Rogers to Wolcott Gibbs was found in the Gibbs correspondence in Philadelphia, Franklin Institute 1874.

The discussion of trends in the development of calculators is based largely on study of the holdings in the National Museum of History and Technology, Smithsonian Institution, and the pertinent patent literature. It is supported by the sparse general literature on the subject. Among general works, Ocagne 1928 and Martin 1925 are especially informative on the development of desk calculators. Comrie 1928, 1932a, 1932b, 1933, and 1946 give excellent accounts, based on first-hand knowledge, of twentieth-century adaptations of mechanical calculating aids to difference techniques. Harvard University 1946 provides the best account of the ASCC, the Mark I relay computer.

Epilogue

References to the chief human participants were given above ("Promotion"). Literature on the Scheutz calculator appeared in spurts. The idea of the machine is alluded to in Academie des Sciences 1838. The earliest and best technical description is the British patent of 1854 (Appendix I). This prompted a variety of notices in technological journals, exemplified by *The Practical Mechanic's Journal* 1855, and Scheutz's Calculating Machine 1855, and in newspapers, for example, New Calculating Machine 1855a.

As noted above, the display in London and the exhibition in Paris in 1855 gave rise to a wealth of popular notices concerning the machine, and the subsequent presentations for the Academy at Paris and the Royal Society of London led to several notes and articles, as well as reports in their respective publications. Next, the machine was described in numerous publications from Albany and Boston, also noted under "Promotion."

Thanks to its wide and carefully planned distribution, *Specimens* 1857 was the most influential account of the machine, on which nearly all subsequent treatments have been based. Unfortunately, the not altogether accurate historical introduction has been used far more than Gravatt's concise discussion of the operation of the machine. Except for an example, this discussion has been reproduced here as Appendix II. Initially, the distribution of *Specimens* focused attention on the machine in two ways: through discussion prompted by receipt of the autographed copies, of which Academie des Sciences 1858 is an example; and through reviews of the publication, examples of which are *Athenaeum* 1857a, Institution of Civil Engineers 1857b, or *Practical Mechanic's* 1857b. Publication of the French version (*Specimens* 1858) had a similar effect. It prompted discussions, such as exemplified in Academie des Sciences 1858, reviews such as in *Siècle* 1858 and analyses, as illustrated in the lengthy *Cosmos* 1858.

Aside from a few sporadic accounts referenced in the text that refer to the presence and use of the machine in Albany after Gould's departure, the machine was discussed less and less as time passed. Calculating by Machinery 1870 is an interesting American article on the machine, appearing at a time when its future at the Dudley seemed bleak. Significantly, it is referenced in Grant 1871. Encyclopedia references have been noted above. In the twentieth century, references to the calculator were usually made in the context of discussions that treated the computation of differences by desk calculators, punch cards or computers (see "Propagation"). The Felt (1920) and Turck (1916-1931) files in Washington, National Museum of History and Technology, contain a few items that pertain to Felt's interest and acquisition of the machine. The last substantive English-language account of the Scheutzes and their calculator was Archibald 1947; it owed much to Bergstedt 1878 for biographical facts concerning Georg Scheutz, and to the *Specimens* 1857 for its account of the machine's creation. I have not listed numerous references to the machine that have appeared since 1947, usually in introductions to textbooks on computing. These are mostly based on an uncritical adoption of statements from previous publications.

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1833. Handbok för bryggning och maltberedning. Translation with additions and revisions [by G. Scheutz]. *Bibliotek för konst slöjd ach tillämpad vetenskap.* Stockholm: G. Scheutz.
[Richert, Joh. Gabr.]
1822. *Ett och annat om korporationer.* Stockholm: Fr. B. Nestius. [Sold and perhaps also published by G. Scheutz.]
Roberts, W. H.
1855. *Den inhemske vinfabrikanten och hembryggaren.* Free revision and translation [by G. Scheutz] based on the fifth English edition. Stockholm: A. Hellsten.
Saint Croix (?)
ca. 1820. *Mysterier, de gamles: Historisk framställning deraf.* Stockholm: G. Scheutz.
Salverte, Eusebe
1831. *Den hemlige vetenskapen.* Translation [by G. Scheutz], 2 volumes. Stockholm: G. Scheutz.
Say, Jean-Baptiste
1823-1824. *Afhandling uti statshushållningsläran.* Translation [by Carl David Skogman] based on the fourth enlarged and revised edition, 2 volumes. Stockholm: G. Scheutz.
Scheutz, Edvard
1836. *Vackra flickor finnas äfven i Siberien: Lustspel i två akter.* Stockholm: G. Scheutz.
Scheutz, Georg
1815. *Nattäfventyret.* Stockholm: F. Cederborgh & c. [Reprint from *Samlaren,* number 3, 1815.]
1817. *Handbok för så wäl enklare som mera konstig blekning winter–och sommartiden.* Stockholm: Cederborgska boktryckeriet.
1819. *Register öfver Stockholms tidningar.* Stockholm: Cederborgska boktryckeriet.
1820. *Handbok för så wäl enklare som mera konstig blekning winter–och sommartiden.* Second edition. Stockholm: G. Scheutz.
1823. *Handlingar, hörande till den i kongl. Götha hofrätt anställda rättegang mot Hrr Adlersparre, Gripenwalett, Kurck, Schultz, Silversköld och Sköldebrand, för deras yttranden vid 1800 års riksdag: Ett bidrag till enväldets historia i Sverige.* Stockholm: G. Scheutz. [Authorship uncertain.]
1832. Handbok i ritkonsten. *Bibliotek för konst, slöjd och tillämpad vetenskap,* volume 2. Stockholm: G. Scheutz.
1834. *Portatif räknemaskin i form af en liten bok. En*

tillämpning af John Nepers, baron af Merchiston, räknestafvar. Stockholm: G. Scheutz.

1840. *Slägtvälde och idévälde, eller det som var ach det som kommer.* Stockholm: G. Scheutz.

1842. *Handbok i ritkonsten.* Second edition. Stockholm: G. Scheutz.

1843. *Vägen till naturens riken: En elementarbok i naturhistorien.* Stockholm: L. J. Hjerta.

1849a. *Handbok för bleckarbeten.* (*Bibliotek för konst, slöjd och tillämpad vetenskap,* volume 9.) Stockholm: Eckstein.

1849b. *Nytt och enkelt sätt att lösa nummerequationer.* Stockholm: N & K Marcus. [Also see Agardh 1849.]

1856a. *Den praktiske affärsmannen: Handbok för handlande och handtverkare.* [Treatment based on the third edition of "Der kleine Rotschild."] Stockholm: J & A Riis.

1856b. *Jorden, illustrerade naturbilder.* Stockholm. [Second edition, revised, with index, published 1857 in Stockholm.]

1860. *Stockholm: Illustrerade utkast.* Stockholm: A. Hellsten.

1860-1861. *Industriens bok.* 2 series, 8 volumes. Stockholm: Thimgren, Blomqvist, Ljunggren.

1862. *Jorden, illustrerade naturbilder.* Third revised edition, with index. Stockholm: A. Hellsten.

1868. *Den praktiske affärsmannen.* Second edition. Stockholm.

1869. Lagerhjelm: Svenska Vetenskapsakademien. *Lefnadsteckningar,* 1(9):71–76.

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1875. *Den praktiske affärsmannen.* Third edition. Stockholm: Alb. Bonnier.

Schiller, [Friedrich von]

1819. *Vielleviiles lefverne och krigsbedrifter.* Translation [by Georg Gabriel Dahlcrona]. Stockholm: Cederborgska boktryckeriet.

Schubert, F[riedrich] Wilh[elm von]

1823-1825. *Resa genom Sverige, Norrige, Lappland, Finland, Ingermanland.* Translation [by G. A. Wulff], 3 volumes. Stockholm: G. Scheutz.

Scott, Walter

1821-1822. *Ivanhoe: Romantisk målning af England, under Richard Lejonhjertas tidhvarf.* Translation [by Joh. Henr. Ritterberg], 3 volumes. Stockholm: G. Scheutz.

1824a. *Fanatismen: Historisk skildring.* Translation [by G. A. Wulff], 3 volumes. Stockholm: G. Scheutz.

1824b. *Midlothians hjerta.* Translation [by G. A. Wulff], 3 volumes. Stockholm: G. Scheutz.

1826-1827. *Woodstock.* Translation by C. R. [Lars Arnell], 3 volumes. Stockholm: G. Scheutz.

Shakespeare, William

1816. *Julius Caesar: Skådespel.* Translation by G. Scheutz. Stockholm: F. Cederborgh & Co.

1820. *Köpmannen i Venedig: Skådespel.* Translation [by G. Scheutz]. Stockholm: G. Scheutz.

1825a. *Konung Richard den andre: Sorgspel.* Translation by Joh. Henr. Thomander. Stockholm: G. Scheutz.

1825b. *De muntra fruarna i Windsor: Lustspel.* Translation by Joh. Henr. Thomander. Stockholm: G. Scheutz.

1825c. *Som ni behagar: Skådespel.* Translation by Joh. Henr. Thomander. Stockholm: G. Scheutz.

1825d. *Trettondagsafton eller hvad ni vill: Skådespel.* Translation by Joh. Henr. Thomander. Stockholm: G. Scheutz.

1825e. *Antonius och Cleopatra: Skådespel.* Translation by Joh. Henr. Thomander. Stockholm: G. Scheutz.

1831. *Julius Caesar: Skådespel.* Translation by G. Scheutz. Second edition. Stockholm: G. Scheutz.

Smith, Horace

1827. *Slottet Brambletye, eller Carl den II och Cromwell.* Translation from the original by C. R. [Lars Angell], 3 volumes. Stockholm: G. Scheutz.

1829. *Joe Hill: Romantisk skildring från Henry VIII:s och Engelska reformationens tidehvarf.* Translation by Lars Arnell. Stockholm: G. Scheutz.

Sommer, M.

1819. *Italiensk läsbok, med dertill hörande ordbok och spraklära.* Based on G. W. Müller; translation with additions and revisions. Stockholm: Cederborgska boktryckeriet.

Spegeln

1837-1838. Stockholm: G. Scheutz.

Sue, Eugene

1844. *Parisiska mysterier.* Translation [by G. Scheutz and others]. Stockholm: L. J. Hjerta.

Svensk illustrerad polytechnisk journal

1852-1854. 3 volumes. Stockholm: C. M. Thimgren.

Svenska bondens tidning

1835-1836. 84 issues. Stockholm: G. Scheutz.

Svenska industriföreningens tidskrift

1834-1839. 61 issues. Stockholm: G. Scheutz.

Svetonius Tranqvillus, C[ajus]

1832. *De tolf förste romerske kejserne.* Translation [by Magnus Luttrop], 2 volumes. Stockholm: G. Scheutz.

Terquem, [Olny]

1832. Handbok i algebra. Translation [by Magnus Luttrop], tables added. *Bibliotek för konst, slöjd och tillämpad vetenskap,* volume 3. Stockholm: G. Scheutz.

Tidning för nörringarne

1840-1842. 64 issues. Stockholm: G. Scheutz.

[Voss, Christian Daniel]

1821. *Markisens af Pombal minister.* Translation. Stockholm: G. Scheutz.

Voss, Julius von

1828. *Ruter Dam och Gips Apollo, eller de svartsjuka makarne: Fars i två akter.* Translation [by Mårten Altén]. Stockholm: G. Scheutz.

Wägner, Wilhelm

1869-1872. *Rom.* Translation from the second edition

by G. Scheutz [volume 1; volumes 2 and 3 by E. Scheutz]. 3 volumes. Stockholm: L. J. Hjerta.

[Walberg, Carl Gustav]
1817a. *Engelbrecht Engelbrechtsson; hjelte, statsman, fädereslandets försvarare mot utländskt förtryck.* Stockholm: Cederborgska boktryckeriet.
1817b. *Soldat-familjen, den 28 januari: Prolog.* Stockholm: Cederborgska boktryckeriet.
1817c. *Oegennytta och uppslysning.* Stockholm: Cederborgska boktryckeriet.

[Wergeland, Henrik Arnold]
1837. Stockholmsfararen. Sjuttonde maj stycke af Siful Siffada. Translation and notes by G. Scheutz. *Spegeln,* numbers 22 and 23.

Werner, F[riedrich] L[udwig] Z[acharias]
1817. *Dalens söner.* Translation [by G. Scheutz], 2 parts, 3 volumes. Stockholm: Cederborgska boktryckeriet.
1864. *Dalens söner.* Translation [and introduction by G. Scheutz], second edition. Stockholm: Huldberg & Komp.

Wright, [Frances]
1826. *Resa genom Förenta staterna i Nordamerika.* Translation [by Mårten Altén], 2 volumes. Stockholm: G. Scheutz.

Xenofon
1829. *Cyri härfärd och de tiotusendes återtåg.* Translation from the Greek by Ludvig Westerberg [revised by G. Scheutz]. Stockholm: G. Scheutz.
1831. *Cyri härfärd och de tiotusendes återtåg.* Translation from the Greek by Ludvig Westerberg [revised by G. Scheutz], second edition. Stockholm: G. Scheutz.

Zimmermann, [Eberhard August Wilhelm]
1809. *Brasilien enligt de nyaste och säkraste underrättelser skildradt.* Translation [from the German by G. Scheutz]. Jönköping.

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