

II

The Technologies of Print

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1 Introduction

Printing was introduced to a world in which the status of the book and its makers was changing. A professional book trade existed well before printing with movable types was introduced in Europe during the 15th century. Thepecia system allowed students at the universities of Bologna, Padua, and Paris in the 12th century to hire an authenticated text, or a part of it, to be copied either by themselves or by professional writers. During the early 15th century, Vespasiano da Bisticci of Florence acquired a reputation as an employer of professional calligraphers and miniature painters who made beautiful manuscript books for rich clients. Such systems and professions point to the opportunities that encouraged the emergence in the 15th century of the printer and publisher who—gambling on the likelihood that a market existed for multiple copies of texts—was willing to invest in the materials and labour necessary to make many identical books (in advance of sales) by mechanical processes.

The terms that were eventually adopted in modern European languages for the ‘printing’ of texts and pictures had a long history: words (such as ‘impression’ and ‘stampa’) typically signified the application of pressure, most often to leave a visible mark. As Shakespeare writes in the Prologue to *Henry V*: ‘Think when we talk of horses, that you see them / Printing their proud hoofs i’ th’ receiving earth.’ Indeed, the principle of using an engraved stone to make repeated characters in a soft material, such as clay, is displayed in many surviving early artefacts, from official Mesopotamian seals (3rd millennium BC) to Roman bricks and tiles stamped before they were fired with their makers’ names.

2 Origins

In the Middle Ages, western books and documents were commonly written on vellum, a prepared animal skin; although some printed books were also made on vellum, there is no doubt that paper (a product consisting of vegetable fibres reconstituted in the form of thin white sheets of a uniform size and thickness (see 10) was necessary for the development of printing in the West. By the 13th century, paper was sufficiently common in western Europe that a decree forbidding its use for the writing of public records was issued in 1231 by the German Emperor Frederick II.

Techniques for making paper evolved in China and spread along the land routes that brought silk and other goods to the West. The traditional date for the invention of paper made from mulberry bark, hemp, and rags is the start of the 2nd century AD (although some scholars maintain that the actual date is between 200 and 100 BC); by the 3rd century, such paper was commonly used in China to write documents. In 1276, paper mills were operating at Fabriano in Italy, and in 1390 the first paper mill in Germany was established at Nuremberg.

It is not known whether awareness of the processes used in China and neighbouring countries to make multiple copies of books had penetrated to the West before a complete system for printing books evolved in Germany c.1450. These, briefly, were the stages of their development in the East (see 42, 43, 44, 45). By the 7th century, inked relief seals, cut on wood and pressed by hand, were used in China to authenticate documents written on paper. Ink-squeeze rubbings were made to provide multiple paper copies of the Confucian texts that were cut on stone and displayed in temples for public reading. A sacred Buddhist text, the Diamond Sutra (868), a scroll made up of strips of paper pasted together, is the earliest datable instance of the use of engraved relief wood blocks to print many copies of an extensive text and an image with ink. The technique of woodblock printing that finally evolved to make printed books required several steps. The text was written by a professional calligrapher on thin sheets of paper and pasted in reverse on a block of wood, so that the writing was visible. Superfluous wood was cut away, leaving a facsimile of the reversed text in relief. Ink was dabbed on the block, and sheets of paper were pressed to it with stiff brushes, thus transferring an image of the writing to the paper. The paper, which tended to absorb the ink, was printed on one side of the sheet only, folded and sewn into books. Until western methods were introduced in the 19th century, this was the usual method of printing texts and pictures in China and neighbouring countries. In 12th-century Korea, movable types reproducing Chinese characters were made from wooden patterns by casting with copper in sand (see 43); such separate types continued in use to some extent in the East, but without displacing engraved woodblocks. The reasons for the very limited use of movable types in the East, compared with the rapidity of their adoption in the West, are complex. The high respect accorded to calligraphy in China, Korea, and Japan, the fluidity and complexity of the forms of Chinese characters

when written by hand, and the very large number of characters probably all contributed.

The mid-15th century 'invention of printing' in the West involved the bringing together of several techniques, devices, and materials. Some of these had long existed but others, such as the paper and the ink, were relatively recent. There may have been several experimenters working at about the same time. Procopius Waldfoghel, born in Prague and established in Avignon in the 1440s, is named in contemporary documents as using a process of 'artificial writing' employing alphabets made in steel, but his method did not necessarily involve the printing of texts. During the 16th century, a claim was made on behalf of Laurens Janszoon Coster of Haarlem as the inventor of printing, but none of the surviving early fragments of printing that originate in the Low Countries bears Coster's name, nor are there convincing biographical details. In the *Cronica van Koellen*, the 'Cologne Chronicle', printed by Ulrich Zell (1499)—in which there is some reference to a 'prefiguration' of printing in the Low Countries—unequivocal credit for the invention of printing with movable type in the West is given to Johann Gutenberg (d. 1468), whose life is well documented; the claim is not seriously disputed today (but see modifications to the traditional account of Gutenberg's invention in the work of Paul Needham and Blaise Agüera y Arcas). From 1454, when the folio Gutenberg Bible of 1,200 pages is known to have been in production, and when the texts of indulgences were also printed on single sheets, a technology existed for the making of multiple copies of books and other documents of an acceptable quality. The use of similar techniques spread very rapidly to European countries, and, although MSS continued to be important (*see 15*), printed texts gradually began taking the place of handwritten ones.

Gutenberg was born c.1400 into a patrician family in Mainz with interests in banking, but there is no evidence that he had direct contact with the technologies of making coins or working in precious metals. In the 1430s he was compelled for political reasons to move to Strasbourg, where he became involved in a partnership that made cast-metal items. Later he returned to Mainz, where he borrowed money from Johann Fust, a lawyer, to develop a project described in legal documents as *werck der bücher* ('the work of books'). In 1455 Fust foreclosed on the debt and took over the materials developed by Gutenberg. Peter Schoeffer, Gutenberg's former business partner, joined Fust and married his daughter; the names of Fust and Schoeffer appear on several of the earliest printed books beginning in 1457. Schoeffer inherited the business, remaining an important and an active printer in Mainz until his death in 1502/3. Gutenberg stayed in the same district until his death, still in possession of the printing materials mentioned in his will; yet he is not named in any printed book as its maker.

Gutenberg's partnership in Strasbourg, which became the subject of acrimonious litigation in 1436, produced, among other goods, mirrors cast in metal for sale to pilgrims. It is sometimes suggested that experiments towards the

making of type and the printing of books began in Strasbourg before Gutenberg returned to Mainz. There is no direct evidence to support this idea, but if the mirrors were made from lead or an alloy using lead, their makers may have developed some of the expertise that would be needed for making type. The earliest surviving fragments of printing that can be associated with Gutenberg appear to date from about 1450, and make use of a type that is less well finished and printed than that of the folio bible (the so-called 42-line bible) known to have been in production in 1454. This bible and the large 1457 psalter, bearing the names of Fust and Schoeffer, are the products of a printing system capable of making fine books that would command a high price, even if some of its elements may still have needed refinement. The constituents of that system are type, ink, paper or vellum, and a press for making an impression on them.

Paper had long been in use in Europe for the writing of correspondence and documents, and to some extent for books, as a substitute for the more durable vellum. However, whereas eastern paper was written on with a writing brush on one side of the sheet, western paper had been adapted to the use of a relatively hard quill pen to write with a liquid, water-based ink on both sides of the sheet. The materials of paper were still vegetable fibres, mostly in the form of rags, discarded woven linen that had served as clothing or for domestic use. To prevent the penetration of the surface by the liquid ink, the sheet was made relatively hard and firm in its substance, an effect sometimes reinforced by adding size (a diluted solution of colloids made from animal skin and bones) to its surface.

The ink used on metal type was a thin film of stiff, coloured varnish, made by boiling and sometimes setting fire to one of the drying oils, generally linseed or walnut: the process was too dangerous to be carried out in a confined urban space. The substance set firmly and permanently, even without exposure to air. To make black ink, soot was added to the clear varnish; red or other pigments made coloured ink. In fact, printing ink is a version of the oil paint that had become widely adopted by European painters by about 1400.

In order to make a satisfactory print on the hard-surfaced paper that was designed for use with the pen, it was necessary to soften its fibres (by dampening it) and to apply firm pressure. After the sheets were printed, they were hung up on poles or lines to dry. The drying sheets, dangerously flammable, must have been one of the most common sources of the fires that destroyed the premises of many printers during the hand press period.

The printing press was no doubt derived from the screw presses that had evolved in the period of the late Roman empire. They were routinely used for pressing out the juice of grapes and also for squeezing the surplus water from newly made paper. It seems likely that such presses would have been adapted for delivering the pressure needed to make a sharp, clear impression from pages of inked type on paper.

The element that was wholly new (if the possibility can be discounted that news of the Korean practice of some centuries earlier had penetrated to Europe)

was the making of 'movable type': a supply of small metal blocks bearing letters and signs in relief, from which multiple impressions could be taken.

How the early types were made is a subject that has been much discussed, although no definitive conclusions have been reached. It is possible that a slow process requiring much hand finishing, or dressing, was used initially (perhaps by sand casting, as was done in Korea). Whatever the first system may have been, it was quite rapidly succeeded by one in which relief steel punches, filed and engraved with the form of the letter, were hardened and used to stamp impressions in a softer metal, copper, to make matrices. Matrices were used together with a type mould that formed the body of the type. As later surviving examples demonstrate, such moulds were simple hand-held devices, formed from two L-shaped pieces that slid against each other to open and close laterally. Accurate castings about one inch high could be made from a sequence of matrices of letters, with each letter being the same height from top to bottom, but varying according to the different widths required for narrow letters such as 'i' and wide ones such as 'M'. Eventually, the manual processes for making types and assembling them into words and lines were mechanized, and alternative methods of placing words and images on paper were devised. Nonetheless, until the second half of the 20th century, most printed texts were produced using printing surfaces cast in lead alloys from matrices stamped with punches.

3 The hand press period, 1450–1830

The analysis of early fragments of printing attributed to Gutenberg has suggested that some early types may have been made in ways that do not correspond with traditional methods. However, the comparison of multiple scanned images of the pages of different copies of the Gutenberg Bible has revealed that the setting of its type was often altered during the course of printing, sometimes in ways that are hardly visible to the eye. The latter observations confirm beyond doubt that this work was set with and printed from single movable types.

The method of printing at the hand press seems to have undergone a slow evolution. It can be shown that, at least until the later years of the 15th century and often long after, the dominant technique was printing by formes, in which the first and last pages of one side of a single sheet or of a gathering made up of several inset sheets (the outer forme) were set in type and printed before the other side of the sheet (the inner forme) or those that came inside the section. The process of casting off copy to determine on which page it should come required painstaking calculation, and the compositors who set the type frequently needed to alter the text—shortening it by resorting to abbreviations, contractions, or omissions, or expanding it by adding various kinds of spacing such as quads or leading—in order to maintain the continuity of the text in the formes which were set and printed later. This technique of printing by formes may help to explain one enduring feature of the traditional wooden press: its platen (the wooden or metal plate that delivers pressure to the paper)

is the size of only one folio page, or half the full forme of type that was later placed on the press.

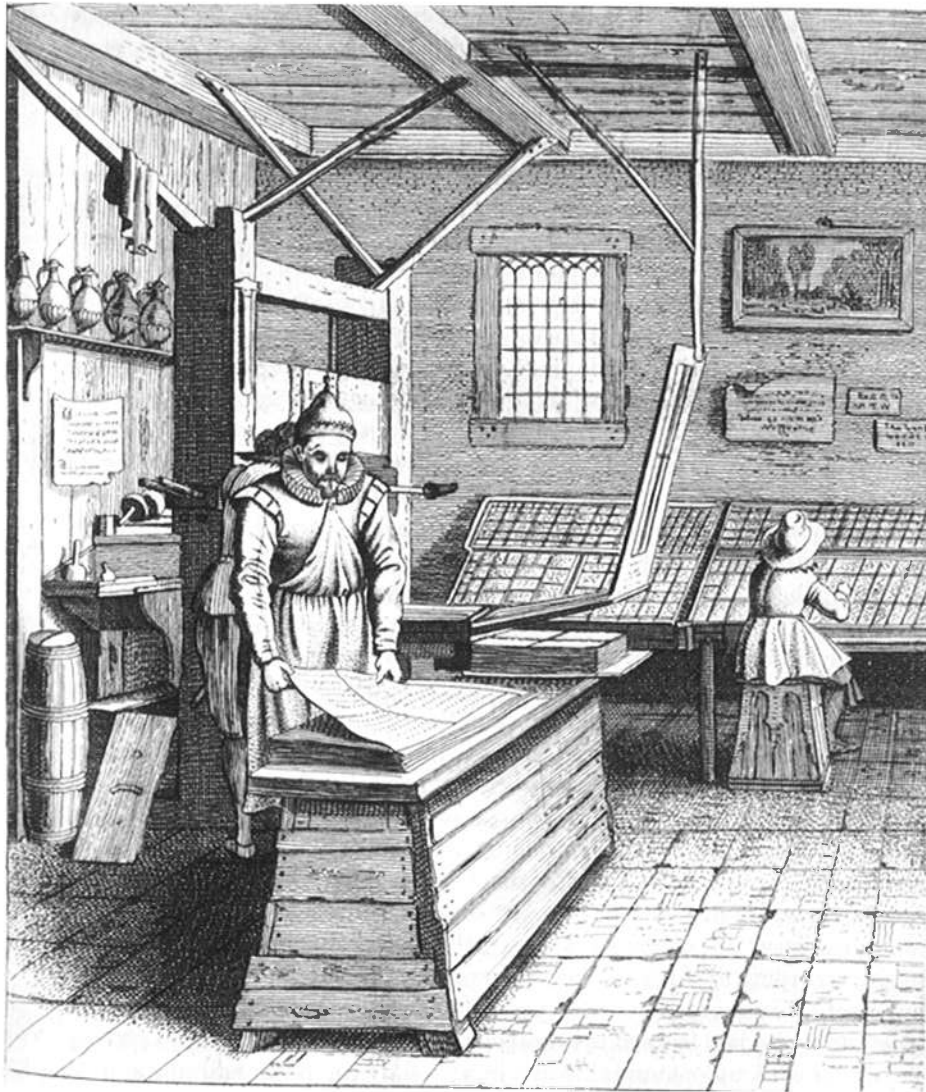
Some slight qualifications aside, there was a long period from the 1480s until around 1800 when the technology of printing was very stable. Type was made by hand and was set, formed by hand into words, lines, and pages. Presses were operated by hand at a rate that did not—indeed could not comfortably—exceed a certain speed. Paper was made, sheet by sheet, by hand: the maximum width of the mould, and therefore of the sheet it made, was limited by the maker's natural arm span, typically about 30in. or 76cm.

The earliest datable image of a printing office is a woodcut in a book printed in 1499. During the first part of the 16th century, representations of the printing office were symbolic of the trade, and appear on several title-pages. The images differ in some small details, but, taken together, they confirm that, once established, the equipment and the actions of the printers did not essentially change until 1800 or so. At that point, slight alterations that had begun as refinements of traditional methods and materials gave way to radical developments as printing was mechanized, production speed increased, and the unit cost of books fell.

During the hand press period, printing offices were generally normal houses, like the work places of weavers, joiners, and other tradesmen. The printer, with his family and apprentices, occupied some of its rooms, and the presses and type occupied others. Some printing offices were designed to impress visitors, such as the new Clarendon Building (completed 1713) of the Oxford University Press, but these were exceptions. Most premises were like that of printer and novelist Samuel Richardson, whose medium-size London printing office in Salisbury Square was also his dwelling, until the weight of the stock of type began to threaten the building's structure, compelling him to move.

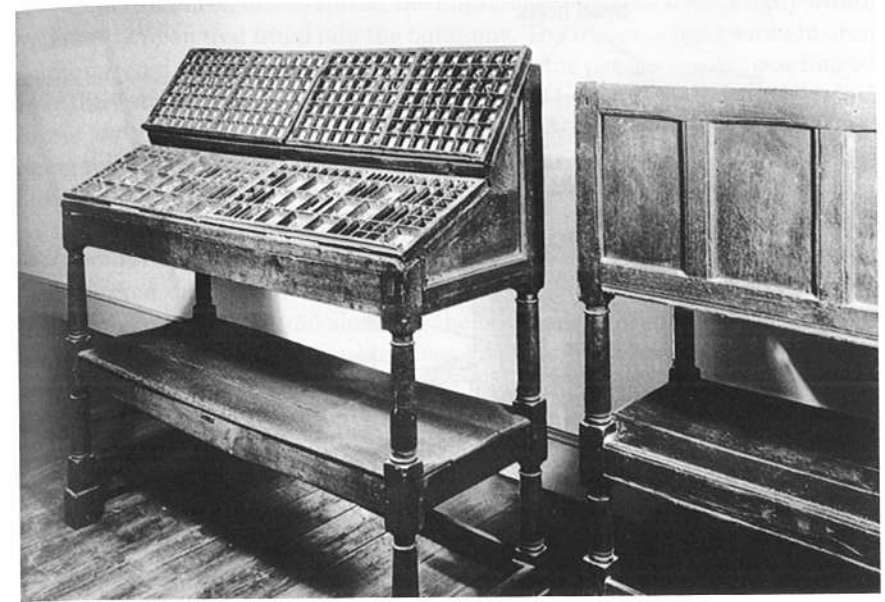
The office's equipment comprised one or more presses and a quantity of type. The type was held in open type cases, subdivided in divisions each of which held multiple sorts of one character. These smaller compartments of the case varied in size according to the frequency with which each letter, number, or mark of punctuation was used, the letter 'e' being the largest of them. The compositor or type setter who had learned the arrangement or lay of the case could pick up each letter without looking at it. Early images show compositors sitting at their work; later it became usual to stand. In some countries, there was a single case, holding both capital and minuscule letters, but in France, and countries such as Britain which followed French practice, capitals and minuscules had a case each, arranged one above the other, so that capital letters became known as upper case and the minuscules as lower case. Whatever its configuration, the case, which held 20–30lb of type (9–14kg), was commonly (like the papermaker's mould) no more than an arm-span wide, so it could be readily lifted and placed on a frame at a convenient height for setting.

The compositor held a composing stick, a tool that allowed several lines of type to be set to a given width. The copy or text for setting was placed where it



Printers and compositor in a Dutch printing office: engraving after a drawing by P. Saenredam for P. Schrijver's *Laure-kranz voor Laurens Koster* in Samuel Ampsing's *Beschryvinge ende lof der stad Haerlem* (Haarlem, 1628). Coster was wrongly supposed to anticipate Gutenberg as the inventor of printing. The Bodleian Library, University of Oxford (Douce A. 219, opposite page 392)

could be seen clearly, sometimes held in a special device called a visorium, or simply placed on the right-hand side of the upper case, which in France or England held the small capitals that were needed only occasionally. The compositor picked up letter after letter and placed them one at a time in the stick, putting



A composing frame with two sets of cases of type: the upper case lies at a steeper angle than the lower case. By permission of Oxford University Press

spaces between words, and working from left to right, reading the line in the stick to check that it was correct. To justify or fill each line, the spaces were added or reduced between words until the line filled the stick firmly. The lines were transferred from the stick to a galley, an open tray, until there were enough for a page. The page of type was tied up with thin cord and placed with other pages on a large flat imposing stone. A chase, an open iron frame, was placed over the pages, along with furniture, pieces of wood cut to size, which filled it exactly and made up the forme for printing. Wooden quoins or wedges were driven against long wedge-shaped sidesticks or footsticks to hold pages and furniture together. If properly assembled, the locked-up forme—made from some thousands of pieces of metal type—was solid and could be safely picked up and placed on the press.

The press in use until the early 19th century was a structure about six feet (two metres) high, made of a solid wood (oak was favoured), and consisting of two uprights with lateral beams. The lower beam received the force of the impression and, accordingly, was fixed; it supported rails on which the carriage, a flat surface bearing the forme, slid in and out under the platen, a solid, flat piece of wood or metal that hung from the screw, which delivered the impression and worked in the beam above. The screw appears in early images to have been wooden, but later was normally made of iron or brass, as was the platen (except in Britain, where it was commonly of wood). The platen hung

Unlike paper and ink, type was not wholly consumed by production. However, type gradually wore out in use or was damaged (known as type batter) and needed to be replaced: this was done at a rate that reflected the printer's standards and the economics of his operation. Surviving records from the early 16th century show that some printers bought sets of matrices for the types they used and a mould to go with them, hiring a specialist founder or caster to make a fount or 'casting' from them—at this date a *fount* (Fr. *fonte*, from *fondre*, 'to melt, cast') was the quantity of type made at one session of casting. This commercial practice was common even in major printing offices such as Christopher Plantin's in Antwerp, which had a big collection of matrices for roman and italic as well as many special types for scholarly and liturgical printing. By the 18th century, the founts held by some major printers weighed half a ton or more. From the later 16th century, specialist typefoundries were established in the principal centres of printing, and it became more usual for printers to buy all their founts of type.

Type was cast by hand. First, the matrix for each letter was placed in succession in a two-part mould, which expanded or contracted to suit the letter's width. Next, a ladle was used to pour molten metal into the mould; a rapid upward thrust of the hands while holding the mould ensured that the metal reached the image of the type stamped in the matrix before it cooled. The process of typefounding involved diecasting in an alloy of lead, a cheap and plentiful metal with a low melting-point, which enabled it to be safely used with hand-held devices. The alloy itself was complex, sometimes including more or less tin to aid the flow, and invariably a quantity of antimony, which not only toughened the metal and gave a sharper cast but eliminated shrinkage after casting.

Punches were cut with files and gravers in steel that had been annealed or softened. The punches were then hardened and tempered in order to survive the hammer blow of striking; each punch would serve to make many sets of identical copper matrices. For bigger types, matrices were sometimes struck in lead from punches cut in brass, or were made in brass by casting replicas from big steel punches. The choice of the style of types was governed by the same conventions as styles of writing. Gothic scripts were used for the vernaculars of the northern languages; gradually, however, the use of the new humanistic upright and cursive forms (roman and italic) spread from Italy and tended to displace the gothic forms, except in Germany. New fashions in typography were influenced by shifts in calligraphic styles. When they were used to cast type by hand, copper matrices did not noticeably wear out. Thus, there is a long period from the second half of the 16th century to the first half of the 18th century when the same types, derived from matrices struck from the same punches, were used by many printers in different European countries.

3.2 Illustration

Images were cut on wood at an early date and used with type to make illustrations or decorations, and sometimes even whole words. Large words on



A box of John Fell's pica italic matrices, with some steel punches for larger capitals beneath them. By permission of Oxford University Press

title-pages were commonly cut in wood. Block printing, which combines images and text cut on a single block of wood, appears to have been introduced during the later 15th century as a simpler imitation of the new books that had been made by using movable type. Any close-grained wood (e.g. apple or pear) could be used, but fine-grained boxwood was especially favoured for smaller images. At an uncertain date, possibly towards the end of the 17th century, engravers began to work on the end grain of the wood, a technique that sometimes achieved finer detail. Its products are known as wood engravings rather than woodcut illustrations (*see* 18).

By the 17th century, however, the woodcut was increasingly supplanted by images made in a wholly different medium and printed on a different kind of press: the incised or etched copper plate. The making of printed images from copper plates developed at about the same date as printing from type, but the first intaglio prints were circulated independently and were not incorporated in printed books. To print the fine engraved line, the plate was inked and its surface wiped clean again. When the inked plate, the dampened paper, and a cloth blanket were passed between the two cylinders of a rolling press, the pressure of the rollers and the blanket transferred the ink held in the recessed engraved line to the paper. Since the rolling press applied much greater pressure than the press used for type, its operation was correspondingly slow. The pressure also caused wear to the plate, limiting the number of images that could be made before it needed to be re-engraved. The early market for copperplate engravings was generally for independently published images sold singly, such as maps, reproductions of paintings, and satirical prints. During the 17th and 18th centuries, however, intaglio prints became widely used for illustrations in books, as well as for adding ornaments and decorative initials to sheets already printed from type. The combination of intaglio and letterpress called for coordination between two different kinds of printer, because the letterpress printer appears rarely to have had the means to print from plates.

3.3 Preserving and duplicating the text

During the hand press period, type was commonly set for only a sheet or two of a book, and then distributed back in the case after the sheet was printed; thus the same type was used several times in the course of printing a book. Very few printers had enough type to set the whole of a text or, if they had, could afford to leave the type idle while waiting to read and correct one work and finding a press free to print it. If a work sold well, the printing of a new edition required the setting, proofing, and correction of the whole text again.

Nevertheless, if a book had a large or reliable market, the heavy financial burden of buying and printing all of the paper at once to produce a large edition could be reduced by spreading it over time, using the return from the sale of the first printing to buy new stock. With enough type, the whole text could be kept in standing type for years and reprinted many times. There are a few documented cases where this is known to have been done.

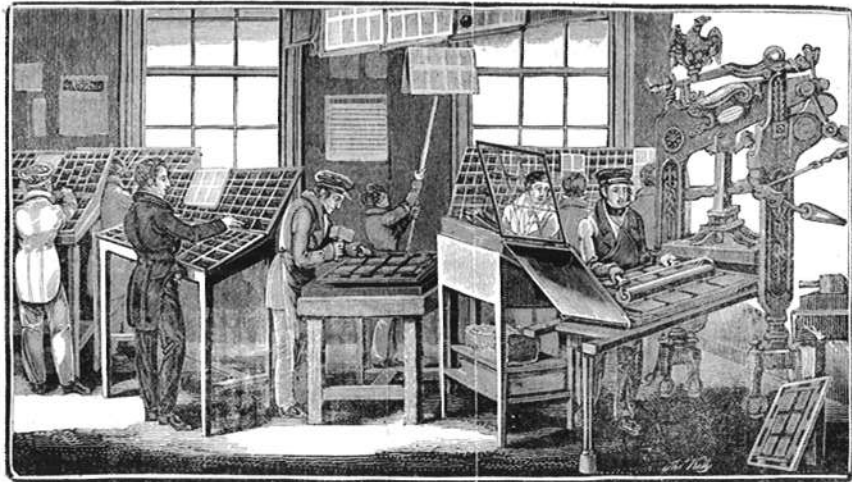
Towards the end of the 17th century, a means was found of casting duplicate plates from whole typeset pages; several works, including bibles, were printed from such plates in The Netherlands. This method of duplication was used from a very early period to make reproductions of woodblocks. Most casts of typeset pages were probably made from a mould of fine plaster, although a German work of the 1690s describes a method employing papier mâché. The practice lapsed for some time, although it may well have continued unobtrusively—if such techniques are well used, there is no easy way of detecting them. At the end of the 18th century, however, interest in the duplication of already composed text revived strongly. Experiments with various processes resulted in one, developed by the Didot family, called *stéréotypie*, or stereotyping in English. Another name coined at the same time, and mostly applied to the duplicating of wood-engraved illustrations and ornaments, was ‘clichage’, known in English as ‘dabbing’; its product, the cliché, passed into French and English as a metaphor for phrases repeated unthinkingly.

Reintroduced in the 19th century, papier mâché moulds were sometimes used to make stereotyped casts of the pages of books. Since these moulds were light and relatively durable compared with those of fragile plaster, they could be more safely and easily stored, and were sometimes sent to distant printers to make duplicate plates for printing the same text somewhere else.

3.4 Improvements to existing technology

During the second half of the 18th century, shifts in taste and economic prosperity, which expanded the market for books, encouraged greater aesthetic refinement of the printed page. John Baskerville, a rich Birmingham industrialist, former professional writing-master, and printer, sought to make books in which the type would reflect the elegance of the work of professional calligraphers; his pages show a smoothness resembling the paper of prints from plates that had passed through the rolling press. This effect was achieved partly by pressing the printed sheets between smooth, heated plates, but also by using James Whatman I’s new wove paper, which was made in a mould constructed from a fabric of woven brass wires so fine that they left no visible mark.

The expanding market for more visually elegant books led to further improvements to existing technologies and materials. The conventional wooden printing press was adapted in ways that enabled it to deliver a more powerful and consistent impression. Around 1800, Charles Stanhope, 3rd earl Stanhope, designed a cast iron press (the Stanhope press), using a system of linked levers to increase its power. Many other iron hand presses using similar systems were developed during the 19th century (e.g. the Columbian and the Albion). They had greater power and durability than the wooden hand press, and were capable of more refined presswork, but they did not print significantly faster. Other improvements in existing processes, such as the aquatint, a means of printing graded tones from a copper plate, assisted the production of expensive books or



Wood engraving by Thomas Kelly of printers and compositors at work using a Columbian press in an English printing office of the 1820s or 1830s. The St Bride Foundation.

of single prints for sale to collectors. Nonetheless, they did not affect the basic processes of printing.

3.5 Lithography

The growing market for separately sold prints and for illustrated books encouraged the development of a new method for placing letters or images on paper. Lithography, the first truly innovative reproduction system to appear for several centuries, would ultimately supersede both relief (letterpress) and intaglio (copperplate) printing. Its development into a practical process lay in the understanding of chemical reactions, a field of scientific research that developed rapidly at the end of the 18th century. Words or images—indeed both together—were drawn with greasy crayon on a polished block of absorbent limestone. The stone was dampened with water, then received an application of printing ink that adhered to the areas drawn with the crayon but was repelled by the dampened parts, which remained clean. The inked image on the stone could then be transferred to paper by putting pressure on it using a specially designed press. Lithography, or ‘stone writing’, was initially conceived as a means of transferring handwritten texts or drawings to paper without the intervention of typesetting or copying by professional engravers. Its inventor, Alois Senefelder, seeking a means of copying music, hit by accident on the rare variety of limestone, found at Solenhofen in Bavaria, that most suited the method. In time, a metal plate of zinc was developed as a substitute for the heavy and fragile stone. Other developments included a specially treated paper on which text could be written, and the image transferred to the stone. Later in the 19th century, another chemical process, photography, would enable both images and typeset text to be transferred to

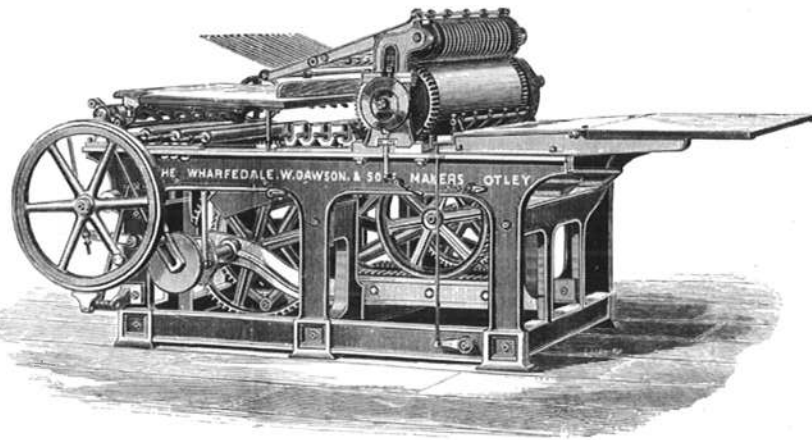
the stone or plate. A further process, initially designed for printing on tinplate employed for packaging, used a rubber cylinder interposed between the plate and the printing surface. This method enabled the image to be offset and transferred more efficiently to the surface to be printed. This technique was subsequently developed for lithographic printing on paper. During the second half of the 20th century, offset lithography displaced other processes to become the normal method of printing text and images in books and periodicals and on posters and packaging.

4 Mechanization

The mechanization of printing was largely driven by the possibilities offered by the development in Britain of new power-driven machinery, which enabled the rapid printing of larger quantities of material by fewer workers. Consequently, the unit cost of the printed item was reduced. During the first decades of the 19th century, methods of mass production were applied to the printing of newspapers and journals, most significantly with the printing in 1814 of *The Times*—the newspaper with the largest daily circulation—on a steam-powered machine. *The Times* needed to print some 7,000 copies of the complete four-page newspaper overnight, something that was hardly possible with the use of the hand press. Using hand press technology, the outer forme for pages 1 and 4 (consisting only of advertisements) was printed during the previous day, and the inner forme for pages 2 and 3 (with news and comment) was printed during the night. At *The Times*, multiple copies of this inner forme were set so that the printing could be completed at several hand presses, whose individual output could not exceed 300 impressions in an hour. This arrangement of contents, with advertisements on the front and back pages and news and comment across the centre spread, survived in newspapers long after the technical need for it had ceased.

With the advent of the new printing machine, the sheet was placed on a rotating iron cylinder under which the flat bed carrying the type, inked automatically with rollers, was carried to and fro. It was invented by Friedrich König of Saxony, an engineer who had established a partnership in London in order to develop his machine with the use of British venture capital. The initial speed of impression was 1,000 copies an hour. One of the early investors in König's machine was *The Times's* proprietor John Walter. However, disagreement with his English investors led König to leave England and set up his own factory at Würzburg with his business partner, Andreas Bauer. König's design was further developed during the 1820s by English engineers, notably the partnership of Applegath and Cowper, who introduced the principle of printing a second impression and delivering a sheet printed on both sides.

A comparable search for venture capital and for purchasers of machinery motivated the Parisian engineer Nicolas-Louis Robert to bring his designs for a paper-making machine to Britain. In this case, the critical innovation was to abandon the mould that made single sheets of paper, and to pour the pulp in a



First made c.1860 at Otley, Yorkshire, by the River Wharfe, for over a century the 'Wharfedale' cylinder press was used for all kinds of printing: from F. J. F. Wilson and D. Grey, *A Practical Treatise Upon Modern Printing Machinery and Letterpress Printing* (1888). The Bodleian Library, University of Oxford (25835 d. 3. fig. 22)

controlled stream on to a long, continuous, rotating band of woven wire. As the pulp dried out, it became paper, which was cut into separate sheets or stored in a roll at the so-called dry end of the machine. Machine-made paper was made and sold from the first decade of the 19th century.

Such innovations transformed the economics of newspaper and periodical printing at a period when the rapid growth in the population and urbanization of industrial nations was expanding markets greatly. Some of the fastest machinery developed at the time employed a principle that was well understood but difficult to apply in practice: namely, passing a continuous band of paper between two cylinders, one bearing the inked text and images, the other applying pressure. After printing, the paper was cut and folded. This process avoided reversing the direction of the heavy flat forme of type—as occurred in the cylinder printing machine—which practically limited the speed of output to about 3,000 sheets an hour. Yet such machines remained in use until the later 20th century for book printing that required relatively short runs and used single sheets of paper.

The principle of rotary printing, as printing from cylinders is known, had been employed by calico printers in Lancashire in the 1780s, where multiple colours were printed simultaneously on a continuous 'web' of fabric from engraved copper plates curved to fit cylinders. Ink was added continuously from rollers and the surplus was removed with a 'ductor' or 'doctor' blade against which the plate rotated before transferring the engraved image to the cloth. This practice of printing on a continuous web was adapted in due course to letterpress, lithographic, and intaglio printing on paper.

The basic requirement of rotary printing was the conversion of the flat printing surface of typeset text to the curved surface of the cylinder. A crude compromise was to lock the type in narrow galleys to the external surface of a cylinder with a radius so big that the lack of curvature was less of an impediment to getting a good impression. This was done during the 1840s on a machine designed for printing the *Illustrated London News*, a magazine that sold 250,000 copies weekly. Multiple stations were set up around the periphery of the cylinder, at each of which was an operator feeding a sheet to be printed with the inked surface. When used for newspaper printing, such presses employed very large sheets of paper, which were delivered folded to the purchaser, who either used a paper knife or struggled with the unopened sheet, like the reader shown in Benjamin Robert Haydon's painting *Waiting for 'The Times'* (1831).

The logical development, when the technical difficulties could be overcome, was a rotary press, printing on a continuous web or roll of paper. This was realized in the 1860s and used initially for newspapers, but the arrangement has become normal for high volume printing of any kind. A mould was made from the flat surface of the forme of type in flexible papier mâché (called the flong, from the French *flan*), then dried and curved so that a cast could be made in the form of a half cylinder. Paper from a continuous roll was fed through inked cylinders, to which pairs of such semi-cylindrical casts had been attached. Having been printed on both sides, the paper was cut and folded at the end of the press. In the early 20th century, the casting process and the machining of the plates to fit the cylinders was made faster and more automatic. With the addition of extra printing units, newspapers with more pages could be produced at speeds reaching 80,000–100,000 copies an hour. To speed production still further, multiple moulds could be made and used to cast plates intended for additional presses in the same location or a distant one. Rotary presses fitted with curved stereotype plates were used until the second half of the 20th century for printing newspapers and, in cases where long press runs were required, for magazine and book production.

4.1 Electrolytic processes

The electrotype, developed c.1840, would for some purposes supersede the cast stereotype, both for the duplication of typeset texts and for the reproduction of wood engravings. In electrotyping, a wax impression was taken from the surface to be duplicated. Then, having been coated with fine graphite to make the surface conduct, the wax was immersed in a bath of copper sulphate solution; as a current was passed through it, particles of copper built up gradually. The resulting copper shell, backed with lead to give it solidity, was capable of a very fine reproduction of the original. It became the standard practice for publishers to keep the original blocks of wood-engraved illustrations (such as those engraved by the Dalziel brothers after Sir John Tenniel's drawings for Carroll's *Alice's Adventures in Wonderland*, 1865) and to supply electrotypes ('electros') to the printer. As they wore out, these were replaced with new plates made from

the original wood blocks. Whether stereotyped or electrotyped, plates were made for all books that were frequently reprinted, such as reference works and popular series of inexpensive classic texts.

4.2 *Machines for typesetting*

Using the traditional hand mould, between 3,000 and 5,000 types could be cast in a working day, depending on the type's body size. In the smaller sizes, equivalent to 10 or 12 point (points are the unit of linear measure for type), the metal solidified as fast as the caster could throw in the metal and open the mould to eject the type. At the beginning of the 19th century, a significant improvement to the hand mould was introduced. A lever at the side enabled the caster to raise the matrix and eject the cast type without opening the mould. This device is credibly said to have raised the daily production by hand to as many as 8,000 small types. Another mechanical aid was the expedient of fixing a pump to the pot containing molten metal, so that the hand mould could be rapidly and more evenly fed. The powered injection of the metal also made it easier to cast finely ornamented types, introduced to rival the lettering drawn by lithographers, who competed for the more elaborate and profitable work of letterpress printers.

In the 1830s, David Bruce, who had emigrated from Scotland to the US where he became a typesetter, invented a machine that incorporated the two halves of the type mould. Using cams mounted on a single shaft, the machine brought the halves together in front of a pump nozzle, mounted on a metal pot, at the moment when it discharged a jet of metal. This 'pivotal' typecaster worked by hand or by power, producing 6,000 pieces of the smaller-bodied types in an hour. They were not finished types, however; as in hand-cast type, the work of breaking off the tang or jet of surplus metal, ploughing the foot, rubbing the edges, and undercutting kerned sorts, had to be done before the type was ready for use. In the 1880s, a new generation of more complex typesetting machines (Barth in the US, Küsterman in Germany) was developed that also cast type in the larger sizes, and delivered the type finished for printing.

The most significant single invention in the field of typesetting was the pantographic machine punchcutter, patented in 1885 by Linn Boyd Benton, an American typesetter. The principle of a rotating cutter, mounted on a pantographic frame and tracing the outline of a relief pattern, had been used since the 1830s to cut big types in wood for use on posters. Its application to the making of steel punches made possible the realization of typesetting machines that changed the market for type for hand setting. It also made possible the creation of types from a drawn alphabet, without the intervention of the hand punchcutter.

4.3 *Mechanized typesetting*

Much attention was given during the second half of the 19th century to the development of machines for setting type. There were two different approaches to the problem. The first system, widely used, stored cast type and delivered it as

unjustified text to a composing stick, where a compositor inserted spaces and justified the line by hand. Such a composing machine, with a keyboard similar to that of a piano, was produced by Young & Delcambre in the late 1840s. More sophisticated machines of this kind were marketed successfully and used well into the 20th century.

The second system, which overtook the first, was for a machine that cast a new printing surface. Several machines of this kind were invented and produced between the 1880s and World War I, but only two of them effectively survived; these divided the larger part of the market between them during the 20th century. In 1887, the Linotype machine was launched by Ottmar Mergenthaler, a German immigrant to the US. A supply of brass matrices was stored in a magazine, from which they were released by keyboard in sequence to form the line of text. The words having been spaced with wedges, the line was cast as a solid bar or slug, the 'line of type' to which its name referred. At first, the Linotype was bought for newspaper composition, but in the US it eventually came to dominate the machine composition of text for all printed matter, including that of books.

A decade later, in 1897, Tolbert Lanston, who as a clerk had seen the potential of punched cards for sorting data, invented the Monotype machine. Its keyboard was separate and freestanding: the operation of the keys punched holes in a paper tape that recorded the characters and added a code to calculate the line's spacing. The tape was read by an automated casting machine, which cast each character and space separately and delivered lines that were ready for placing on the printing machine.

The casting of separate type enabled corrections to lines cast on the Monotype to be made by hand. In the Linotype, a line needing correction was reset and recast. This could be done quickly, however, and Linotype slugs were more stable than single types when they were made up into formes on the composing stone. Accordingly, the Linotype, together with some related machines, retained its hold on the market for newspaper and periodical composition. For the composition of books, the Monotype, which was capable of certain typographical refinements, was often favoured.

4.4 *Photomechanical processes*

During the later 19th century, highly complex processes were developed for the reproduction of images, some of which had a profound effect on printing processes generally. The principle was simple, although in practice great technical skill was needed. A photographic image of a black-and-white drawing was printed on to a zinc plate with a substance that formed a resist, and the rest of the metal was etched away to leave an accurate relief facsimile of the drawing, ready for printing, without the intervention of a professional engraver to interpret it on wood (*see 18*).

During the 1880s, images for reproduction in books and magazines (a fast-growing market) were increasingly derived from photographs, but these were necessarily interpreted by professional wood engravers who simulated the

continuous tone of the photograph by creating the perceived shades of grey with the skilled use of their tools. The mechanical reproduction of photographs was achieved by breaking up the image with a regular screen of fine crossed lines to create half-tones (comprising dots of varying size) and etching the image in relief on copper. The drawback of the half-tone block was that properly printing its fine detail required the use of a specially prepared smooth paper, ideally one that was coated with china clay, and known as 'art paper'.

Similar techniques were employed to treat photographs to produce a printing surface for lithographic or intaglio printing. The latter process led to the development of photogravure, printed either from flat etched plates or from copper cylinders from which both photograph and text could be printed on large web-fed rotary presses. The process of photogravure printed on rotary machines, which at that date produced a denser image than either letterpress or offset lithography, enabled the production of large-circulation pictorial magazines in the years between the two world wars; it was also used for some books of photographs.

4.5 *Colour printing for the commercial and popular market*

To print in more than one colour, the same sheet must be printed repeatedly; this adds to the cost and demands accuracy in placing the paper, so that the colours print over each other in register. During the 19th century, multiple colours were increasingly used to increase the effectiveness of new kinds of printing: e.g. posters and packaging, and books for children (*see* 17). In the 20th century, that market would also include large-circulation periodicals. At first, colours were mixed by specialist printers to make tints that worked in harmonious combinations. With the development of colour theory at the end of the 19th century, processes were introduced that could reproduce all possible colours from the superimposition of three successive printed colours (cyan, magenta, and yellow). However, with experience it became evident that, in addition to the three colours, an additional black printing was needed to give added density to dark hues, thus making a four-colour process.

4.6 *Photocomposition of text*

A system for setting type by photography was patented in Britain in 1896, and experimental devices for small-scale typesetting were invented and used during the 1930s. It was not until after World War II, however, that systems for text setting were manufactured and marketed on any scale.

One obstacle to the use of photography was that letterpress relief printing was still the dominant means of producing texts. The product of photocomposition was an image on film; using it for letterpress printing required the making of an etched relief on zinc or magnesium, an expensive process that risked some loss of quality. Although photogravure was too small a part of the market, offset lithography was more promising. It generally employed text that had

been set in metal, then photographed to make the lithographic plate, so direct photocomposition of the text could eliminate this detour. It is not surprising, therefore, that the early photocomposing machines were designed and made in the US, where offset lithography was gaining a steadily increasing share of the market for printing. For printing books, the process had an additional advantage over letterpress, one that it shared with photogravure: photographs could be printed alongside text on the same paper, rather than segregated in a separate section of plates.

Some early photocomposing or filmsetting machines were based on existing machines for making metal type, and produced by their manufacturers in order to gain a share of the future market. Such machines included the Fotosetter of Intertype (makers of a version of the Linotype) and the Monofoto, made by Monotype. In these, photographic negatives were, in effect, substituted for the brass matrices in which metal had been cast; a beam of light created the text, letter by letter, building up lines and pages on film that was then developed. The most innovative machine, designed from first principles rather than adapted from existing models, was the Photon (called the Lumitype by its French inventors, Higonnet and Moyroud, and marketed under that name in France). On the Lumitype, letters were picked out in rapid sequence from images on a spinning glass disk with an electronic flash and the capacity for multiple sets of types or fonts. (During the middle years of the 20th century, the designs of the printing types sold by typefounders or provided by the makers of composing machines were widely known as typefaces. With the development of photocomposition and digital typography, for which many of the older designs were adapted and redrawn, the term 'font'—the US spelling of the term more commonly spelt 'fount' in Britain—became routinely used for individual designs.)

The first generation of these machines all posed the same problem: to make a correction, it was necessary to set a new line or paragraph and physically strip it into the existing film. It became apparent that the only way of working around this difficulty was to read and correct the text before, rather than after, the type was set and almost ready for printing, as had hitherto been the practice. In the new generation of typesetting machines, the text was entered on a keyboard, coded for such instructions as size of type and bold type and italics, and held on magnetic tape in order to permit correction and alteration that could be viewed on a screen and checked on an intermediate print. The computer had entered the printing office and, within a generation—having irrevocably altered the relationship of author, publisher, and printer—it would change the meaning of 'text'. During the 1970s, a third generation of typesetting devices moved away from photocomposition on film, substituting the generation of type in digital form.

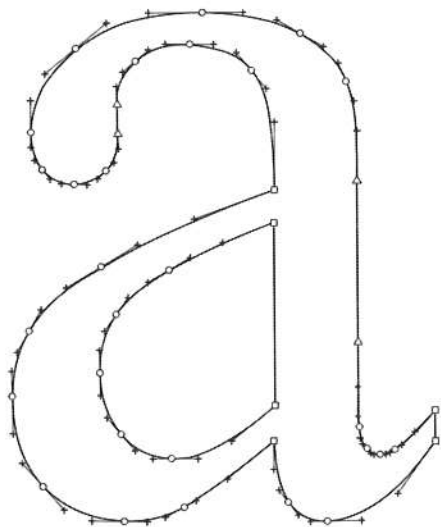
4.7 *Digital typography*

The Apple Macintosh computer, with its mouse and GUI (Graphics User Interface), was launched in San Francisco on 24 January 1984, a date that is often

cited as marking the beginning of the digital revolution in printing and publishing (see 21). In addition to the Apple Macintosh computer ('Mac'), four other products marketed in 1984 and 1985 may together be seen as having initiated the practices that ultimately became a normal part of the process of making books and all kinds of printed matter. The page description language Adobe PostScript enabled the integration of text and images on a range of different computers and printers. The LaserWriter, introduced in 1985, was a laser printer with a raster image processor that incorporated the Adobe PostScript interpreter. Macropedia's Fontographer was a program for drawing new digital fonts, and for adapting existing ones. Aldus PageMaker was a program that facilitated the setting of type, the handling of images, and their placing on a page. Thus, the design and assembly of a publication's parts—originally the printer's responsibility and, during the 20th century, increasingly shared with a design or production department within a publisher's office—could now be performed by one person with a small computer on a desk. By providing their text in digital form, authors became the primary typesetters of their own books. The advent of the electronic book was in many respects an outgrowth of these new, computerized production technologies.

5 Conclusion

The printed book as an object has not changed radically since its introduction in the 15th century. To be sure, the varieties of its form are now very great indeed, with images integrated into text, an abundance of colour, and a wide range of formats. Yet, in order to convey straightforward texts, lines of black words are still placed on white paper, arranged in a sequence of pages, and made up into a



The 'a' of a TrueType font of Times Roman, with all the points that govern its Bézier curves and straight lines. Courtesy of Professor James Mosley. Line drawing by Chartwell Illustrators.

book that can be placed at a comfortable distance for reading. The shapes of the letters may vary from time to time under the influence of changing preferences, but many types in current use are derived directly from those created during the 20th century for machine composition in metal. Indeed, it is generally agreed that—although the appearance of offset lithography is subtly different from that of letterpress printing—digital types and typesetting have on the whole enhanced the look of printing without altering it noticeably.

Nevertheless, the underlying technical processes employed to produce the printed page have changed tremendously. The widespread use of metal type had effectively ceased by about 1980: such type is now employed only rarely, to make special kinds of books. Words are still generally placed on paper with ink, but carbon particles (or toner) fused by an electrostatic process are more likely to be used to generate copies of digitized books that are printed on demand. So too, many works are designed to be read directly from a screen without ever being printed on paper. The processes of making and diffusing texts are still developing in directions that are not easy to predict.

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