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nation through the grace of God," but mentions only that this excellent book had been printed and bound in Mainz, due to "the marvellous accordance in size and proportion between patterns and moulds."

Not even later, when, owing to the expansion of the new art, the number of professional printers had increased, do we encounter sources of information which would fully initiate us into the technique of typefounding. Nor do occasional references to it, especially in the written legal proceedings of the fifteenth century thus far published, yield satisfactory information. Those skilled in the art have, with few exceptions, shown far too little interest in the early history of their profession, and those who have concerned themselves with the subject have allowed themselves to be led into erroneous technical hypotheses and conclusions through the reports of persons surrounding Gutenberg, such as we find in the *Cologne Chronicle* and in the report of Trithemius.

Printing with individual movable letters cannot well be imagined apart from the process of casting types. Thus the invention of typefounding must necessarily have antedated typographic printing. This truism is expressed in the following words in 1745 in a petition by journeymen of the Egenolff-Luther typefoundry at Frankfurt am Main: "In speaking of the fame and distinction of the invention of this art, no one can deny that type-cutting and typefounding existed first as the true typo- and chalcographia, and that the *ars impressoria* [art of printing] can only be considered a consequence or development of the former." To explain how this "true typo- and chalcographia" in all probability developed, and how it reached a higher perfection, will be the task of this essay, which neither can nor will claim to be

an exhaustive treatise on this extremely difficult yet all the more interesting subject. The author has, however, welcomed the opportunity which enables him, as an active participant in the printing industry, to publish the results of many years of research in the history of his own profession.

This reconstructive study on the technique of typefounding would not have been possible without outside support and assistance. Dr. jur. et phil. h.c. E. J. Haeberlin of Frankfurt a. M., a descendant of the Luther family of typefounders and the present owner of the unique inventories of that firm, which played so important a rôle in the history of typefounding, has been kind enough to permit me free use of the material in his collection. In addition, upon seeing my experiments in casting in sand, this gentleman, who is an expert on early coins, called to my attention a similar technique used in the casting of Roman coins, which, according to an original model in the museum at Bologna, showed the use of the same process as the later sand-casting device for making type. My greatest thanks, however, are due to the typefoundry of the D. Stempel A.-G. in Frankfurt a. M., whose founders and directors, Messrs. D. Stempel and W. Cunz, undertook in the most generous way, undeterred by the considerable expense involved, experiments lasting over several years, most of which were performed within their own plant. They encouraged this work at all times with their active interest and support. I am also under obligation to Prof. Dr. Zedler of Wiesbaden for the encouragement and helpful suggestions which proceeded from his great interest in the subject of my inquiry. Nor do I forget the generosity with which Prof. Dr. Ebrard, the Director of the Frankfurt Stadtbibliothek, gave me access to the rich collection of early printed

specimens in that institution; and the many suggestions and helpful kindness of Prof. Dr. E. Sarnow, whose thorough acquaintance with the subject disclosed many a source hitherto unknown. May this brief study contribute to the knowledge of the development and growth of Gutenberg's art which has, like no other invention of the German mind, become in the course of centuries the common heritage of the civilized world.

Investigation lasting over several years to determine what had become of the Egenolff-Luther typefoundry, which flourished in Frankfurt a. M. from 1530 to about 1810, was rewarded by discovery of the originals of the punches for the so-called "Cologne cursive [Current] German black letter type [Fraktur]" in the possession of Dr. E. J. Haeberlin in Frankfurt a. M. These punches, which Münden mentioned in his report on the third centenary of the invention of the art of printing in 1740, were supposed to have been cut by the *Briefdrucker*, Hans von Pfeddersheim, who was one of Gutenberg's assistants. Even though the view held in Münden's time that Pfeddersheim who, according to authentic proof, worked as a *Briefdrucker* in Frankfurt a. M. after 1450, made these "flattened brass punches [platten Messingstöcke]" did not stand investigation, the fact remains that examination of the technique followed in making them, showed us the way to Gutenberg's original process of typefounding. The workmanship of the punches, which averaged a thickness of from four to six millimeters, showed that they had been moulded from a wooden pattern by the process of casting in sand, an assumption which proved to be correct. The discovery of this technique showed clearly that the old traditions, according to which wood-block printing had been the origi-

nal process on which printing with movable types was based, were to a certain degree justified, though almost all investigators had refused to accept them. Further experiments bore proof to these findings. I too, therefore, accept wood-block printing or rather the wood-cut itself as the starting point of my discussion.

True wood-block printing involves two processes: the making of the printing block and the process of printing. I need not speak of the earliest technique of cutting in wood, in which long-grain blocks of beech, linden, or pear wood were used as material, with the knife as the tool, nor of the technique of printing, which in ancient times was done by means of leather balls. The wood block, especially when the prints were made on parchment, was not strong enough to endure the wear and tear of the mechanical process of wood-cut printing in quantity, which process, according to authentic documents, was in use in Southern Germany as far back as the latter third of the fourteenth century. The comparatively soft quality of the wood out of which the wood block [Druckstock] was made, the influence of the thin, liquid printing ink, as well as the pressure produced by the balls [Reiber] often caused cracks and breaks, especially when there were fine lines in the printing surface. It therefore seemed advisable to make the wood blocks out of some more resistant material. To avoid replacing a damaged woodblock with a new one, the cutting of which would take much time and would not then be very effective, inasmuch as the latter might meet with the same fate, it became necessary to duplicate the block in a stronger material before it had a chance to wear out. Another circumstance which made the mechanical reproduction of wood-cut forms desirable was the steadily rising demand

for wood-cut prints, the producers of which incorporated and formed a guild of their own. The artist who drew the design to be reproduced did not always cut the block himself, and we may take it for granted that many of the more obscure professional wood-block printers did not master the art of cutting. It must have been the custom, at a still earlier period than is commonly believed, to exchange or to sell wood-cut blocks, especially those reproducing sacred subjects to be used at church festivals in localities far distant from each other. Besides, it must have been to the wood-cut printer's interest to find a way to obviate the necessity of cutting and re-cutting the same subject because of the time such work would consume. This relief was afforded by the technique of reproduction in metal, through the process of casting in sand.

The method of reproducing printing forms by the cast metal technique appears all the more plausible if we consider the high artistic perfection to which the technique of metal casting had attained as far back as the thirteenth century. We have authentic proof that this art was already practised during the pre-Christian era—recall for example the casting of Roman coins—and further demonstration is afforded by many well preserved tomb tablets and plates, a great many of which were made by a mechanical duplicating process, namely casting, chiefly in bronze.

This process is one of the few practised today in almost the same form as several centuries ago. The material used for making the moulds for casting in metal is a fine grade of sand, so-called moulding sand, mixed with clay and charcoal dust to a consistency which makes it sensitive to the finest impressions, and allows the escape of vapors caused by pouring the hot metal into the mould. The receptacles

in which the forms are made, the so-called moulding boxes, or flasks, are generally made of cast iron and consist of two frames without bottoms which fit tight on the contact surfaces and generally have an opening at their narrow side where the hot metal is poured in. The shaping of the future sand mould is done by placing one half of the moulding box on a board somewhat larger than the box, and by filling the hollow space thus created with moulding sand as high as the pattern requires, tamping it down afterwards. Then the pattern—in this case the wood block—is sprinkled slightly with the so-called separating powder [Scheidungspulver] to prevent the damp moulding sand from adhering to it. After that, the block, with the picture side up, is forced with slight pressure into the sand, and enough sand is tamped tight into the spaces between the walls of the frame to reach up to the upper edge of the one half of the moulding box, while the picture side of the wood block rises about five millimeters above that edge. After sprinkling the surface of this half of the mould, the second half, which is provided with dowels corresponding with guide-holes in the lower half of the box, is placed on top and again tightly filled to the upper edge with sand. Into this fine sand all the details of the picture face of the model are impressed.

Owing to the separating powder, the upper half of the moulding box can be removed without difficulty, the model (the wood block) is lifted out, and the hollow space produced by setting the two half moulds one above the other, offers an exact inverted image of the original. After incision of a hole in the side of the sand mould corresponding to that of the moulding box, and a few channels along the sides to allow the air and gases to escape, and after

finally having been slightly sprinkled with powdered charcoal, the sand mould is ready for founding. When it comes to the process of founding itself, the two halves of the moulding box are set upon each other once more, the upper and lower surface of the sand mould being supported by boards, while the whole is held together by a screw-clamp especially devised for that purpose. After the metal has been poured in and allowed to cool, the clamps are opened and the two halves of the moulding box, together with the two halves of the sand mould, are taken apart. Inside we find the finished cast, a faithful reproduction of the original. Then the jet is cut off, the sides of the cast smoothed with a file, and the back of the plate levelled. The plate, which had been thinned down by introducing into the mould before casting a sand core of a given thickness, is then blocked on wood bringing it to the desired height to paper. In most instances, the finished casts were at the most five millimeters in thickness. The blocking process is clearly demonstrated by frequent impressions showing protruding tacks. These indicia bear irrefutable proof that the process here described was the one actually in use.

Some examples will show that, under certain conditions, this technique fully satisfied more exigent demands and lent itself even to the reproduction of a certain kind of wood-cut known by the name of "shot-prints." The Frankfurt Stadtbibliothek has in its collection a small print made by Johann Landen in Cologne (Bertholdus, *Horologium devotionis*) which dates back to the end of the fifteenth century, and which among its thirty-six illustrations contains twenty-seven shot-prints, partly of a still earlier date. Without exception, these shot-prints, some of which are reproduced in Plate I, show characteristics peculiar to the pro-

cess of casting in sand. Plates II to IV illustrate the latter. In addition to Peter Schoeffer, whose two-color initials in the Psalter of 1457 offer an exceptionally fine illustration of the process of casting in sand, the itinerant printer Johann Numeister applied the same technique to the numerous illustrations contained in the "Meditations" by Cardinal Turrecremata, printed in Mainz in 1479, as well as in those which accompany the "Agenda ecclesiae Maguntinensis" published in 1480. On studying Plate II, which through error has been reproduced somewhat smaller than the original, the heavier printing along the edges strikes us at first glance. This, however, is not to be attributed to the process of printing. The original—as it was planned—should have been like the print shown in the reconstruction on Plate III. But since, owing to the laws of physics, a substance heated to the melting point always cools and solidifies from the outside towards the center, the edges, on the original print, congealed immediately after the metal had been poured into the moulding flask, while, owing to the slower process of cooling at the center of the plate, the latter "shrank" a little, which means that the surface at the center of the plate lay somewhat deeper than that nearer the edges. Consequently, that center part did not come out quite so distinctly in the printing (Schoeffer tried to make up for the same deficiency in the printing of the Psalter initials, by heavier inking.) Here and there little fragments of the cast broke off when the wood-cut model was removed from the sand mould. At the same time also, a few grains of the fine moulding sand had been dropped on the middle of the plate, and some light spots resulted. The new cast made by sand mould casting on Plate IV which, owing to the lack of the original wood block, was

produced from a zinc etching of Plate III, such as is used today for almost all line reproductions, presents a few slight deviations from Plate II, especially in the lines of the lower part. These are due to characteristics peculiar to the process of casting in sand, as mentioned above. Former doubts as to whether the original print had been made from metal plates have been definitely dispelled by unmistakable traces of tacks used to fasten down the plate along the edges.

There is, however, still another reason which caused shot-prints to be made from wood-cuts by the intervening step of casting in sand. The technique of prints in which the dark background is made lighter with a punching iron excludes the direct method of metal cutting. By the blows of the punching iron the metal is also forced sideways so that the background, while becoming lighter through the depressions appearing as white dots in the black printing surface, also becomes uneven because the edges of the depressions rise. These uneven edges can be scraped off. However, in doing this, the area affected is lowered and will not come out strongly enough in printing, since the lines of the design retain their original level. On the other hand, when a plate made by casting in sand "shrinks," the transition from one level to the other will be gradual. When the punching iron is used on wood, to lighten up a darker background, there is no danger that the surface will become uneven, since the material is very soft, so that the punching iron can hardly produce any raised edges.

The above explanations bear on the much debated topic of what is generally called the "metal-cut." How vague this term is, and how often conclusions are wrong, is demonstrated by the many points held by some authorities to distinguish the wood-cut from the metal-cut. Weigel con-

tends that even a very crude wood-cut always shows sharp lines, the ink is not massed and forced out to the sides, small details such as eyes, mouth, etc. appear clear and distinct, while in a metal-cut such lines usually run together. He also maintains that no wood-cut shows a slurred surface throughout. By these criteria, he claims, we can differentiate between the two, almost beyond possibility of error. In view of the reproduction of wood-cuts by the metal process, Weigel's distinction does not hold good as far as the true metal-cut is concerned. If the sand used for the mould was sufficiently fine, the cast fully corresponded to the original (aside from some inconsiderable shrinkage). Even the marks of the cutting knife were faithfully reproduced from the wood-cut. Touching up with the graver, re-cutting, etc., was hardly necessary, especially in wood-cuts of open design; the only prerequisite was a good cast of the original. The peculiar distribution of color whenever the rather liquid ink of those days ran or blotted when applied to the metal surface, offers no distinguishing feature, since both the metal-cut and the reproduction by casting in metal offer the same reaction to ink. Therefore it is impossible to state whether we have to do with a metal-cut or not, except in the few cases where the design was cut directly into the metal by the engraver himself, and where the latter's technique in using the graver can be recognized in the smooth edges of the lines. It is easier to prove the reproduction of a wood-cut by means of the metal technique, where different prints of it have been found in different places. Here occasional damage in the wood block or its copy may—on closer comparison—lead to a clue for differentiation. Since it has been proved that wood-cuts have actually been reproduced by the metal technique, Passa-

vant's opinion as to the difficulty of distinguishing metal-cuts from older wood-cuts has been justified.

The difficult technique of perfect reproduction of lettering, especially in the larger texts, which called for exceptional dexterity on the part of the wood-engraver, leads us to suppose that the old-style wood block, containing more or less xylographic text, called for a division of labor. Not all wood-engravers were or are able to draw type. Thus, at a very early date, there developed a class of engravers who specialized in cutting type. We are supported in this belief by the discovery of a document at Louvain, which informs us that, in 1452, the guild of the wheelwrights, carpenters, turners, and coopers of that town, complained to the Municipal Council that a certain Jan van den Berghe refused to join their guild as a member. The accused, feeling more inclined to join the clerks who often were united in a guild with the xylographers (Bilderschneider) and goldsmiths, claimed in his defense that the cutting of type and illustrations was a special art which had never, up to that time, been practised in Louvain.

Soon, however, the type-cutters themselves realized that this work took too much time, and they looked for an easier method, which again could be found only in a mechanical form of reproduction. The fact alone that the words cut into one integral plate served but one specific purpose, and only allowed the reproduction of one unalterable text, called imperatively for a simpler method of type-cutting, and at the same time for a new way of using the same set of letters for the mechanical reproduction of any text. This impulse was still further enhanced by the very general aspiration to better education, an influence which became more and more powerful.

This resulted in the increasingly frequent publication of small books which were calculated to meet the requirements for study and reading. The Latin grammar by Aelius Donatus, which in its numerous editions was generally called the "Donatus," after the name of its author; a Latin grammar in verse by Alexander Gallus, the so-called "Doctrinale"; as well as other texts the reproduction of which seemed to be justified by the great demand for them,

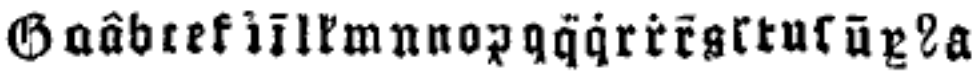

FIG. 1. Wooden models.

FIG. 2. Types produced by the sand-casting process: Some figures were purposely placed out of line so as to show the transfer of the alignment in the wooden model, to the founded type.

promised to be good sellers and helped to pave the way for a mechanical reproduction of type. Nothing seemed more natural than to apply the technique with which we have become acquainted in speaking of the reproduction of woodcuts by casting in metal, and which was now to reach its highest expression in the reproduction of type by the metal founding technique.

The transition from the xylographic text to the casting of type did not offer any great difficulties. The first thing for the type-cutter to do was to engrave into a wooden plate all the characters he needed, including the ligatures and punctuation marks of the type selected for reproduction, in a way which would allow the type face only to stand out, while all the area which was not to show in printing was, of course, cut deeper.

In addition he had to keep the letters accurately aligned and leave considerable space between them. This wooden

type block was then cut into lines of equal depth, care being taken that the ascenders remained within the upper edge of the line, while the descenders touched its lower edge. Then these lines, in their turn, were cut up into individual characters, and the latter studied and altered until the width of the type was in harmonious proportion. These individual wooden types formed the models for the process of casting in sand, the technique of which is familiar to us. Between the individual characters of the sand-cast mould, however, channels had to be cut in order to allow the melted metal to enter the different cavities. Plate V shows distinctly all these details, and justifies my not going more deeply into the subject. In order to avoid damage to the wood block when it had to be used repeatedly as a model for casting in sand, as well as to save time in the founding of types, which were more frequently used than others, a series of cast reproductions were probably made in an alloy of copper and zinc and used as models in founding the printing type proper in tin or some similar metal.

All these technical explanations, taken together, form the foundation for the history of the growth and development of the art of typefounding, invented by Gutenberg. In the record of the civil court proceedings of Strasbourg for the year 1439, which have unfortunately been lost, Gutenberg was mentioned for the first time in connection with a professional activity which, being obscure and ambiguous, lends itself to the most varied explanations in histories of printing. Since the materialization of his extensive projects by far exceeded the means at his disposal, Gutenberg found himself obliged to enter into a contract of partnership with the Sheriff Hans Riff of Lichtenau for the fabrication of mirrors, the sale of which promised to be a profitable busi-

ness proposition during the great pilgrimage to Aix-la-Chapelle. Later on Andreas Dritzehn and Andreas Heilmann also became associated with them. In the course of their common business, Gutenberg's partners discovered that he was working in another art which he had kept secret from them, and they persuaded him to let them have a part in it also. In 1438, their insistence led to the signing of a second contract which covered a period of five years. After some hesitation, Gutenberg agreed that, if his two partners, Dritzehn and Heilmann, paid him a sum of 250 florins each, he would "teach them all his arts and inventions, and not keep from them whatever knowledge he might acquire and whatever problems he might solve in the future." A further paragraph stipulated that in case one of the partners should die before 1443, the year which marked the end of the contract, all the arts, formulas, tools, and appliances, and all the work finished should belong to the two other partners, who pledged themselves to pay 100 florins to the heirs of the deceased at the end of the five years. The event provided for actually transpired. Before the expiration of the contract, Andreas Dritzehn died. He was behind 85 florins in his payments to the partnership. His heirs asked Gutenberg to take them into partnership. The result was a lawsuit, and I will deal briefly with the depositions of the witnesses. In the course of these depositions, there is mention of a press which had been made by the turner Konrad Sahspach and stood in the home of the deceased Andreas Dritzehn. Directly after the latter's death, Gutenberg sent his man-servant, Lorenz Beildeck, to the brother of the deceased, asking him to remove from that press the four "objects" which were supposed to be in it, and to take them to pieces, so that no one might know what they were. The same order was sent by

Andreas Heilmann to Sahspach, who, however, claimed "the object in question" was not there any more. Lorenz Beildeck confirmed the request sent by Gutenberg to the dead man's brother and certified that he himself had asked Klaus Dritzehn to walk up to the press and to open the "things with the two screws," because then the pieces would fall apart. The "objects" found he then should place within or on top of the press, and no one would know what they were for. Andreas Heilmann, one of Gutenberg's partners, certified that the latter had sent his man to the two Andreas (himself and Andreas Dritzehn) with the order to bring back all the forms. These forms had been melted under his eyes which made him "feel sorry" for some of them. Of importance is the deposition of the goldsmith Hans Dünne who informed the Court that about three years previously—that is in 1436—he had made 100 florins through Gutenberg, "only in material which pertained to printing."

However obscure and enigmatical the depositions of these witnesses may appear, and however varied the interpretations which have been made of them, their solution is perfectly simple if we approach them with the technique of casting in sand in our minds. Gutenberg had succeeded in reproducing a text in types by this technique. In 1436, we find him in business relations with the goldsmith Dünne, who descended from a Frankfurt family of goldsmiths and cutters of dies for coins. Dünne's clear references to the very essence of printing have been incorrectly applied to all kinds of other activities, except to the art of printing itself, though the latter had already become, before 1439, a definite term. In what, then, did Dünne's business connection with Gutenberg consist? To see clearly

on this point, we must know that casting in sand was an essential part of the goldsmith's technique, and had, in this very craft, reached its highest artistic perfection. The goldsmiths possessed, furthermore, the ability of executing more or less difficult engravings in any desired material, and were in consequence often entrusted with the cutting of dies for coins. Dünne's unequivocal reference, therefore, proves that he undoubtedly made the models which Gutenberg (who was probably not able himself to do type-cutting) reproduced by the sand-casting method. There is no doubt that Gutenberg used this method. Several witnesses attested to this, especially with relation to the "four pieces" which are characteristic of his Strasbourg casting technique (Plate VI). The old flask-shaped sand-casting mould, the characteristics of which can still be recognized in the four essential parts of present-day hand moulds (two frames and an upper and a lower board) was held together by a clamping device [Wuerbelin]. When released, the mould would fall apart so that the uninitiated would be unable to understand the purpose of the four pieces. The shaping of the printing form was made considerably easier as compared with the solid wood block; yet it was still difficult and time consuming, so that Gutenberg "felt sorry" after he had "melted," for the sake of security, some of the forms, which had been kept in two different places.

The method described was so cumbersome that the length of texts to be reproduced had to be kept within certain limits. It could be used to advantage only for the reproduction of short texts for which there was a quantity demand, such for example, as a grammar.

The sand-casting process has many faults and imperfections. The steady improvement in Gutenberg's early print-

ing shows his endeavors to perfect the technique and to remedy the deficiencies of the process. Aside from the fact that every new founding required the moulding of a new sand form, which caused quite some delay, the resulting casts were not of uniform quality. There were impurities in the moulding sand; small particles, especially in the sharp points of the characters, came loose when the wood-block models were withdrawn. Occasionally these particles remained in the sand mould and caused holes in the cast, so that one character, though made from the same model, would look differently in different casts. All these imperfections caused Gutenberg considerable dissatisfaction.

An examination of numerous fragments of printing, probably executed at Mainz, which have come down to us, shows a continuous improvement in technique and gives evidence of Gutenberg's endeavors to perfect the process of casting. The earliest extant specimen of Gutenberg's printing, according to prevailing opinion, is the so-called "Fragment of the World Judgment," or rather a fragment of the "Book of the Sibyls," printed probably in 1444 or 1445. It shows Gutenberg's improvement in the casting technique. The fragments of editions of the Donatus and especially the Astronomical Calendar for 1448, printed in 1447, prove that Gutenberg gradually overcame the difficulties which he had encountered.

How must we conceive these technical improvements which made Gutenberg the inventor of the art of printing? Without changing the method of casting, Gutenberg could not have overcome the deficiencies already described which are characteristic of the process of casting in sand. It must have been his aim not only to produce a type which would be always more or less the same, and showed no variance

from the original wooden model, but also to devise a method which expedited the process of founding and simplified the finishing of the cast types before their use in printing. There was no possibility of reducing the time which the fabrication of a new sand mould necessarily required, since a new one was needed whenever type had to be cast. If this method had been continued, Gutenberg would never have succeeded in working out his plan of using individual cast types for printing extensive texts. His ambition, therefore, must have been to find a method which provided a less perishable casting mould. This he found when he developed the metal mould. Moulds of that kind could not be made by the mere process of founding, as Gutenberg's first experiments taught him; however, by using a comparatively harder pattern and by driving it well into the metal that was to form the type, a more durable mould could be produced. The types which heretofore had been cast in lead by the sand mould method could not be used as patterns. If, however, the soft lead used for type was selected as metal for the mould, a type pattern could be founded in a harder metal. While using the sand-mould process, Gutenberg proceeded to reproduce the wooden patterns heretofore used, introducing a sand core into the mould, so that the head of the type (or "face") became about four millimeters in height. The metal used for the type pattern was brass, or bronze which was still harder. The resistance of these metals had been demonstrated by the bookbinder's punches, the use of which for stamping leather bindings was undoubtedly well known to Gutenberg. The metal type heads thus produced, however, were not used for the actual printing, but for making a more durable and less perishable casting form, the matrix, which

could be used repeatedly for casting. In this process culminated the development from the sand mould which could be used for one casting only, to the permanent solid casting mould which is the characteristic feature of Gutenberg's invention of typefounding. (Plate VII.) A prerequisite of the sand-mould process had been that the wooden model for the types had to be cut very precisely in regard to size, alignment, design, height, and width, so as to avoid time-consuming adjustments. The permanent casting mould which embraced the type face only did not provide for all this so that an instrument had to be devised to accomplish justification and, at the same time, to bring each character on its own body. This was achieved by the casting square, about three centimeters high, made of brass or iron. The shorter sides of this instrument limited the greatest dimension of the type face, the "size" or "body." By adjusting the two pieces of the square, according to the width of the letter to be cast, an open space was created which determined the size of the type not only pointwise but also setwise. A spring held together the two parts of this very primitive casting form and prevented its spreading apart under the pressure which was caused by the influx of the heavy molten metal.

Let us next consider the preparation of the permanent casting form, the matrix. By means of small frames or boxes, lead was cast in blocks, which were then polished on one side. The patrix (or type head) was then placed on this surface and driven in with the mallet until the base of the typeface touched the polished surface of the lead. The forcing aside of the metal made the surface of the lead block rather uneven, so that the latter had to be levelled once more. Then the matrix was ready for casting. To avoid adhesion

between type and matrix, which were of the same metal, some powder (pulverized red chalk or soot) was sprinkled on the contact surfaces, just as in sand casting. The two sides of the casting square held together by the spring were placed on top of the matrix. A mark on the latter made possible accurate positioning of all characters on the body, to make for even alignment. The opening between the two

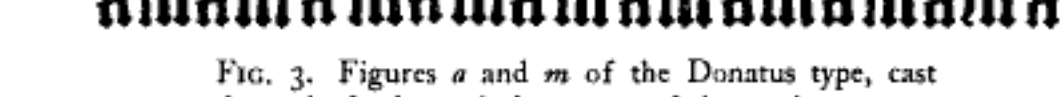

FIG. 3. Figures *a* and *m* of the Donatus type, cast from the lead matrix by means of the casting square.

parts of the casting square and the depression in the matrix determined the contour of the character cast when the molten metal was poured in. Slight irregularities in the face of the matrix would produce sharp burrs on the letters. All that remained to be done was to bring the character that had been cast on its own body in one operation, to a height uniform with all the other types. This was probably done by filing.

The task of bringing the types to a uniform height proved very difficult. With the types cast in sand moulds, the wood-block pattern guaranteed a uniform height for all the letters, since it was easy enough to level accurately the wood block on which the patterns had been cut. From the moment, however, that every individual type, which had been founded from the lead matrix by means of the casting square, differed in height from other types and had to be brought down to uniform height in order to provide a perfectly even printing surface, inefficient methods failed. The slightest variation in the height of the individual types, sometimes only a fraction of a millimeter, caused a heavier impression where one type was too high, accompanied by

a light or imperfect impression of the adjoining types, or even a blank where they were much too low. This was especially conspicuous when the types were joined together. In much early printing, such an imperfect impression has been attributed to the occasional giving out of the press. This, however, cannot always have been the cause, since in some specimens the connection of the individual letters necessary to the production of a harmonious type page was done by hand. This would not have been done with a misprint due to faulty impression; for the cost of another impression would have been inconsiderable compared with the cumbersome and time-consuming retouching by hand. Heavier inking could not fully make up for differences in the height of the types. This difficulty was obviated only after a method had been invented which ensured a uniform height for all the types cast. Where we still find this defect in later printing, it must be attributed to error on the part of the typefounder, a thing that occasionally happens even today, when the most perfect milling machines are being used.

It is difficult to determine whether Gutenberg's earliest printing types were provided during process of founding, with the nicks which are needed by the compositor for convenience in type-setting. The process of casting in sand the complete types made it impossible to provide them with a nick, for the pattern could not then have been withdrawn from the sand mould. Nor do I believe that the casting square used with the lead matrix was provided with nicks. There is no nick on the oldest type mould which has come down to us—a mould undoubtedly dating back to the beginning of the sixteenth century, and now in possession of the oldest Dutch typefoundry, owned by Johann Enschedé

en Zonen in Haarlem (Plate VIII). Neither of the devices mentioned being equipped with a nick, we come to the conclusion that this was added in a separate operation after the casting was completed.

While reviewing the development of Gutenberg's early casting technique—illustrated step by step in Plate VII—we begin to understand the early reports, according to which printing with movable individual metal types had its origin in wood-block printing. Also the information which we owe to the architect Daniel Specklin of Strasbourg—whose testimony, it is true, cannot always be relied upon—as well as the later reports by Nikolaus Serrarius, the chronicler of Mainz, the "Discourse on the Origin of Printing" by Johann Friedrich Faust of Aschaffenburg, the notes by Paulus Pater and Bodmann—all find now, at least in part, their justification. Daniel Specklin says: "I have threaded one by one on a string line." All the witnesses mentioned had seen wood-block patterns (Holzmodelle) for brass punches founded in sand moulds. These wooden patterns were considered to be the oldest forms of Gutenberg's printing types, even by the professional printers of those days, since even they knew nothing about the original technique of typefounding. The holes in the wooden types which led to the myth that the lines of type had to be threaded on a string or wire for support, can be explained easily enough by the way in which the wood-block patterns were hung up while not in use, so as to dry in the shortest time possible.

The further development from the casting square to the casting mould was accomplished by Gutenberg before he began printing his 42-line Bible. It was his aim to increase the rapidity of casting as well as the accuracy of alignment

and setwise adjustment. The first requirement was to perfect the casting mould so that it could be better operated by hand. This was accomplished by covering the casting square with wood and by attaching a device, probably a "spring," on the under-side which pressed the matrix up against the two members of the casting square. A movable bar on the long side of the casting square guaranteed the positioning of the characters on an even line, while two additional bars regulated the width of the types. The oldest casting mould which has been preserved (now in the possession of the Enschedé Foundry) shows only the second kind of justifier. The main adjustments of alignment and width were provided for in making the matrix, and the mould admitted of minor adjustments only. This can be observed in ancient matrices, which are adjusted in part for alignment and type width. An inscription by Egenolff on a case which contains the original punches already mentioned (Plate X) demonstrates this. Furthermore, it had been noticed that a longer jet, on account of the weight of the metal, brought out much better the fine lines of the design. The face became clearer. This hand-casting mould (Plate VIII) and its improved form (Plate IX) helped greatly to accelerate the founding process, especially since the matrix stood up for a considerable number of casts. It was still made of lead, but could easily be replaced when worn. Often 500 or more casts from the same matrix showed not the slightest change in the type face. This can be seen from the reproduction (Figure 4) of part of the first page of the second volume of the 42-line Bible set with types cast at the Stempel foundry by this very method.

From the fragments which have survived, we may assume that up until 1450 Gutenberg's activity was limited to the

production of brief texts. He may have had far-reaching plans which he hoped to carry out with more perfect technique; plans which he made for the printing of larger works, the expense of producing which, however, far exceeded the comparatively slender means at his disposal. The first of these was the Bible, of which he printed two editions, designated according to the number of lines per column, as the 36-line and the 42-line Bibles. It might be supposed that the first named is the earlier, judging from the fact that the Donatus and Calendar type provided a considerable number of punches and matrices ready for use, and that the more plausible development in technique would have been a progression from the founding of larger bodies to casting of smaller ones. However, careful comparisons show that, except for the first page, the 36-line Bible is a reproduction of the 42-line book. Once Gutenberg undertook to print such a voluminous work (Plate XI), an entirely new outfit was required. The types had to be cast in considerably larger quantities. To facilitate quick printing, the number of the presses at work had to be increased. In addition, there was the expense for training assistants (founders, compositors, and pressmen), since the former personnel had been small. The cost of all this required more capital than Gutenberg had at his command, so that he was obliged to seek a money-lender to make possible the printing of the Bible. A Mainz citizen, Johann Fust, was willing to assist him. Fust was well informed as to the practicability of the undertaking, since Gutenberg's previous printing was at hand. So Fust, about 1450, advanced to Gutenberg the sum of 800 florins so that the latter should "do the work" for his own benefit. Even the 800 florins proved insufficient, probably because Guten-

berg realized that by using the larger Donatus and Calendar type the work would exceed all reasonable proportions. So he was forced to use a smaller type, and Fust advanced a

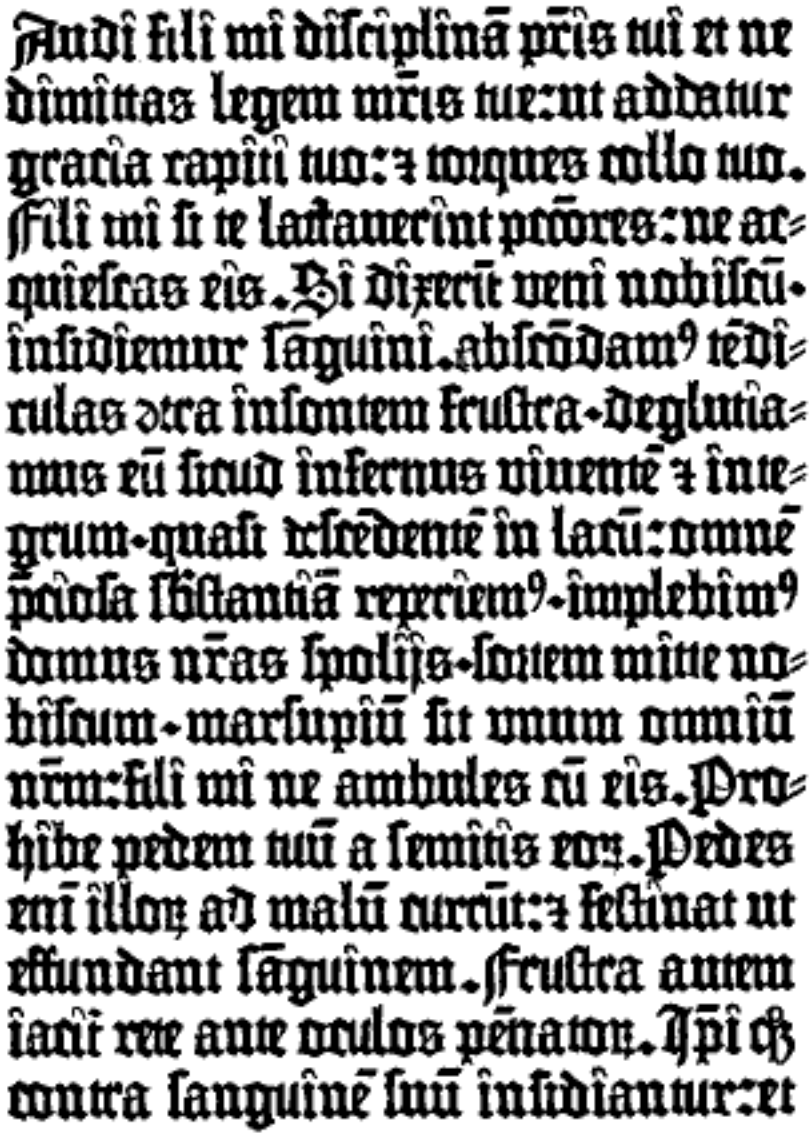
Audi fili mi disciplinā pris tui et ne
dimittas legem mris tue: ut addatur
gracia capiti tuo: z torques collo tuo.
Fili mi si te lactauerint pcores: ne ac-
quiescas eis. Si dixerit veni nobiscū.
insidiemur sāguini. abscōdam⁹ tēdi-
culas oīa insontem frustra. deglutia-
mus eū sicud infernus viuentē z inte-
grum. quasi descendentē in lacū: omnē
pciosa substantiā reperiem⁹. implebim⁹
domus nras spoliis. sortem mitte no-
biscum. marsupiū sit unum ommiū
nrm: fili mi ne ambules cū eis. Pro-
hibe pedem tuū a semitis eor. Pedes
enī illor ad malū curūt: z festinat ut
effundant sāguinem. Frustra autem
iacit rete ante oculos pēnator. Ipi ēt
contra sanguinē suū insidiantur: et

Fig. 4. Part of the first page of the second volume of the 42-line Bible. Reset by the Stempel Foundry, Frankfurt a. M.

second 800 florins, but arranged to participate in the profits which were to be reaped from the sale of the Bible.

The fact that the type size had been changed is proved by a closer examination of the 42-line Bible, for which the types appear to have been founded in great haste, probably in order to make up for lost time. Evidently the short letters

(these form the basis of alignment) and the types with descenders (which latter reach exactly to the lower edge of the bodies) were cast first. By mistake, however, the type-body selected was too small in size, smaller than the body height of the pattern which had been cut in wood. This mistake was not noticed until the ascending letters came to be cast. When finished, therefore, these ascenders overhung the body and were more or less damaged, when the types were filed down without proper care after casting.

Wherever in the type page overhanging but undamaged ascenders came in contact with descenders, they interfered, and a justification of the lines was utterly impossible. In an attempt to achieve this, the first 40-line pages set up in type were "leaded" by two strips of paper. This procedure, of course, was only an emergency measure, and had to be avoided in the future. Since by this time, however, it was impossible to change the type body for a larger one, a partial re-cutting of the overhanging characters was decided upon. In the meantime, an attempt was made, on one page, to get along with one paper "lead" only, which brought the number of lines in a column to 41. Since the casting of types with the re-cut ascenders was undertaken immediately, these could readily be exchanged for the old ones. This exchange, however, was not made consistently, for in the printed Bible which, after removal of the paper "leads" had 42 lines to the column, quite a few filed-down ascenders can be distinguished.

The printing quality of the types permits us to form an opinion as to the composition of the type metal used. Enschedé has called attention to the sharp edges in the impression made by the individual types of the 42-line Bible and their rapid disappearance during progress of the work

(the reader may refer to the discussion on page 106 *et seq.* of the technique of reproducing wood-cuts by the metal process) and concluded that the type metal must have been fairly soft. This conclusion is proven to be correct because of the necessity of rubbing the types after casting, for in the process of rubbing, a small burr was created on some letters. This tapered upwards and showed in printing as a fine line, the so-called "feather." It was repeatedly interpreted as a worked-up space. However, it was merely a characteristic of the lead used for casting, possibly without any alloy. It was so soft that it did not wear off, but was pressed into a raised ridge.

In addition to this, a few words must be added as to the depth of the type face. I mentioned before that the wooden model used as pattern in casting was cut about three millimeters deep, and that the punch cast from it was driven into the small lead plate down to the base of the type face. During the subsequent adjustment of the matrices, the depth of the face was slightly diminished, and we shall not be far wrong in assuming the depth to have been two to three millimeters. Experiments which I have made to determine the depth of the face in the matrix, proved that the color of the type face depended to a large extent on the depth of the matrix. The deeper the matrix, the thinner the face of the cast type. This was due to the behavior of the molten type metal which, on being poured into deeper cavities, did not fill completely the bottom of the matrix, in other words the face of the type. The face then becomes more or less attenuated, and can—in cases where for the same type several matrices with varying depths of face have been used—lead

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Illustration opposite: Fig. 5. A page from Schoeffer's Missal. Set in types cast from lead matrices by the Stempel Foundry, Frankfurt a. M.

et calicem ✠ salutis ꝑpetue-Hic eri=
gat manus supra calicem Supra
que ꝑpito ac sereno vultu relpicere
digneris-et accepta habere-sicuti ac=
cepta habere dignatꝰ es munera pu=
eri tui iusti abel et sacrificium patri=
arche nostri abrahe-et qđ tibi obtulit
summus sacerdos tuus melchisedech-
sanctum sacrificium immaculatam
hostiam, Hic inclinet se transpositis
manibus, Supplices te rogamus
omnipotens deus: iube hec perferri pr
manus sancti angeli tui in sublime
altare tuū ante conspectū diuine ma=
iestatis tue, Hic erigat se et osculetur
altare. Ut quotqt ex hac altaris
✠ participatione sacrosanctū filij tui

to the belief that different punches have been employed. The shallower the matrix, the more rapidly the metal flows over the whole surface of the type face. The matrix, however, must not be too shallow, since that would leave the kerns too weak and would cause them to break off easily. I am inclined to believe—and the earliest examples of printing prove this—that neither Gutenberg nor his followers had precision instruments, such as our adjusting needle, to help them cut their patterns to uniform depth. On the contrary, I believe that the depth of the type face of the individual letters differed. Thus, whenever the type-face of a matrix founded with overhanging kerns was cut somewhat deeper, the letter next to it—if cast from a shallower matrix—had to undergo special after-treatment and shaping to prevent the kerns from breaking off. Later the letters with much free space above or below the line, called "shoulder," or, to use the original term, "spectacles" (Brillen), were filed off or hammered to prevent the shoulders from appearing in print. This explains the peculiar shape which some letters occasionally present, such as we find in Madden's "Lettres d'un Bibliographe."

About the time when Gutenberg split with Fust, the art of typefounding underwent a considerable improvement. The 42-line Bible type presents about the extreme limit for a method by which the sand-cast punch can be hammered into the lead plate without the aim being missed. With punches of a still smaller size produced by the same process, the worker could not help missing his aim repeatedly, before he succeeded in driving a smaller type punch into the lead. If it was done unevenly the height of the finished type would vary. In addition, the deficiencies of the process of sand casting were more conspicuous in smaller types

and with it the abolition of all but the indispensable ligatures. All type fonts produced by the sand-casting process had followed as closely as possible the practice of the scribes as to ligatures, contractions, and "tied letters." With the breaking up of combination types and the elimination of special characters, there was effected a distinct simplification in the technique of type-setting.

It is peculiar that the new method of punch-cutting by hand was at first used exclusively for types used in printing the letters of indulgence. However, a comparison of the different letters of indulgence, which were printed in large editions, will make clear this situation. On May 2, 1452, the Papal legate, Nicholas de Cusa, authorized the prior of St. Jacob's Monastery in Mainz, whose relation to the art of printing in its early days has not yet been clearly established, to distribute before the end of the month two thousand letters of indulgence, similar to those which had been distributed in Mainz, among the citizens of Frankfurt. According to a further report, Bartholomew's Church in Frankfurt a. M. was, on March 22, 1488, given an indulgence which was valid until March 30, 1488. This indulgence was extended for seven more days, and 2,400 letters of indulgence were issued. The short period of validity of the indulgence itself, as well as the great number of letters which had to be distributed, made a hand-written form of reproduction out of the question, and the infant art of printing with movable types was called upon, in order that the edition might be ready in time. Larger editions, like the Cyprian indulgence, were not restricted to one printing office only. The setting up of the 30-line letter of indulgence, the types of which as stated above I personally attribute to Gutenberg, took place in 1454, at the time

when Gutenberg and Fust parted. The break between the two men prevented Gutenberg from making full use of the types cast for that purpose. During that very year, however, Gutenberg opened a new printing office with the equipment for printing the 36-line Bible, which had remained in his possession. He immediately undertook the printing of the letter of indulgence, the types of which, by that time, showed decided improvement.

While the punches of the 30-line type show all sorts of fanciful design especially in the capital letters, the punch-cutter of the 31-line type, owing to the harder and to him unfamiliar material, had to avoid all unnecessary features. This, it is true, made his work easier, but it also reduced the design of the letters to essential simplicity. It must remain undecided whether the material used was bronze or steel, the method of tooling with the graver being about the same for both. For the time being, the metal for the matrices, which was refined lead, remained the same, though soon after it was replaced by copper or brass which had much greater strength. The following small specimens may illustrate this transition:

U30

Domini

FIG. 7. Engraved brass punches, lead-matrices, founded in a hand-casting mould.

V31

Domini

FIG. 8. Engraved steel punches, copper matrices, founded in a hand-casting mould.

We have thus become acquainted with the two methods (casting punches in sand and engraving punches) which characterize Gutenberg as the inventor of printing from movable types—the inventor of letterpress printing. For quite a long period both methods were practised side by side, and only with the advent of the seventeenth century

shown in the re-setting of a page from Schoeffer's Missal (Figure 5) is an example on a large scale of the application of the process evolved by Gutenberg, and undoubtedly was worked out by the master printer himself. At any rate, the designs for the wonderful initials were the work of Gutenberg's master hand, though Schoeffer later called them his own. It was owing to the prestige they gave him, and to the knowledge of typefounding and printing he had acquired from Gutenberg, that caused Fust to take Schoeffer into partnership.

As far as I have been able to ascertain, the technique of sand casting was used not only for the reproduction of wood blocks and initials, but also for the purpose of founding words composed of several types or even of shorter texts —the latter especially for explanations and place names on maps, such as Münster's "Cosmographia" or Apian's "Bavarian Maps." The initials and punches cast from a sand mould in an alloy of copper and zinc, or in brass, are frequently met with in inventories of old printing shops under the designation of "capitals cast in sand," or the heading "brass on lead," or merely as punches proper. This can be seen from the punches for the "Cölnisch Current-Fraktur," attributed to Christian Egenolff, which are still extant. The engraved steel punch and the copper or brass matrix came in vogue soon thereafter, and took the place of the engraved brass punch with a lead matrix, so far as the smaller type-sizes up to the two-line English were concerned. Lead matrices were chiefly used in typefoundries up until the end of the eighteenth century for types in the large sizes, a practice deserving of special consideration in relation to work of the best-known punch-cutters and typefounders.

In the past it has often been claimed that Gutenberg's

influence on the invention of printing was overestimated; that this art owed its development to the conditions existing at the time, and that sooner or later some one would have discovered it. The facts we have deduced, however, show that Gutenberg alone—building, it is true, on an already existent and related technique—made possible the reproduction of the written word by the difficult metal-casting process. While others continued to use the sand-casting method, Gutenberg brought his process to a perfection which has made possible the high standards of the printing art today. On the consequences of his invention is based the preponderance of western civilization. To his energy and perseverance, to his tenacious pursuit of the aim which he set for himself in Strasbourg in 1436, the world owes one of the finest creations of human ingenuity. As long as printed books exist they will ever bear vivid testimony for Johannes Gutenberg of Mainz and his discovery of the art of printing with separate types cast from moulds of permanent character.