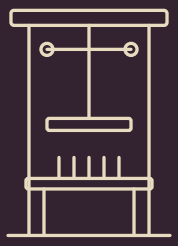
Industries of India

THE PRINTING PRESS

A Machine for Multiplying Thought



Ketineni Ramarao



The press and the multiplied word: loose type rising from the forme as birds over a European river town. AI-generated illustration in the engraver's manner; no real person is depicted.

The Printing Press

A Machine for Multiplying Thought — from the Diamond Sutra to the digital press

KETINENI RAMARAO

INDUSTRIES OF INDIA · A RESEARCH EFFORT TO MAP ALL INDUSTRIES,
APPROACHED THROUGH STUDY AND THEORY

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PROLOGUE

The Cheapest Miracle

Hold a printed page up to the light. It weighs almost nothing. The paper is wood, water and energy pressed into a skin a tenth of a millimetre thick; the words are a film of ink so thin that a single kilogram of it can carry more than a hundred million letters. Everything about the object is unremarkable, and that is the remark. This page is the cheapest miracle in the material world.

Consider what the page had to defeat. For most of human history, copying a book meant copying it by hand: a scribe, a desk, months of labour, and a finished object that contained, inevitably, the scribe's mistakes along with the author's words. A Bible was a small library of labour. In the fifteenth century a single hand-copied Bible might cost a clerk's wages for three years; the book you are reading now, for all its length, can be manufactured for less than the price of the meal you had yesterday. Between those two facts lies one machine.

Industries of India studies industries by studying their items: not the company, not the brand, but the thing itself and the world built around it. The item of this book is the printing press, and it resists a casual definition. The printing press is not merely a device that presses. It is a manufacturing system for identical meaning: a way of fixing language, image and number into a material form that can be repeated without loss, at a cost that falls every century. The screw and the platen, the metal letter and the oil-thick ink, the steam cylinder, the rubber blanket, the laser and the inkjet nozzle: each is a generation of the same idea, and each generation multiplied what the last could do.

Most inventions change what people can make. A few change what people can know. The printing press did both, and in that order: it was a way of making things, and the things it made altered the thinking of everyone who touched them. The Reformation, modern science, the newspaper, universal schooling, the novel, the ballot, the catalogue, the paper money of states and the labels on the food in your kitchen all stand downstream of the press. If sugar is an industry of appetite and copper an industry of conduction, the printing press is an industry of memory and address: it lets a thought made once be delivered everywhere, unchanged, to people the thinker will never meet.

This book follows the item the way the item actually travelled. It begins before the press existed, with the surfaces and inks and block-cut pages of Asia, because the press arrived into a world that had been printing for seven hundred years. It goes to Mainz, where a goldsmith assembled four borrowed things into one new thing. It walks with the printers who carried his system across Europe, and it sits in the workshops where the wooden press became iron, the iron press took steam, the steam press became a rotating river of paper, and the river of paper learned to be written by light. It ends, as every study of a living item must, with the press as it is now: a global industry measured in hundreds of billions of dollars, mostly invisible, printing fewer words for reading and more for everything else, and with the strange electronic child the press itself created.

A note on method. The item comes first, and the item is global. India appears in this story, as it does in every story about paper and print, but it is not forced to the front of it; the country's own press history will take its turn once the item stands established. Where this book gives a number, the number has a source, and the sources live in their own companion volume, tagged to the chapters and claims they support. Forecasts are labelled as forecasts. Where the historical record is a lawsuit, a patent, a surviving machine or a counted edition, this book says so, because the record itself is often the most interesting part of the story.

One more observation before the story starts, because it frames everything after it. The press did not begin as a machine for books. It began as a machine for copies, and its first customers were not readers in the modern sense at all. The miracle was never the page. It was always the second page, and the ten-thousandth, and the fact that they are the same.

How this book itself was made

It is a convention of the craft that a book about printing should account for its own making, and this one will not break it. The text you are reading was composed as structured digital type, the direct descendant of the hot-metal page, rendered to a designed electronic document, and delivered to you through the very network that Part VII of this book describes. No lead was melted, no sheets were folded, no press ran; yet the chain of the craft is intact, because the type on these pages descends from the punchcutter's steel, the page's proportions from the golden formats of the hand-press book, and the portable file format that carries it from the PostScript language that first let a computer describe a page. Wherever you are reading this, on paper printed on demand or on a screen, the object is the press's child.

The illustrations in this book are engraved-style images created with generative tools, a technology that sits, historically speaking, on the far side of phototypesetting, and they are labelled here, once, as AI-generated illustrations, in keeping with the series' rule of honest provenance. No real person's face has been synthesised or altered for this book. The historical figures who walk its pages, Gutenberg, Senefelder, Mergenthaler, Carlson, are drawn from documents, and where the documents are silent, the text says so.

The lens

A word on the series perspective, since this book is written in it. Industries of India practises material thinking: look at the glass and ask who manufactured it, through what steps, at what cost. Applied to the printing press, the lens is unusually apt, because the press is where material and meaning most completely merge. Every abstraction in this story, an idea, a religion, a science, a newspaper's public, had a material carrier with a supply chain and a price, and the carrier's economics quietly governed what could be thought and said. Keep that lens on as you read, and the familiar names in the story change shape: the Reformation becomes a story about pamphlet unit costs, the scientific revolution about fixity and citation, the newspaper about paper mills and the price of a penny. None of that diminishes the ideas. It is how ideas become history.

PART I

Impressions Before the Press

Paper, blocks and movable letters: seven centuries of printing before the press.

PART I · IMPRESSIONS BEFORE THE PRESS

1 · Clay, Silk and Mulberry Bark

Every printing technology is, before anything else, an argument with its surface. The press that eventually appeared in Mainz was shaped at every point by the material it printed on: thin, cheap, flexible, absorbent paper. To understand why the press rose when and where it did, begin with the long argument over what words should rest on.

The weight of keeping words

Civilisation's first writing surfaces were the surfaces at hand, and each one rationed writing. Clay tablets in Mesopotamia were free and nearly indestructible, but a library of them was a building of brick-sized paragraphs, and nothing about clay travelled well. The Egyptians' papyrus was light and rollable, but it grew in one river delta and frayed where it was folded. Parchment, made from the scraped and stretched skins of calves, sheep and goats, was durable, beautiful and murderously expensive: a large Bible required the skins of an entire herd, some two hundred animals or more. In every case the surface taxed the text. Words were worth keeping only in proportion to what keeping them cost.

China's answer arrived, by tradition, in the year 105 CE, when the court eunuch Cai Lun reported to the Emperor a process for making a writing material from mulberry bark, hemp waste, rags and fish nets, pulped, suspended in water, and lifted out on a screen to dry. The archaeology has since pushed the date earlier, and scraps of true paper survive from the second century BCE, but the tradition points at the right idea: paper is not a found thing, it is a manufactured one. Felted fibres, beaten apart in water and re-formed into a sheet. Any cellulose would do. That indifference to raw material is paper's whole character, and it is why, of all writing surfaces, only paper could become cheap.

It also had the right physics for what came later. A paper sheet takes an impression. It is thin enough to flex against an inked surface, porous enough to drink ink in a fraction of a second, smooth enough to hold a fine line, and strong enough, when the fibres are long and well-beaten, to be handled for a thousand years. Museum collections still hold Chinese papers from the first millennium that remain flexible and legible, which is more than can be said for most digital files from the 1990s.

The slow road west

Papermaking stayed inside China for five centuries, a guarded imperial craft, and then walked west along the trade roads. The standard account gives its escape a date and a battle: 751 CE, Talas, near Samarkand, where the armies of the Abbasid Caliphate defeated a Tang force and, the story runs, captured papermakers among the prisoners. Samarkand became a paper city; Baghdad opened its first paper mill around 794; the craft

moved through Cairo and Fez and crossed into Europe through Islamic Spain and Italy. By the 1150s there was a paper mill at Xàtiva in al-Andalus, and by 1276 the Italian town of Fabriano was making rag paper of a quality Europe had never seen, sizing it with gelatin and marking sheets with the first watermarks, the faint wire designs that still let bibliographers date and place old paper.

European paper was rag paper, and its raw material was exactly what the name says: old linen and hemp cloth, collected, rotted, beaten to pulp in water-powered stamping mills. The supply of rags set a hard ceiling on the supply of paper, and through it on the supply of everything paper could carry. That ceiling matters to this book, because when the printing press arrived in the 1450s it collided with the rag ceiling almost immediately, and the collision shaped the paper trade for four hundred years.

Why the surface came first

It is worth pausing on the sequence, because it is the reverse of the usual telling. Printing did not create a need for paper; paper created the possibility of printing. A block-printed page or a pressed type page is a negotiation between three things: a raised image, an ink, and a surface that will take both. China had all three early because it had paper early. Europe had expensive skins and cheap rags, and its printing had to wait for the cheap surface to arrive from the East, a journey of more than a thousand years from Cai Lun's vats to the mills of the Rhine.

The same sequence repeats inside every later generation of the industry. When steam-driven presses arrived in the nineteenth century, they were starved of paper until the Fourdrinier machine made paper in an endless web, and then starved again until wood pulp replaced rags. When digital presses arrived in the 1990s, they demanded papers engineered for toner and liquid ink rather than for oil-based letterpress. The surface has always led. The press follows the sheet, and the sheet follows the fibre, and the fibre follows whatever a civilisation has too much of: mulberry bark, fishing nets, old shirts, spruce forests.

There is a materialist lesson here that runs through this whole book. The industries that look like industries of ideas turn out to be industries of stuff. The history of knowledge is written in rag prices, timber quotas, lampblack, linseed oil, lead and rubber. The press multiplied thought, but it did it with a supply chain, and the supply chain kept score.

Workshop: a sheet of rag paper, by hand

The European hand paper mill of Gutenberg's century was a water-powered factory in miniature, and its product deserves a walk-through. Rags, linen and hemp, were sorted, washed, and left to ferment in heaps for weeks, a controlled rotting that broke the fibres' bonds. The retted rags went to the stamping mill: a wooden trough where water-driven trip-hammers, great wooden pestles shod with iron, beat the rags for hours into a pulp of separated cellulose fibres. The pulp floated in a vat of water; the vatman dipped a mould, a wooden frame strung with a screen of laid wires and crossed chain lines, shook it with a practised rocking motion to

felt the fibres in both directions, and let the water drain through the wire. The wet sheet was couched, flipped onto a felt, stacked sheet and felt alternately, and pressed in a screw press to squeeze out the water, the very press technology that printing would borrow. The sheets were parted, hung to dry in the loft, dipped in gelatin size to make them resist ink, pressed again, and burnished. A skilled vatman made three or four thousand sheets a day; every sheet carried, in its wire shadows, the laid and chain lines by which bibliographers still read its birth.

The watermark and the detective work of paper

Sewn into the mould's wire was a small bent-wire design, the watermark: a bull's head, a crown, a letter, a bunch of grapes. It printed itself into the sheet as a thinning of the fibre, visible against the light. Watermarks began in thirteenth-century Fabriano and spread everywhere, and they became, centuries later, a forensic instrument: because every mill's mark was distinct and every mould wore out in a year or two, the marks in a book's paper let scholars date and place its making, expose forgeries, and map trade routes of the paper itself. The Gutenberg Bible has been re-dated by its watermarks; so have Rembrandt's prints. The paper remembers its own manufacture, and the study of paper, filigranology, is one of the stranger scholarly crafts the press called into being.

Paper and the state

Paper's quiet conquest was administrative before it was literary. Long before the press, paper had become the medium of empire: the Abbasid bureaucracy ran on it, the Mongol chanceries ran on it, and Europe's chancelleries and merchants adopted it through the fourteenth and fifteenth centuries because it was a tenth the price of parchment and infinitely more convenient. The ledger, the letter, the writ, the account book: the paper office preceded the printed book and created the habits, filing, copying, archiving, into which the press would fit. When print arrived, the state was already a paper animal, and it took to printed forms, decrees, indulgences, proclamations and, eventually, paper money with the ease of an animal given a new organ. The printed form, the blank to be filled in, is one of the press's most consequential and least celebrated products: the state made fillable.

PART I · IMPRESSIONS BEFORE THE PRESS

2 · The Block and the Diamond

Printing is seven centuries older than the printing press. Long before anyone cast a metal letter, artisans in China were doing the essential thing: cutting a page's worth of words and pictures, backwards, into a flat surface, inking it, and transferring it to paper, over and over, as

many times as anyone wanted. The technology is called xylography, woodblock printing, and its masterpiece is the oldest dated printed book in the world.



A woodblock printing workshop of Tang-dynasty China: the block is inked, the sheet laid, the impression taken, as it was for seven centuries before the press.

A scroll from the desert

In 1900, a Taoist monk named Wang Yuanlu, caretaking the cave temples at Dunhuang on the edge of the Taklamakan desert, noticed a crack in the plaster of a corridor wall. Behind it lay a sealed chamber, the Library Cave, packed with tens of thousands of manuscripts and printed documents closed away around the start of the eleventh century. Among them was a printed scroll of the Diamond Sutra, a central text of Mahayana Buddhism in Kumarajiva's Chinese translation: seven sheets of paper pasted into a roll more than five metres long, opening with a frontispiece of the Buddha preaching to his disciple Subhuti, cut and printed with a fluency that speaks of a mature craft. At the scroll's end sits a dated colophon: the ninth year of the Xiantong era, 868 CE, printed for free distribution by a man named Wang Jie in honour of his parents.

The date earns the scroll its title: the world's earliest securely dated printed book. It is not the oldest printed thing; single-sheet charms and dharani prints survive from earlier in the eighth century, in both China and Korea and Japan, where the Empress Shōtoku was said to have ordered a million printed charms for

distribution in pagodas around 770. But the Diamond Sutra is a book, whole and intentional, and its quality is not the quality of an experiment. The carving is confident, the impression even, the illustration composed. Behind this scroll stands a tradition already generations old.

The logic of the block

Woodblock printing is a replicator of a particular kind: the whole page is one object. A skilled carver takes a smooth plank, pastes or brushes the text onto it in reverse, and cuts away everything that is not the writing, leaving the characters standing in relief. The block is inked with a brush, paper laid over it, and the back of the sheet rubbed with a dry pad to pull the impression. One block, cut once, can print for years; the great sutra projects ran to tens of thousands of blocks stored in libraries of their own. The Tripitaka Koreana, the complete Buddhist canon carved in thirteenth-century Korea and still preserved at Haeinsa temple, runs to more than 81,000 blocks, and the temple's storage halls were designed so air could circulate to keep the wood stable for centuries.

The economics of the block are the economics of the long run and the fixed text. The cost is all in the carving; the impressions are nearly free. For a scripture, an almanac, a primer, an official calendar, the works that an empire wants in identical copies for centuries, the block is superbly rational. Buddhist institutions understood this early, and used print the way later institutions would use every new medium: to multiply the sacred beyond the reach of any scriptorium. Printing in its first five hundred years is mostly a technology of devotion.

But the block's strength is also its limit. A block can say one thing. A new page is a new plank, a new carver, weeks of new labour, and a library of lumber to store. The entire page is locked in wood, and nothing in it can be corrected, rearranged, or reused for another text. The next invention in the story attacks exactly this limit, and it is worth naming precisely, because it is the invention the word "printing press" is usually and wrongly made to cover: not printing itself, but printing from pieces.

What the block teaches

The woodblock centuries established things the later press would inherit wholesale. They proved there was demand for multiplied texts, and built the readers to receive them. They industrialised paper: the sutra trade and the state between them consumed paper on a scale that pushed Chinese and Korean mills into true batch manufacturing. They trained generations of carvers, inkers and printers whose hands understood registration, impression and editioning. And they settled a piece of cultural grammar: that a text could be a thing with copies, that two copies in two temples were the same text, and that this sameness was a kind of power. When movable type arrived, it did not have to invent the idea of print. It had to compete with a mature industry that already embodied it, and in East Asia, for reasons the next chapter examines, it largely failed to do so.

Workshop: cutting and printing a block

The block printer's craft began with the plank: seasoned wood, pear or jujube or cherry, sawn along the grain, planed glass-smooth and oiled. The text was written by a calligrapher in reverse on thin paper, or written normally and pasted face-down so the translucent sheet showed the characters mirrored; the carver then cut away the blank ground around each stroke with gouges and knives, leaving the characters standing in relief a millimetre high. A great block for a sutra page carried several hundred characters and might take a master carver days; the block had to be cut so that centuries of printing would not flatten the finest strokes. To print, the block was brushed with water-based ink, a sheet laid over it, and the back rubbed with a padded baren or brush until the fibres picked up the ink evenly. Colour printing, perfected in Ming China and raised to an art in Japanese ukiyo-e, meant a separate block per colour and the craft of registration: small carved guides, the kento, into which each sheet's corner and edge were set, so that ten colours landed on one sheet within a hair's breadth.

The million charms

The scale the block could reach is best told through one order. Around 770 CE, the Empress Shōtoku of Japan, in thanks for the end of a rebellion, ordered the printing of Buddhist charms, the Hyakumantō Darani, to be enclosed in a million tiny wooden pagodas and distributed to the great temples. The order was executed; pagodas and printed rolls survive in their thousands today, and they are among the oldest printed objects on earth. A million impressions, from carved blocks, in eighth-century Nara: the mass production of texts is not a European fifteenth-century story at all. What Europe added, later, was not multiplication but the cheap re-programmability of the pattern.

The block's other lives

The block was never only sacred. It printed paper money in China from the Song dynasty, the first government-printed currency in the world, with all its consequences, including the first printed inflation. It printed playing cards, which rode the trade routes west and carried the idea of the printed image to every social level; the playing card may be the most widely handled printed object of the pre-press world. It printed New Year pictures, devotional images, examination primers, and official proclamations. In Europe, block books like the Biblia pauperum, picture Bibles cut whole into wood, were produced well into the age of movable type, proof that the old technology served the poor market the new one could not yet reach cheaply. And in Japan the block never died: ukiyo-e, the "pictures of the floating world" of Hokusai and Hiroshige, carried woodblock printing to its aesthetic summit in the eighteenth and nineteenth centuries, with editions printed in the thousands for a mass urban public. The Great Wave is a print run.

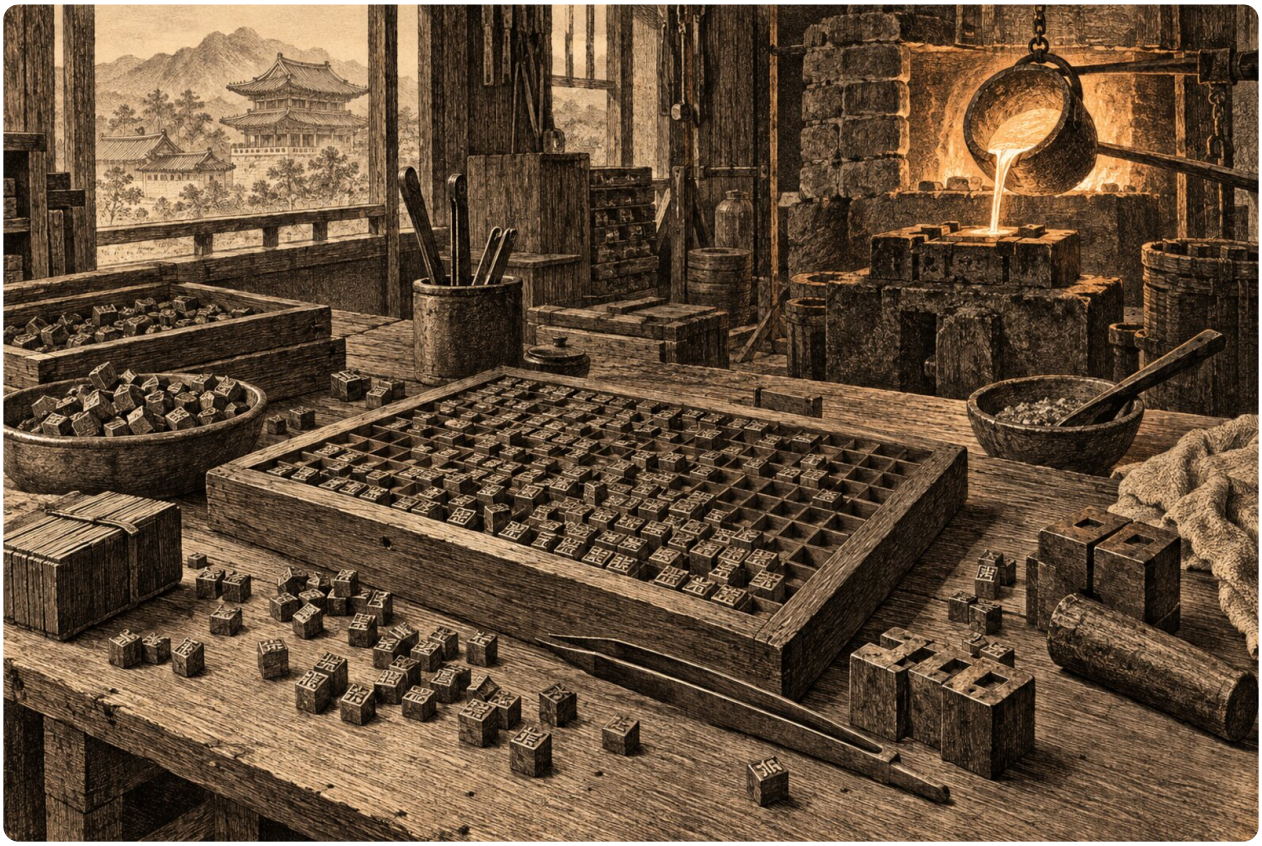
The colophon

The Diamond Sutra's last lines are a colophon, and it is the most human sentence in the whole history of printing: 'On the fifteenth day of the fourth moon of the ninth year of the Xiantong reign, Wang Jie reverently made this for universal free distribution, on behalf of his two parents.' The eleventh of May, 868: a named man, a named day, a named purpose, and a print run whose whole point was that it could be large. The work is not a poor copy of a manuscript but a confident industrial object, its frontispiece of the Buddha preaching to Subhuti cut with a sophistication that speaks of generations of practice behind it. The scroll rested in the sealed cave at Dunhuang for nearly a thousand years until Wang Yuanlu found it in 1900, and in 1907 the explorer Aurel Stein carried it, with thousands of other manuscripts, to London, where it sits in the British Library today, the oldest dated printed book on earth, made not to be rare but to be multiplied.

PART I · IMPRESSIONS BEFORE THE PRESS

3 · Letters of Clay and Bronze

The idea of movable type, print assembled from individual reusable characters, was invented in China around 1040, four centuries before Gutenberg, by a man we know only through one admiring paragraph. That it did not then conquer the world is not a story of failure. It is a story about what writing systems demand of machines.



Bronze movable type set in a wax tray, Goryeo Korea: the Jikji of 1377, printed from such type, is the oldest surviving metal-type book.

A commoner named Bi Sheng

Nearly everything known about the first movable type comes from the Dream Pool Essays, the notebook of the Song-dynasty polymath Shen Kuo, written around 1088. Shen Kuo records that during the Qingli reign period, in the 1040s, a commoner named Bi Sheng made type from fired clay: characters carved in relief on small blocks of sticky clay, baked hard like pottery. To compose a page, the printer took an iron plate coated with a cement of pine resin, wax and paper ash, set an iron frame on it, packed the clay types into the frame until it was full, warmed the plate to soften the cement, pressed the types flat with a board, and printed. To break up the page, he reheated the plate and the types came free, each sorted back into its compartment by rhyme. For a few copies, Shen Kuo notes, the method was no easier than the block; for hundreds or thousands, it was wonderfully fast. He adds the small human detail that when Bi Sheng died, his fonts of type passed to Shen Kuo's own cousins, who kept them as treasures.

The account is technical, complete and modern in its instincts: it describes the material, the fixturing, the registration and the storage system, the whole loop of composing, printing and distribution that every later type technology would re-enact. Wooden type followed; the Yuan-dynasty official Wang Zhen, in his 1313 agricultural treatise, described rotary type cases holding tens of thousands of carved wooden sorts and gave the craft a full manual. In Korea, the technology took its decisive step: by the early thirteenth century,

printers of the Goryeo kingdom were casting type in bronze, and the foundry records and coin-casting traditions of the peninsula made metal type a state craft.

The oldest metal-type book

The proof survives in one book. In 1377, at the Heungdeoksa temple in Cheongju, Korean printers produced an anthology of Zen Buddhist teachings compiled by the monk Baegun: the Jikji. The book's own colophon gives its place and date, and the surviving copy, kept today at the Bibliothèque nationale de France, is recognised by UNESCO and the record books as the world's oldest extant book printed with movable metal type. It predates the Gutenberg Bible by seventy-eight years.

Metal type in Korea was not a curiosity. The Goryeo and then Joseon courts ran official type foundries, casting fonts by the hundreds of thousands of sorts; kings treated a new font as an act of state, and Korean printers developed the full discipline of composing, inking and pressing metal type on paper. When European observers finally catalogued this history, the uncomfortable fact was unavoidable: every element of "Gutenberg's invention" existed in East Asia generations before Gutenberg.

The alphabet's arbitrage

Why, then, did the technology flower in Europe and not where it began? The answer is not talent or curiosity; it is arithmetic. Chinese writing requires a distinct character for each word-root of the language. A working font for ordinary printing needs several thousand characters; a font for the classics needs twenty thousand or more. Wang Zhen's cases held around sixty thousand sorts. Each character is a separate object to be cut or cast, stored, found, set and put back, and the frequency distribution is brutal: the printer must keep dozens of copies of a few thousand common characters and one or two of ten thousand rare ones, all of it indexed by rhyme or radical in a warehouse of little boxes. Composing stays slow, the capital cost of a complete font is enormous, and the rival technology, the woodblock, needs no font at all: the carver simply writes and cuts whatever the text contains. In East Asia, movable type competed with a mature block industry on its least favourable ground.

The alphabet changes the arithmetic by four orders of magnitude. Latin script needs a few dozen letters; with capitals, small capitals, ligatures, figures and points, a complete font is a few hundred characters. Typesetting a page means reaching into a case of roughly a hundred boxes. A single foundry can cast type for every printer alive, because every text in Europe draws on the same tiny set. The invention did not change between Cheongju and Mainz; the writing system did. The press is an amplifier, and what it amplifies is the combinatorics of the script it serves.

There is a last irony here, and it belongs to the material thinking this series stands on. The Chinese and Korean printers invented the idea. The Europeans, by accident of having twenty-six letters instead of sixty

thousand, got the industry. Ideas travel; industries form where the materials, and the alphabet, make them cheap enough to form.

What Shen Kuo actually wrote

The Dream Pool Essays passage on Bi Sheng deserves close reading, because it is the first technical description of printing from movable type in any language and it is astonishingly complete. Shen Kuo names the material, sticky clay cut and fired; the fixturing, an iron plate spread with a resin-wax-paper-ash cement and bounded by an iron frame; the method of flattening the set types with a board so their faces stand level; the release, reheating the cement so the types drop free; and the storage, types sorted by rhyme into labelled wooden cases. He adds two details any engineer would respect. For a single copy the method is no faster than the block, he writes; its advantage begins at hundreds and thousands of copies, an early statement of setup cost versus unit cost, the founding equation of all printing. And he notes that the two plates should be worked alternately, one printing while the other is composed, so that "the speed is very great": the principle of parallel operations, pipelining, stated in the eleventh century. Shen Kuo was one of the great scientific minds of his age, and his little paragraph is the birth certificate of an industry.

The foundries of Goryeo and Joseon

Korean metal type was a state technology. The Goryeo court founded a national type foundry, the Seojeogwon, in the thirteenth century; its successor kingdom, Joseon, cast great national fonts with names and dates: the Gyemi font of 1403, said to number in the hundreds of thousands of sorts, and repeated recastings under later kings. King Sejong, the scholar-king who gave Korea its alphabet Hangul in the 1440s, presided over a court where metal-type printing was a normal instrument of rule: codes, Confucian classics, agricultural manuals, histories. The casting method used matrices pressed into sand or clay moulds from wooden master patterns, a different casting tradition from Gutenberg's punch-and-mould, but the product was the same: a durable, interchangeable bronze sort. Korean printers also solved the composition problem their way, setting types into trays with wax, and printed works of real elegance. The technology then did something historians find endlessly suggestive: it stayed. The character count, the bureaucracy of the font, the cheapness of the block, and the preferences of a scribal elite held movable type inside court and temple, and it never became the engine of a commercial book trade.

The lesson of the stalled revolution

The Asian experience corrects a lazy habit of invention history, the idea that a better tool wins by being better. Movable type was, for Chinese and Korean purposes, only sometimes better, and always more expensive to set up; the block was deeply embedded, and the script made the font a warehouse. Technology diffuses where its economics beat the incumbent's, and the incumbents differ by script, by market and by

institution. Europe's accident was a tiny alphabet inside a hungry, fragmented, competitive market of cities and churches. Asia's was a vast script inside stable courts with a superb block industry. The press's history is decided less by genius than by this kind of arithmetic.

The Korean bronze tradition

Korea did not borrow the idea of movable type; it industrialised it, and for reasons its geography explains. Goryeo and then Joseon Korea sat at the end of the paper road, with excellent paper, a state that governed through documents, and a script problem that made casting economical: Korean was written in Chinese characters then, thousands of them, but a metal type could be cast in the hundreds and reused for decades, and bronze, which the peninsula's founders had mastered for ritual vessels and coin, cast beautifully. The state ran type foundries the way other states ran mints, with named founts and royal commissions; the royal foundry cast its first great bronze fount in 1403, and its fifteenth-century successors were made in the tens of thousands of sorts. The Jikji of 1377 survives from this world, not as an isolated miracle but as one product of a mature state printing culture, and the tradition ran on, fount after fount, into the nineteenth century. East Asia had movable type printing at industrial scale when Europe was still copying by hand; what it did not have was the screw press, the oil ink and the alphabet, and on that difference the next four centuries turned.

PART II

Mainz

A goldsmith, four borrowed technologies, and the book that proved the system.

PART II · MAINZ

4 · The Goldsmith of Mainz

Johannes Gutenberg is the most consequential inventor about whom we know almost nothing. No portrait from life, no diary, no signed book, no grave that can be pointed to with confidence. The man survives mostly in court records and loan documents, which is fitting: his invention was born in the workshop economy of the fifteenth-century Rhine, where the paperwork of credit is what history keeps.

What the documents say

He was born in Mainz around 1400, son of a patrician family associated with the archbishop's mint; the family name was Gensfleisch, and "Gutenberg" came from the house they lived in, a common Rhineland naming habit. He trained, the records suggest, as a goldsmith, and the goldsmith's trades cluster behind everything he later did: cutting small hard things precisely, casting soft metals cleanly, working to tolerances no carpenter or scribe ever needed.

By 1434 he was in Strasbourg, and the Strasbourg documents give the story its texture. In 1439 a lawsuit over a venture to make polished metal pilgrimage mirrors for the Aachen pilgrimage lets us overhear him: the investors speak of a secret "art and enterprise" involving presses, of forms and stockings and four pieces held together by screws, of money spent on lead. Whether these fragments describe printing experiments or some intermediate mechanism, historians still argue; what is plain is that by 1439 Gutenberg was spending other people's money on something he refused to name, behind locked doors, with craftsmen sworn to secrecy. The mirror venture collapsed when the pilgrimage was postponed by plague. The secret work continued.

In 1448 he was back in Mainz, borrowing 150 guilders from a relative, and by 1450 he had found his great backer: Johann Fust, a wealthy Mainz moneylender, who advanced 800 guilders against the "work of the books," and later 800 more. A professional scribe named Peter Schöffer, trained in Paris, joined the shop. Through the early 1450s the workshop produced smaller jobs, indulgences, grammars, calendars, while the main work climbed toward its goal. In March 1455 a papal legate's secretary, Aeneas Silvius Piccolomini, the future Pope Pius II, wrote from Frankfurt that he had seen gatherings of a Bible of extraordinary clarity shown by a "miraculous man," and that copies were already spoken for before the work was finished.

The mirror and the letter

It is worth dwelling on the mirrors, because they show what kind of inventor Gutenberg was. The pilgrimage mirror was a badge of polished metal sold to pilgrims, who held it up to catch, as it were, the reflected virtue of a relic. Thousands could be pressed from one pattern. The business insight and the technical insight are

the same: make a pattern once, stamp out the copies, sell near the shrine where demand crowds. Gutenberg's printing is the pilgrim mirror raised to the level of language: a fixed pattern, a press, a multitude of identical impressions, and a market of the faithful. He did not set out to change the world of letters. He set out to manufacture, and the thing he found to manufacture was the book.

The shape of the legend

The caution of the sources has not stopped the legend, and the legend is instructive in itself. In it, Gutenberg is the lone inventor, struck by a single divine idea, ruined by a greedy partner, dying poor and unrecognised. Almost every part of that is wrong or unprovable. Printing existed; movable type existed; metal type existed. Fust was, by the record of the lawsuit itself, a partner in a joint venture, not a villain, and Gutenberg was not ruined: he kept property in Mainz, went on printing, and in 1465 was taken into the service of the Archbishop of Mainz with a pension of grain, wine and clothing. What Gutenberg actually did was smaller and greater than the legend: he took a handful of existing crafts and engineered them into a system that worked at industrial reliability, and then proved the system with the most ambitious book in Europe. The next chapter takes the system apart, piece by piece.

Mainz and the world of the Rhine

Gutenberg's city is not incidental to his invention. Mainz in 1450 was the seat of the greatest ecclesiastical prince of the Empire, the Archbishop-Elector of Mainz, Archchancellor of Germany, and a commercial city of perhaps twenty thousand souls on the greatest trade artery of northern Europe, the Rhine. It had a mint, a goldsmiths' guild, a market in wine and cloth, and a university founded only in 1477 but long served by monastic schools. The Rhine carried paper from the mills of the upper river, wine to the low countries, and news everywhere. An invention that needed metal, paper, capital and a Church's hunger for documents could hardly have been better placed. It is no accident that the press's first great products, the Bible and the indulgence, served precisely the markets that flowed through Mainz.

The Strasbourg secrecy

The Strasbourg years, roughly 1434 to 1444, are the darkroom of Gutenberg's life, lit only by lawsuits. The 1439 action brought by the Dritzehn brothers, investors in his ventures, reveals the structure: Gutenberg took partners' money for a set of "arts" kept strictly secret, subcontracted work to joiners and smiths on compartmentalised tasks so no craftsman could see the whole, and bound everyone by oath. One document mentions a press; another, four pieces held by two screws; another, sums spent on lead. When the partner Andreas Dritzehn died, Gutenberg refused to admit his heirs to the venture, and the court, by the record, accepted the secrecy as legitimate. Historians read these fragments as the sound of the printing system being

assembled: the press being built, the metal being bought, the knowledge being kept from competitors. If so, secrecy was not paranoia but method: the invention's value lay in being first and alone.

What a lawsuit preserves

The Helmasperger Instrument of 1455, named for the notary Ulrich Helmasperger who drew it, is the founding document of printing history, and its accidental completeness is a gift. Because Fust sued over money, the record itemises the enterprise: loans, their dates, their purposes, the cost structure of a pressroom in paper, vellum, ink and wages, the existence of a stock of equipment and of a shared "work of the books". Without the quarrel, the first decade of printing would be nearly undocumented. There is a general lesson the industry would re-teach for centuries: the paper trail of print, contracts, accounts, lawsuits, is often more durable than the machines. The press made records; records preserve the press.

Strasbourg: the hidden decade

Before Mainz there was Strasbourg, and Strasbourg is where the invention was actually made, in a fog of commercial secrecy that has never entirely lifted. The documents, surfacing in a 1439 lawsuit, show Gutenberg taking partners and investors into a venture whose nature he contractually concealed: mention of 'a press', of lead purchased in quantity, of something involving 'four pieces' held apart until the partnership was sealed. Investors' relatives tried to peer into the workshop; the partners swore to keep the work from all eyes. When the investor Andreas Dritzehn died at the end of 1438, his brothers sued for his place, and the court papers, in trying not to say what the secret was, tell us it already existed: a press, forms, the apparatus of printing, in Strasbourg, a decade before the Bible. Whatever Gutenberg carried back to Mainz around 1448, it was not an idea; it was a nearly finished machine that needed only capital, and the capital is what Mainz, and Fust, supplied.

PART II · MAINZ

5 · Anatomy of an Invention

Call the printing press one invention and you miss what actually happened in Mainz. The system Gutenberg assembled was four technologies locked together, three of them borrowed and one genuinely new, and the genius of the thing lies in the fit between them: each one exists because the other three demand it.



A Mainz printing workshop around 1450: the screw press, the type case, the dampened sheets, the system assembled.

The mould: the one new thing

The heart of the system is the hand mould, and it is the only component for which Gutenberg had no existing model. The problem it solves is unforgiving. To print, you need type: thousands of small metal blocks, each carrying one raised letter in mirror image, and they must be interchangeable. Every sort of the letter e must be exactly the same height from foot to face, or the page prints like a ploughed field; each must have the same body width as its siblings, or lines cannot be justified; and a busy shop needs hundreds of copies of the common letters, cast fast, day after day. Carving type by hand cannot do this. Casting in fixed moulds cannot do it either, because every letter has a different width.

The hand mould is the elegant answer: a two-part metal mould whose halves open and close like a pair of L-shaped jaws. Because the halves slide, the cavity's width adjusts to the letter being cast while its height stays fixed and identical. The typefounder hangs a matrix, a small copper block with the letter struck into its face by a hardened steel punch, at the bottom of the cavity, clamps the mould shut, fills it with molten type metal, gives it a practised flick to drive metal into the hairlines, opens it, and drops out a finished sort, cast in a few seconds. A skilled founder could cast several thousand sorts in a day, every one the twin of its matrix. The mould is the machine tool of the invention: the tool that makes the tools. Modern microscopic studies of early printing types confirm the system: the same matrix leaves its identical fingerprint in sort after sort.

Behind the mould stands the punchcutter, the goldsmith's trade Gutenberg knew best. For each character, a letter is engraved in relief, in reverse, on the end of a steel rod, hardened, and struck into copper to make the matrix. One careful act of cutting becomes ten thousand castings. This chain, punch, matrix, mould, sort, is the reproductive system of movable type, and it remained essentially unchanged for four hundred years.

The metal: a letter's alloy

Type metal is its own quiet invention. Pure lead is too soft; it deforms under the press. Pure tin is expensive and casts poorly at small scale. The working alloy, settled early and kept for centuries, is lead hardened with tin and antimony: lead for weight and cheapness, tin to wet and flow into the finest lines of the matrix, antimony to harden the alloy and, unusually among metals, to expand slightly as it solidifies, forcing the molten metal into the crisp edges of the letterform. The result is a sort that casts sharp, prints hard, and melts at a temperature a workshop furnace reaches easily, so the same metal can be melted and recast forever. The Gutenberg Bible's type has been analysed: a lead-tin-antimony alloy of exactly this family. Type founding is one of history's oldest continuous metallurgical practices, and the alloy outlived the hand mould itself, serving the Linotype and Monotype machines into the twentieth century.

The ink: paint taught to print

The ink is the most underpraised element, and the one whose absence strangled earlier attempts. Manuscript ink, and the water-based ink of East Asian block printing, will not work on metal type: it beads on the metal, runs, dries slow, and blurs. What metal type demands is an ink that is stiff, tacky, fast-grabbing and durable: a varnish, not a wash. Gutenberg's answer came from the painters. Since the early fifteenth century, Northern European painters, the world of Jan van Eyck, had been building oil paints on boiled linseed oil. Printing ink is that technology re-pointed: linseed oil cooked until it thickens into varnish, loaded with lampblack, the fine soot of burned oil or resin, ground fine between stones. It sits on the metal face like paint on a palette knife, transfers decisively to damp paper under pressure, holds a razor edge, and dries by oxidation into a film that survives centuries. The blackness of fifteenth-century pages, still dense and glossy after five hundred and seventy years, is the varnish showing off.

The press: a borrowed muscle

The press itself was the oldest and least mysterious component. The screw press was everywhere in the fifteenth century: wine growers pressed grapes with it, papermakers pressed water from their sheets with it, cloth finishers pressed nap with it. Gutenberg's adaptation kept the furniture: a stout wooden frame, a great threaded screw, a flat platen that the screw drives down. The printer inks the type, laid in its forme on the press bed, positions a dampened sheet on the tympan, a framed membrane that holds and protects the paper, folds a frisket over it to mask the margins, slides the bed under the platen, and pulls the bar. One pull prints

one page of the sheet. Two pulls for a full forme. A good crew, a beater to ink and a puller to press, could manage around 250 impressions in a working day, and the arithmetic of the craft, the compositor setting type while two presses alternated formes, stayed the grammar of printing into the age of steam.

Damp paper is a detail worth keeping. The sheet was moistened before printing so the fibres would soften and accept the ink under pressure, and so the impression would bite evenly. The whole system is tuned to that damp sheet: the tacky ink, the hard type, the single firm pull. Change any element and the others complain.

Why it counts as one invention

Historians rightly insist that printing existed before Gutenberg and that no single component of his system was without precedent. The claim of Mainz is different and stronger: a complete, reproducible manufacturing process for text, in which punchcutting, matrix-striking, adjustable-mould casting, oil varnish ink, damp rag paper and the screw press interlock so well that a trained crew could produce hundreds of identical pages a day, day after day, to a standard a scribe could not match. The evidence for the claim is not a patent or a memoir; Gutenberg left neither. The evidence is the product: a Bible of nearly 1,300 pages, set in a type of jewelled regularity, printed in an edition that reached buyers from Rome to the Baltic. The system is the invention, and the Bible is the demonstration.

Workshop: the compositor's case

Set type by hand and you learn the alphabet's true shape. The compositor stood before a pair of sloped trays, the type cases: the upper case held the capital letters, the lower case the small letters, and from that physical arrangement English still names them. Each compartment held one sort: many e's and t's, few q's and z's, the case laid out by letter frequency so the hand's travel was shortest. In his left hand the compositor held the composing stick, a small adjustable tray; with his right he plucked sorts and set them, upside down and in mirror order, line by line, spacing each line to exact measure with spaces and quads. A full stick was emptied onto the galley; full galleys became pages. A good man set about 1,500 characters an hour, and could justify a line by eye, letterspace a title, and read the whole world backwards and upside down without noticing. It was, until 1886, among the most skilled routine occupations in any industry.

Imposition: the geometry of the folded sheet

The press prints sheets, not pages, and the sheet is where printing becomes mathematics. Print four pages on each side of a sheet and fold it once, you get a folio of four leaves; fold twice, a quarto; three times, an octavo, sixteen pages to the sheet. The pages must be laid out in the forme so that after folding they run in order, which means page 12 must sit beside page 5, upside down relative to page 6, in a pattern called imposition. Get it wrong and the book reads as a shuffled riddle; every printer's apprentice learned the imposition

schemes as tables to be memorised, and the signatures, small letters printed at the foot of the first page of each gathering, let the binder check the sequence. The octavo's arithmetic is why books traditionally come in page counts divisible by eight or sixteen, and why "signature" survives as a word for a batch of pages. The sheet, not the page, is the true unit of book manufacture, and the formats, folio, quarto, octavo, duodecimo, are the fossil record of folding.

The pull and the rhythm

A two-man press crew had a rhythm as settled as a dance. The beater took up the ink balls, two leather-stuffed handles, and beat the forme to an even film of ink; the puller laid a damp sheet on the tympan, folded down the frisket, cranked the bed under the platen, pulled the bar, released, cranked back, and lifted the sheet to the drying line. Two hundred and fifty impressions an hour per press was a working figure for a good crew on a common press; the compositor, meanwhile, set the next forme while the current one printed. The system's balance was delicate: too many pressmen and the compositor starved them, too many compositors and the presses idled. Printing is the first industry whose internal pacing was studied, timed and balanced, and the balance, set, print, correct, reprint, is still the rhythm of the trade.

PART II · MAINZ

6 · The Work of the Books

The first great product of the new system was not a pamphlet or an experiment. It was the largest, most prestigious text in Latin Christendom: the complete Vulgate Bible, forty-two lines to the column, two columns to the page, 1,286 pages in all. The audacity was the point. Gutenberg was not proving that printing worked; he was proving that printing was better.



The typefounder's art: molten lead-tin-antimony poured into the adjustable hand mould, fresh sorts cooling in rows.

Making the 42-line Bible

The Gutenberg Bible, as it came to be known, was printed in Mainz between roughly 1452 and 1455. Its scale needs translation into workshop terms. A page carries about 2,600 characters; the whole Bible contains something over three million. The compositors worked from a manuscript exemplar, setting the text in a stately textura type that mimicked the formal liturgical hand of the best professional scribes, complete with hundreds of abbreviation marks so the printed page would match the manuscript look buyers trusted. The presswork was done in stages and, the surviving copies show, with mid-course corrections: the number of lines per page changed early in the run, the inking deepened, and some sheets had to be reprinted when the edition size was increased, a decision visible today in pages that exist in two different settings. The edition was about 180 copies, most on paper, around thirty to forty-five on vellum. The paper for it was an industrial order in itself, drawn from mills that supplied the Rhine trade; the vellum copies took the skins of thousands of calves.

What the buyer received was not yet a finished book. The press printed the black text; then the copy went to rubricators and illuminators, often in the buyer's own city, who added the red initials and headlines and, in fine copies, full illumination by hand. The two volumes were bound locally, in whatever style the owner preferred. The Gutenberg Bible is thus a machine-made object finished by craftsmen, a perfect emblem of its transitional moment: identical in text, unique in dress.

The lawsuit that preserves everything

In November 1455, Johann Fust sued Gutenberg. The surviving record, the notarised document historians call the Helmasperger Instrument, is the single richest source on the whole enterprise, and it reads like the first financial statement of the printing industry. Fust's complaint itemises the venture's costs: loans of 800 guilders twice over, and money advanced for paper, vellum, ink, labour, and an unnamed apparatus. The court found for Fust; the workshop and its contents passed to him, and the Bible project, essentially complete, was finished and sold under the name of Fust and his new partner, Peter Schöffer. In 1457 the firm of Fust and Schöffer issued the Mainz Psalter, a book of astonishing technical ambition, printed in two colours with red and blue initials printed from metal, not drawn by hand, and bearing the first colophon in the history of printing: a printed statement naming the printers, the place and the date. The printer's pride in print begins there.

The older legend made Fust a usurer who destroyed the inventor. The documents will not carry that story: Gutenberg continued in Mainz, kept property, and in 1460 produced, most scholars believe, the Catholicon, a great Latin dictionary whose colophon praises the achievement without naming its maker, as if the shop had learned reticence. In 1465 the Archbishop of Mainz, Adolf von Nassau, enrolled Gutenberg among his courtiers with an annual pension. He died in 1468. The fortune of the business went to others; the technology had already escaped.

What the Bible proved

About forty-nine copies of the 42-line Bible survive, substantially complete or in fragments, from an edition of about 180: a survival rate that tells its own story about how carefully the object was treated. It was never a cheap book. A printed Bible on paper cost a fraction of a manuscript one, but still a serious sum, and buyers were institutions and wealthy men. Yet the demonstration ran deeper than price. The Bible showed that the system could hold quality across three million characters, that an edition could be planned, financed, enlarged mid-printing, sold across Europe, and that copies in Rome, Vienna and London would be word-for-word the same book. Every book you have ever read rests on that demonstration. The publishing industry, edition sizes, print runs, errata, second printings, begins in a workshop in Mainz with a lawsuit over paper, vellum and 1,600 guilders.

The Bible as an object

Spend time with a surviving copy and the book instructs. The paper is heavy rag, still strong after five and a half centuries; the type is a large textura, about 20-point, its dense black varnish ink barely faded; the page is double-columned, 42 lines, about 2,600 characters. The two volumes run to 643 leaves. Because the edition was increased during printing, the first gatherings exist in two settings, and because the buyers finished their own copies, no two Bibles are alike: the Morgan Library's great vellum copy is illuminated like a psalter; plain

paper copies carry only red initials stroked in by a provincial rubricator. The census of survivors, about forty-nine substantially complete copies, is itself a data point in the economics of treasure: the book was always an object of value, kept in institutions, rebound and guarded. When a complete copy last came to auction in 1978 it made a record price for any printed book; single leaves, the so-called Noble Fragments of a broken copy, sell as relics to collectors who will never own a whole one.

The indulgence: the press's first cash crop

The Bible was the proof, but the indulgence was the business. Printed indulgences, certificates of remission of penance sold to raise funds for crusades, cathedrals and the papal treasury, were among the earliest products of the Mainz press, and they were ideal for it: a short fixed text with blank spaces for the buyer's name and the date, wanted in tens of thousands of identical copies, paid for in cash. The 31-line indulgence of 1454-55 is among the earliest dated products of European printing. Consider what the form represents: the first true mass-market printed product, personalised in its blanks, distributed through a sales network that reached every parish, and priced for nearly every purse. It was also, of course, the product that provoked the Reformation: the indulgence trade Luther attacked in 1517 was a print industry, and his theses were answered in kind, by print. The press's first cash crop seeded its first revolution.

What a book cost

The price evidence, fragmentary but consistent, is the engine of the whole story. A hand-copied Bible in 1450 represented years of a scribe's labour; the 42-line Bible on paper sold for a fraction of that, perhaps the equivalent of a clerk's salary for several months, still a treasure but a purchasable one. Ordinary books fell faster and further: by the 1480s, small printed schoolbooks and devotional works sold for sums that students and priests could pay, and by the 1520s a pamphlet cost pennies. Every halving of the book's price multiplied its public. The long arc from the three-year Bible to the penny pamphlet to the dime novel to the paperback is one curve, the curve of the cost of the copy, and most of this book is the story of the machines that bent it.

The presswork

The edition's scale matched its ambition: about 180 copies, of which roughly three dozen were printed on vellum, the rest on paper, a few years of continuous work for a shop running several presses. The paper alone was an industrial procurement, tens of thousands of sheets ordered from the mills of northern Italy; the vellum required the skins of thousands of calves. Composition proceeded in parallel, several compositors setting different quires at once, which is why the surviving copies show the type evolving as the work advanced, the 40-line opening pages giving way to the 42-line body when Gutenberg saw he could fit more text to the page. Every copy was then finished by hand: the red initials and headlines added by rubricators, the illumination by artists, the binding by local shops, so that the forty-eight substantially complete copies that

survive are each a collaboration between the most mechanical and the most manual book crafts of their century. The Bible was never merely printed; it was printed and then made, copy by copy, which is exactly the transitional object it was.

PART III

The Press Walks

From one workshop to two hundred and fifty cities in fifty years.

PART III · THE PRESS WALKS

7 · The Mainz Diaspora

The printing press spread across Europe not as a blueprint but as a migration. In October 1462, Mainz was sacked in a war between two rival archbishops, and the city's printers scattered. Within a generation the craft they carried had reached nearly every commercial city in Europe. The technology moved in the hands of journeymen, and it followed the trade roads, because a printing shop is first of all a business.

Walking craftsmen

The chronology of the spread reads like a railway timetable of the fifteenth century. Bamberg and Strasbourg had presses by about 1460; Cologne by 1464; Basel by 1466. Ulrich Zel, Cologne's first printer, had learned the craft in Mainz. Arnold Pannartz and Konrad Sweynheym, two Germans, carried printing over the Alps to the Benedictine monastery at Subiaco near Rome in 1465, and to Rome itself by 1467. Johann Neumeister brought it to Foligno. Paris got its press in 1470, installed inside the Sorbonne by German hands at the invitation of humanist scholars. Nuremberg, Lyon, Barcelona, London, Antwerp, Kraków, Prague, Stockholm: by 1500 presses worked in more than 250 cities and towns. The map of printing in 1500 is the map of European commerce, with a few scholarly exceptions that prove the rule.

The men who walked were mostly German, and for decades the Italian towns complained that the trade was a German monopoly. They carried more than tools. They carried the tacit knowledge of the whole system: how to cut a punch and strike a matrix, how to judge type metal by its ring, how to boil linseed oil to varnish, how damp the paper should be, how to impose pages so a folded sheet reads in order. The craft had no manuals at first; it had persons. This is why the sack of one city could seed two hundred: the press is portable because the printer is the manual.

The mathematics of the incunable age

The first half-century of European printing is the best-counted birth of any industry. The Incunabula Short Title Catalogue, the international census of fifteenth-century printing, lists about 30,600 surviving editions from before 1501, and bibliographers estimate that the great majority of editions left at least one surviving copy, so the true total lies only modestly higher. Edition sizes in the period typically ran from a few hundred to about a thousand copies. Multiply it out and the conclusion is startling: by 1500, Europe's presses had produced something in the range of eight to ten million books, more books than all the scribes of Europe had produced in the previous thousand years. Roughly 450,000 of those incunabula survive today, scattered through about 4,000 libraries.

The content of that first flood deserves a correction to the modern imagination. It was not a wave of novelty. The incunable presses printed the existing canon: Bibles and liturgies, the Church Fathers, canon law, school grammars, the Latin classics, medical and astronomical manuals, almanacs, and a rising tide of indulgences, the printed pardons whose blank spaces for names and dates were the form letters of the age. Print began by industrialising the texts Europe already had. The transformation of what Europe wrote came after, and it came because the economics of the press rewarded finding new things to say.

The business of the hand press

An early print shop was a capital-hungry little factory, and its cost structure explains much of publishing's future behaviour. The fixed costs were brutal: type had to be cut or bought and cast, presses built, journeymen hired, and above all paper bought in advance, by the bale, for the whole edition. Paper alone could account for well over half the cost of an ordinary book. The presswork was fast, but the money was tied up for months before a single copy could be sold, and every unsold copy was paper turned back into dead stock. Printers therefore behaved exactly like their descendants: they printed what was already selling, shared risk through partnerships, swapped sheets with printers in other towns to widen their lists without widening their costs, and failed in great numbers. The history of early printing is littered with one-book shops.

Two consequences follow. First, the industry concentrated where capital and paper were, in the great trading cities, above all Venice, which by 1500 held a large share of all European printing, and where the next chapter will linger. Second, the printer's economic problem, how to sell five hundred identical objects, quietly created the modern book trade: catalogues, fairs, title pages as advertisements, printed book prospectuses, and eventually the publisher who commissions rather than merely prints. The machine that multiplied words also invented the industry of guessing which words would sell.

Venice by the numbers

The concentration of early printing in Venice deserves figures. Of the roughly 30,600 incunable editions in the ISTC census, Venice accounts for the largest single share by far, on the order of one edition in eight or nine worldwide, with Paris, and the German cities, Lyon, Rome and Milan following. Some 150 or more printing offices worked in Venice at various times before 1501. The mix of its list shows a mature industry: law, medicine, theology and the classics for the universities; liturgical books for the whole Latin Church, printed to diocesan use; Greek and Hebrew texts for specialist markets; and a rising trade in the vernacular. The city was to fifteenth-century books what the Rhine mills were to its paper: the place where the trade's capital, materials and skill pooled.

The journeyman's life

The press spread because the printer could walk. A journeyman compositor or pressman carried his skill in his hands and his wage negotiations in his guild's discipline: tramping from shop to shop across the German lands and beyond, working by the week, moving when work or quarrels moved him. The journeymen formed some of Europe's earliest organised craft associations, with initiation rites, secret customs and, by the sixteenth century, strikes: the Lyon printers' work stoppages of the 1530s and 1570s, over wages, hours and the infamous issue of board and lodging, are among the first documented labour actions in the printing trade and among the earliest in any industry. The press made an industrial working class before the industrial revolution: literate, mobile, organised, and conscious that its hands were the machine.

How the books moved

Selling the edition was the printer's oldest headache, and the solutions became institutions. The Frankfurt fair, held twice yearly, became the central exchange of the European book trade; printers issued catalogues of their wares, and from 1564 the fair itself issued a collective catalogue, the ancestor of all books-in-print. Sheets were traded unbound, in bales, because the buyer bound to taste; international firms opened agencies in a dozen cities; titles were financed by subscription and presold by prospectus. The unbound sheet is a revealing detail: the book as an object was finished where it was read, and the trade in between dealt in paper by the hundredweight. Printing created the first global trade in a manufactured cultural good, with all the apparatus, agents, credit, piracy, that such trades require.

The geography of fifty years

The spread can be told as a list of arrivals, each one a small drama of transport and capital: a press is a heavy thing, and type heavier. Paris had printing by 1470, brought by Germans invited to the Sorbonne; Rome the same year, Venice a year before; Cologne 1465, Basel by 1468, Nuremberg 1470, Antwerp and London 1476, Stockholm 1483, Constantinople 1493, and across the Atlantic at Mexico City by 1539, a century before the English colonies of North America had one. The carriers were mostly German journeymen, a diaspora of the craft walking outward from Mainz with their moulds in their baggage, funded in each city by a local merchant or prelate who had seen what the machine could do. The geography was commercial before it was intellectual: presses went where paper, credit and readers already were, which is why the dense map of the incunable world is the map of European trade, the Rhine, the Alpine passes, the Hanseatic routes, the Italian city-states, with the press arriving as the newest cargo on the oldest roads.

PART III · THE PRESS WALKS

8 · Venice and the Portable Book

If Mainz invented the press, Venice invented the book as we know it: small, affordable, classical, and bought by individuals rather than institutions. The agent of that change was a humanist scholar named Aldus Manutius, and his workshop is the first modern publishing house.



A Venetian printing office around 1500: small octavo classics, proof sheets and bales of paper in the capital of the early book trade.

The capital of print

Venice in 1490 was the natural capital for the industry: rich, tolerant, sitting on the sea routes that brought Greek scholars and manuscripts west after the fall of Constantinople, with paper mills in its hinterland and a merchant class that understood long-range trade in lightweight goods. Within thirty years of the press's arrival, the city held scores of printing houses and produced a large share of Europe's books. The Venetian Senate also created, in 1469, an early form of copyright: the privilegio, an exclusive grant to print a particular work, first given to the printer Johannes of Speyer. The monopoly logic of the privilegio would echo through publishing law for centuries.

Aldus and the book in the pocket

Aldus Manutius came to Venice not as a craftsman but as a scholar: a tutor of Latin and Greek who decided, late in life, to rescue the whole of Greek literature from manuscript extinction by printing it. He founded the

Aldine Press in 1494 and ran it for twenty years, and his list was a program: the Greek classics, most of them printed for the first time, in editions edited to scholarly standards, alongside Latin classics and contemporary humanists. His workshop employed émigré Greek scholars as editors and compositors; his punchcutter, Francesco Griffo of Bologna, cut type designs of lasting beauty, including the first italic type, modelled on the slanted chancery hand of Italian humanist scribes and cut so compactly that more words would fit a page.

The italic was not decoration. It was a format decision. In 1501 Aldus launched his series of octavo classics: small books, an eighth of a full sheet, printed in the new compact type, without the weight of commentary that filled scholarly folios, priced within reach of students and travellers. Before Aldus, a classical text was a lectern object, big, costly, chained to a library desk. After Aldus, the classics were portable. He had invented, in effect, the pocket edition, the ancestor of every cheap classic series and every paperback on every station bookstall. His printer's device, a dolphin twined around an anchor, from the old proverb "make haste slowly", became the first great brand mark of publishing.

The Aldine shop also shows the industry's growing division of labour: scholar-editors, punchcutters, typefounders, compositors, pressmen, proofreaders, woodcut illustrators, and a sales network that reached the book fairs of Frankfurt and the courts of Europe. The famous Hypnerotomachia Poliphili of 1499, a dream-romance printed with woodcut illustrations of extraordinary poise integrated into the type page, demonstrated that the printed book could be a designed object, not merely a duplicated text. Printing had acquired art direction.

The long shadow

Aldus died in 1515; the press continued under his descendants to 1597, four generations of one publishing family. What it bequeathed was a template the industry still runs: find great texts, edit them well, give them a recognisable design and a brand, price them for a defined readership, and sell them everywhere. Mainz had made the book manufacturable. Venice made it merchandise, a thing an ordinary reader could own, carry, and love. The remaining step, making it cheap enough and interesting enough for everyone, would take the steam engine.

Griffo and the letters of the Aldine page

Francesco Griffo of Bologna, Aldus's punchcutter, deserves his own paragraph in type's history, for he cut the designs that fixed the look of the printed word. His roman types for Aldus, based on the humanist book hand and the inscriptional capitals of Rome, established the model that every later "old style" serif followed; when you read a modern Garamond or Bembo, you are reading Griffo's great-great-grandchildren. His italic of 1500-01, cut for the octavo classics, compressed the chancery hand into a space-saving letter, and the two families he defined, roman for the body, italic for emphasis, still govern the architecture of text. Griffo's life

ended in violence and obscurity, he was hanged for the killing of his son-in-law, but his letterforms are read every minute of every day. The punchcutter is the invisible author of all authors.

The economics of the octavo

The Aldine octavo was a manufacturing calculation as much as a humanist gesture. A folio Bible consumed sheets and money; an octavo classic printed sixteen pages per sheet, cut the paper cost per page dramatically, required smaller formes, and could be bound cheaply in limp vellum. The format matched the customer: a student, a lawyer, a courtier travelling. Priced at levels the professional classes could meet and issued in steady series, the Aldines created the repeatable, brandable, collectable book line: the first "collected editions" and the proof that readers will buy a format as much as a text. Every uniform edition since, the Everyman's Library, the Penguin paperback, the Pléiade, is an Aldine idea.

The scholar's workshop

Aldus's household was a new kind of institution: the printing office as academy. Greek scholars ate at his table, corrected proofs, and taught; his New Academy set the standard of the edited classical text, with the printer personally answerable for accuracy. The colophon and the preface became places where the printer argued for his editorial standards, the birth of the publisher's voice. When later centuries separated the publisher from the printer, the Aldine model of the publisher as an editor with a press remained the ideal the great houses, Plantin, Froben, the Estiennes, and much later the modern trade houses, continued to chase.

The business of the octavo

Aldus's portable classics were a manufacturing strategy as much as a scholarly one. A folio Bible tied up capital in paper, vellum and press-time for years; an octavo Virgil could be composed, printed and sold in weeks, in editions of a thousand or more, to students and officials who bought books the way they bought instruments. The Aldine shop became a vertically integrated publishing house before the word existed: scholars editing texts in the house, punchcutters on contract, paper bought in bulk from the mills of the Veneto, a distribution web reaching Rome, Florence and beyond the Alps. Success invited imitation at industrial scale: Lyonese printers counterfeited the Aldine octavos within months, italic, dolphin-and-anchor device and all, and Aldus took to printing warnings to the reader in his own prefaces, an early lesson that a reproducible product has a reproducible identity. The firm's answer was to compete on correctness and quality, to keep issuing texts nobody else could edit. It was the right instinct and an incomplete defence, and the whole future publishing industry would live inside that tension: print makes a book cheap to copy for its publisher and for its pirate alike.

PART III · THE PRESS WALKS

9 · The Merchant Printers

Between 1470 and 1700 the printing trade grew from a novel craft into one of the most sophisticated manufactures in Europe: international, capitalised, quality-obsessed. Its characteristic figure was the merchant printer, half industrialist, half editor, and its characteristic products were the two things Gutenberg's system made newly possible at scale: the big illustrated book and the national literature.

Nuremberg and the book as spectacle

Anton Koberger of Nuremberg built the largest printing business of the fifteenth century: at its height he ran more than twenty presses with over a hundred workmen, with agents from Lyon to Budapest. His masterstroke was the Nuremberg Chronicle of 1493, Hartmann Schedel's illustrated history of the world, a vast folio of over six hundred pages carrying some 1,800 woodcut illustrations printed from over six hundred separate woodblocks, from the workshop of Michael Wolgemut and Wilhelm Pleydenwurff, where the young Albrecht Dürer was then apprenticed. The Chronicle was a planned publishing event: financed by subscription, advertised with a printed prospectus, issued in Latin and German editions. It was also, in its way, a lesson in print economics: the same woodcut of a generic city is recycled dozens of times for different towns, and the same stock portraits stand in for whole lineages of kings. Even at the summit of the fifteenth-century book arts, the printer kept an eye on the cost per cut.

Caxton and the making of English

England came late to the press, and through a merchant. William Caxton had spent decades in Bruges in the cloth trade, where he learned printing in Cologne's orbit and set up a press in the Low Countries. There, in 1473 or 1474, he printed the Recuyell of the Historyes of Troye, his own translation, the first book printed in English. In 1476 he set up at Westminster, at the sign of the Red Pale, and over fifteen years printed around a hundred books: Chaucer, Malory's Le Morte Darthur, the chronicles, devotional works, and a stream of translations he made himself.

Caxton's deepest product was not any single book but a language decision. English in 1476 was a thicket of regional dialects, and printing forced a choice on every page. Caxton printed mostly in the English of London and the court, the dialect of his market, and the sheer weight of printed London English helped fix it as the standard written language. Wherever the press went, it did this: it selected one dialect, froze its spelling into type, and taught a whole nation to write alike. Standardised spelling, grammar books, dictionaries, the

very idea of "correct" language, are downstream of the compositor's case. The press did not just reproduce languages; it manufactured their standard forms.

Antwerp, Paris, Lyon: the industrial chapter

The sixteenth century raised the trade to industrial scale. In Antwerp, Christophe Plantin ran what was perhaps the largest printing office in the world: in the 1570s his house, the Golden Compasses, ran the greatest printing plant in Europe, and his eight-volume polyglot Bible, with its parallel Hebrew, Greek, Latin and Syriac, was the most complex scholarly publishing project yet attempted. His house and type collection survive intact today as the Plantin-Moretus Museum in Antwerp, a UNESCO World Heritage site and the only early printing office to come down to us entire. In Lyon and Paris, the Estienne family married scholarship to printing; in Basel, Johann Froben made his shop the home of Erasmus, whose editions of the Greek New Testament and whose satires were the continent's first intellectual bestsellers, carried by print to readers Erasmus never met.

Alongside the printers grew the craft they depended on: independent typefounding. Once a printer no longer cut his own type, foundries could sell the same font to hundreds of shops, and type design became a business of its own. Claude Garamont in Paris cut the romans that still bear his name; the Granjon family spread type across Europe; in the eighteenth century William Caslon in London made English type independent of Dutch imports, John Baskerville in Birmingham pushed letterpress toward a precision of form and presswork that dazzled and divided Europe, and the Didot family in Paris and Giambattista Bodoni in Parma drew the modern-face types of the Enlightenment. Pierre-Simon Fournier gave the trade its common measure: the point system, a standard unit for type sizes, refined by the Didots into the unit European printing still uses. An industry had grown organs the item alone could not have predicted: foundries, format standards, typeface design as an art, and the first copyright statutes, from the Venetian privilegio to England's Statute of Anne in 1710, the first law to vest copyright in authors.

The hand press underneath it all, it should be said, had barely changed. The wooden common press of 1700 would have been familiar to Gutenberg's journeymen. For three hundred years the press spread, multiplied, and created industries around itself while its own mechanism stood nearly still. The stillness ends in the foundry towns of the industrial revolution, and it ends in iron.

Inside the Golden Compasses

Christophe Plantin's house in Antwerp is the first print shop we can walk through as a business, because it survives. The Plantin-Moretus Museum preserves the building, the presses, the type, the punches and matrices of Garamont and Granjon, the foundry, the proofreaders' room, the accounts. The accounts are the revelation: Plantin ran his house on ledgers of astonishing granularity, journeymen paid by the piece, paper bought by the bale and charged to each book, sheets shared with other publishers to spread risk. At its peak

in the 1570s the house ran sixteen presses; its polyglot Bible employed scholars, correctors and Hebrew, Greek and Syriac type; and its owner corresponded with half the learned world. After Plantin the Moretus family ran the firm for three centuries. Here the press completes its transformation from craft to company.

The letterfounders

Typefounding separated from printing during the sixteenth century, and the founders became the press's upstream industry: Claude Garamont in Paris, whose romans were bought by half of Europe and whose name now denotes more revivals than any designer in history; the Plantin-era masters whose matrices Plantin bought and preserved; the Dutch founders whose types England imported until William Caslon cut his own in the 1720s and made English typography independent at a stroke. Caslon's types carried the publications of the American colonies, the Declaration of Independence's first printing is set in Caslon. John Baskerville, the Birmingham japanner turned printer, pushed type and presswork toward a new brilliance in the 1750s: sharper, higher-contrast letters, hot-pressed paper, ink of his own making; Voltaire and Franklin admired him. Didot and Bodoni closed the century with the "modern face", extreme contrast, hairline serifs, and Fournier and Didot gave the trade the point, the unit that finally let a French and an Italian printer speak of the same size. Type had become an international product with standards, brands and stars.

The law discovers the book

Print made text property, and property made law. The Venetian privilegio, the imperial and royal privileges, and the Stationers' monopoly in England were all mechanisms of the same kind: exclusive rights to print, granted to printers and stationers, policed by the state. England's Statute of Anne, 1710, "An Act for the Encouragement of Learning", broke the pattern by vesting the right in authors for limited terms, and it is the ancestor of every copyright statute on earth. The United States wrote copyright into its Constitution in 1787. The press thus created not only the book trade but the legal concept of the work: the idea that a text is an object its maker owns. Every argument since, over piracy, term length, photocopying, file sharing, machine training, is an aftershock of the moment when copying became a machine's job.

The polyglot and the humanist

Two projects show the merchant printer at his ceiling. Plantin's Biblia Polyglotta of 1569-72 ran the Bible in parallel Hebrew, Greek, Latin, Syriac and Aramaic across eight folio volumes, a scholarly apparatus of lexicons and grammars beside it, the most complex typesetting and financing exercise yet attempted, backed by Philip II of Spain and nearly ruining its maker when the promised subsidies lagged. In Basel, Johann Froben built his house on a single relationship: Erasmus lived and worked in the Froben shop, correcting Greek texts at the case while the presses waited, and the resulting editions, the New Testament of 1516 above all, carried scholarship to every university in Europe at the speed of print. The merchant printer at his best

was neither tradesman nor patron but something new: an industrialist of learning, betting capital on texts, and the bestseller lists of the sixteenth century, the classical editions, the polyglots, the Erasmus satires, were written by men who understood both the ink and the market.

PART IV

The Multiplied Word

Reformation, science, news: what the machine did to minds and states.

PART IV · THE MULTIPLIED WORD

10 · Luther's Weather

Every new medium eventually meets the movement it was made for. For the printing press, that movement was the Protestant Reformation. The meeting was not planned by anyone, and it changed both: it made the Reformation the first mass movement in history to be carried by a machine, and it taught the press what it was capable of.

The theses go to press

On 31 October 1517, Martin Luther, an Augustinian friar and professor at the small university of Wittenberg, sent his Ninety-five Theses against the sale of indulgences to the Archbishop of Mainz, and, the tradition holds, posted them on the castle church door. They were written in Latin, for academics. What happened next was not his doing: printers took the theses, translated them into German, and within weeks they were being read from one end of the Holy Roman Empire to the other. Luther himself was astonished by the speed. He had stumbled onto the machine's central property: it does not just copy a text, it detonates it.

He learned fast. Between 1518 and 1521 Luther wrote more than a hundred separate works, and the German presses printed them in a flood without precedent: sermons, pamphlets, treatises, catechisms, and polemics, short, cheap, vernacular, and furious. Historians counting the output find that in the crucial years a single author, Luther, came to dominate a significant share of everything printed in German. Thousands of Reformation pamphlets, the Flugschriften, survive in libraries today. The pamphlet was the perfect native form of the press: one gathering of a few sheets, printed in a day or two, sold for pennies, carried in a pocket, read aloud in taverns to the illiterate. Print did not merely reflect the Reformation; its economics dictated the movement's literary form.

The vernacular Bible and the printed Word

The movement's anchor text was Luther's German Bible: the New Testament in 1522, translated from the Greek in eleven weeks at the Wartburg, the whole Bible in 1534, with Lucas Cranach's workshop supplying woodcuts. It was a publishing phenomenon. Printers beyond counting produced editions, authorised and pirated, and the Luther Bible did for German what Caxton had done for English: it gave a fragmented speech a printed standard that whole peoples could learn to read. Protestantism's demand, every believer reading the Word, created the mass readership; the press supplied the Word; and the two together built the first mass literate culture in Europe. Across the Atlantic later, the same engine ran in English: the King James Bible of 1611 became, over centuries, the most printed book in the language.

The counter-evidence

An honest account must note the limits. Print was no automatic Protestant machine. The Catholic world used the same presses, and the Church's response, the Index Librorum Prohibitorum from 1559, the licensing of printers, the stake and the fine, showed that states and churches had also learned the machine's power: their answer was to throttle it. Nor did print guarantee truth; the same presses that carried Luther carried hysterias of every kind. And modern scholarship, looking at the market data, has made the connection more precise: where printing firms were, Protestant ideas measurably took root more strongly. The press did not cause the Reformation. It was the Reformation's weather system, and no movement without it would have had that sky.

The anatomy of a Flugschrift

The Reformation pamphlet was a precision instrument of the press, and its form explains its effect. A typical Flugschrift was a quarto of eight or sixteen pages: one or two sheets, no binding, a woodcut title border, dense vernacular text. A journeyman crew could print an edition of a thousand in a day or two; a pedlar could carry hundreds in a pack; a reader could buy one for the price of a small meal; a tavern audience could hear it read in an hour. The pamphlet's shortness was its velocity: it answered events within days, and opponents answered back within the week, so that the 1520s saw the first fully realised public controversy conducted in print at the speed of the post. The great printers of the movement, Wittenberg's own shops, Rhau-Grunenberg foremost, and the pirate printers who reprinted everything saleable, made fortunes from the flood.

The Wartburg translation

Luther's New Testament of 1522 was also a manufacturing marvel. Hidden at the Wartburg under the name Junker Jörg, Luther translated the Greek New Testament into German in about eleven weeks, aiming, he said, at the language of the mother in the home and the children in the street. Back in Wittenberg, the September Testament was printed in an edition of several thousand and sold out within weeks; reprints and piracies followed across the Empire. The complete Bible of 1534, with the Cranach workshop's woodcuts, went through edition after edition for the rest of the century. The Luther Bible's deeper work was linguistic: it gave the German lands a common written language at the moment print could entrench it. The press and the vernacular Bible together made the German-speaking world, and the same pair did comparable work in Dutch, English, Swedish and Danish.

The market decides

The Reformation's print history is also a lesson in media economics. The pamphlet flood was not subsidised by a movement; it was profitable. Printers printed Luther because Luther sold, and the data of the time,

editions, reprints, the share of evangelical titles in total German output, show a market swinging toward a bestseller. Modern quantitative studies find that cities with more pre-existing printing firms produced disproportionately more Protestant material, and that the movement took hold where the presses were. The machine did not take sides; the market did, and the market followed the readers. This is the template for every later moment when a medium's economics bent a politics: the medium rewards what engages, and engagement becomes power.

The economics of the pamphlet

The Reformation's weapon was not the book but the Flugschrift, the flying writing: eight or sixteen pages, a single folded sheet or two, printed in a day, sold for the price of a modest meal, read aloud in taverns and markets and passed hand to hand. The economics were irresistible. A printer needed little capital and no patron; the press paid for itself on a sermon. A writer needed no permission beyond a willing printer. The supply chain from author to reader shortened from years to days. Wittenberg, a small town, became one of the largest printing centres in Europe on Luther's output alone; the painter Lucas Cranach ran both the workshop that made the Reformation's images and a stake in its printing. When Luther's German New Testament appeared in September 1522, the first edition of three thousand copies sold out within weeks, and printers across Germany reprinted it whether Wittenberg liked it or not. The press had found its first mass product that was not a Bible in Latin: argument itself, manufactured daily.

PART IV · THE MULTIPLIED WORD

11 · The Republic of Letters

Modern science is impossible to imagine without print, and not because print spread its conclusions. Print changed what a conclusion was. A scientific claim in the age of the manuscript was a private possession, copied with errors, owned by whoever held the parchment. In the age of the press it became something new: a fixed, public, citable object, the same for every reader in every city, against which the next researcher could measure reality.

The year 1543

It is one of the great coincidences of intellectual history that two books published in a single year mark the start of the scientific revolution, and both were products of the printing trade at its most ambitious. De revolutionibus orbium coelestium, Copernicus's argument for a sun-centred cosmos, was printed in Nuremberg in 1543 and, the story goes, reached its dying author on his last day; its dense pages of astronomical tables and geometric diagrams were exactly the kind of technical matter that hand copying corrupted hopelessly. The same year in Basel, the house of Johannes Oporinus published Andreas Vesalius's

De humani corporis fabrica, the founding atlas of modern anatomy: more than six hundred folio pages whose hundreds of large, precise woodcut illustrations of the dissected human body, from the workshop of Titian's circle, could only exist because they could be printed identically into every copy. Anatomical knowledge had always decayed in transmission because no two scribes draw alike. After Vesalius, every student in Europe could dissect with their eyes along the same authoritative images.

The pattern generalises. Tycho Brahe built his own press and paper mill at Uraniborg so that his star catalogues could be printed under his own control. Galileo used the printed page as a weapon, publishing his Italian dialogues for a lay readership that Latin science had never addressed. William Gilbert's De magnete (1600), Kepler's astronomical works, Harvey's De motu cordis (1628): the press turned discoveries into durable public objects, and turned natural philosophy into a cumulative enterprise. When Newton published the Principia in 1687, under the imprimatur of the Royal Society, he published into a world where every competent reader in Europe could obtain the same text, check the same diagrams, and answer in print. That is what a scientific community is: an argument conducted through identical copies.

Fixity and the footnote

The historian Elizabeth Eisenstein gave this transformation its classic formulation: print culture's deepest gift to learning was typographic fixity, the preservation of texts without the drift of hand copying. Fixity made new scholarly furniture possible and necessary. Pagination and title pages made citation precise; indexes and cross-references turned books into instruments; errata sheets admitted error into print without erasing it. The printed catalogue, the printed dictionary, the printed encyclopedia all rest on the same property: a reference is only a reference if every reader's copy has the same page 212. The eighteenth century's Encyclopédie of Diderot and d'Alembert, twenty-eight volumes of text and plates glorifying the mechanical arts, was at once a product of this culture and a portrait of it: the press printing the knowledge of every trade, including its own.

The furniture of fixity also created a new figure, the editor, and a new commerce, the learned journal. When the Journal des savants and the Philosophical Transactions of the Royal Society both began in 1665, they added periodical rhythm to the fixity of print: science as a continuous, datable, citable conversation. Every peer-reviewed journal, every citation index, every DOI of the electronic age is an heir of that arrangement.

The republic itself

Above the books and journals hovered a new kind of community that its members called the Republic of Letters: a cross-border commonwealth of scholars who had never met, conducting their business in print and in letters, judged by readers rather than patrons. Print did not create curiosity, but it changed curiosity's economics. A discovery could now be announced to everyone at once, priority could be claimed with a dated publication, and a reputation could be built entirely in print. The machine had begun as a way to multiply

the Bible and the classics. It ended by making an entirely new class of text: the research result, addressed to everyone and owned by no one, which is the textual form of the modern world.

The theatre of machines

Print fed the machine age directly through a genre the press made possible: the book of machines. From the 1560s and 1570s, Agostino Ramelli's Diverse et artificiose machine and its fellows, Besson, Zonca, later Zeising and Leupold, published plates of pumps, mills, cranes, and engines, engraved so that any craftsman in any city could study the mechanisms. Before the theatre of machines, mechanical knowledge moved with the craftsman or not at all; after it, an engineer in Lyon could rebuild a pump he had never seen, from a book printed in Paris. The genre is a turning point in the history of technology: print turned craft secrecy into published art, and published art into cumulative engineering. The press did not just describe the coming industrial world; it was one of its transmission mechanisms, in both senses.

Maps: the printed world

Cartography was transformed the same way. Manuscript maps were treasures; printed maps were instruments. Martin Waldseemüller's great world map of 1507, the first to name America, was printed in a thousand copies; Ortelius's Theatrum orbis terrarum of 1570, the first modern atlas, was a publishing enterprise, reprinted and translated for decades; Mercator's projection of 1569 spread through print to every navigator's cabin. The printed map did for space what the printed text did for thought: it made it uniform, comparable, cumulative. Every sailor's chart, every school atlas, every road map descends from the discovery that geography could be multiplied. And the map trade was an industry in its own right: Amsterdam's houses, Blaeu above all, ran the finest print works of the seventeenth century on the strength of atlases and charts.

Priority, credit and the date stamp

Print rewired the incentives of discovery. In a manuscript world, priority was ambiguous and knowledge was guarded; in a print world, the dated publication fixed credit, and the race to publish began, with its familiar pathologies, haste, priority quarrels, plagiarism, and its decisive virtue, openness. The printed journal institutionalised the race from 1665. It is not too much to say that the modern reward system of science, publish, be cited, be first, is a social technology built on the press's physical one: only identical, datable, distributed copies can settle who said what when. The Republic of Letters ran on the post and the press; its constitution was the printed page.

The press observes the heavens

Tycho Brahe understood the press's role in science so completely that he manufactured it himself. On his island of Hven he built not only the great observatory of Uraniborg but a paper mill and a printing office, so that the star catalogues on which his life's authority rested would be printed under his own roof, on his own paper, in editions he alone controlled: the first big-science laboratory included a press as core equipment. Galileo played the same game at the level of rhetoric, writing his Dialogo in Italian rather than Latin precisely so that the argument would circulate beyond the universities, and living to see what the press's amplification of a condemned book looks like from inside the Inquisition. The pattern runs through the century: instruments make observations, but identical printed tables, diagrams and claims are what make observations cumulative. Science as a public enterprise is, in a precise sense, a pressroom product.

PART IV · THE MULTIPLIED WORD

12 · News and Noise

For its first century and a half the press served the past: scripture, classics, law. Then it discovered the present tense. The newspaper, a printed bulletin issued on a schedule, is the press's second great invention after the book, and with it came the press's permanent companions: censorship, propaganda, advertising, and the long legal war over who may print what.

The first newspapers

The honour of the first true newspaper belongs to Strasbourg, 1605, where a publisher named Johann Carolus, who had been copying news reports by hand for subscribers, made the obvious calculation: if you are writing the same bulletin for many customers, print it. His weekly Relation aller Fürnemmen und gedenckwürdigen Historien, "Account of all distinguished and commemorable stories", is recognised as the world's first printed newspaper. The idea spread along the trade routes: weekly newsbooks appeared in the Netherlands, Germany, England. The corantos of the 1620s and 1630s brought foreign news to English readers; the first daily paper, the Leipziger Zeitung, appeared in 1650. A new rhythm entered public life: the world delivered in identical copies, on a schedule, cheaply enough that taverns and coffeehouses could keep a copy for everyone.

The economics were as new as the form. A book is made once and sold slowly; a newspaper is made daily and sold instantly, and it dies at sundown. The newspaper press therefore invented speed as a product, and with it the entire apparatus of the news trade: correspondents, postal privileges, advertising as the subsidy that made cheap papers possible, and the defining figure of the modern information economy, the deadline.

The censor and the licence

Authority had understood the press from the start. The Church's Index of Prohibited Books (1559 onward) policed titles; England's Licensing Order of 1643 required pre-approval of everything printed; the Stationers' Company held the monopoly that made enforcement possible. It was against this licensing that John Milton addressed the English Parliament in 1644 with Areopagitica, the founding argument against prior restraint: let truth and falsehood grapple, he wrote, for who ever knew truth put to the worse in a free and open encounter. The argument lost its immediate battle, licensing continued for another half-century, but it armed every later defender of a free press.

The law's grip loosened in fact before it loosened in principle. England let its licensing act lapse in 1695, and the unlicensed newspaper flooded in: the first English daily, the Daily Courant, in 1702; the great essay papers, the Tatler and Spectator; and, in reply, the state's quieter weapon, the Stamp Act of 1712, taxing paper, advertisements and the papers themselves to price the popular press out of reach. The "taxes on knowledge" shaped the British press for a century and a half before repeal in the 1850s and 1860s.

Zenger's jury

The contest crossed the Atlantic with the press itself. In 1733 the New York printer John Peter Zenger began publishing the New-York Weekly Journal, the opposition paper against Governor William Cosby, and printed attacks on the governor that were, by the law of seditious libel as it then stood, criminal precisely if they damaged the government, whether true or not. Zenger was jailed and tried in 1735. His lawyer, Andrew Hamilton of Philadelphia, made the argument that became American law's foundation: the statements were true, and truth must be a defence. The judge instructed the jury otherwise; the jury acquitted anyway. The Zenger verdict changed no statute that day, but it fixed an idea in the politics of the English-speaking world: a press that may be punished for true criticism of power is not free. The First Amendment's press clause, and every newsroom's instinct since, stands in that courtroom's shadow.

Noise

The press never produced only enlightenment. The same machine that carried the Royal Society's Transactions carried witch panics, forgery, propaganda, and the manufactured rage of party papers. Print standardised error as efficiently as truth, and it paid for outrage exactly as it paid for investigation. The lesson, learned in the seventeenth century and relearned in every medium since, is that the press is an amplifier without a conscience; its social value is not automatic, but constructed, by editors, courts, markets and readers. The next parts of this book are about how the machine was made faster. This chapter is the reminder of what the speed would amplify.

The coffeehouse and the coranto

The newspaper created a new public space around itself. In the London of the 1650s the coffeehouse arrived, and the two institutions fused: for a penny you bought coffee and the loan of the news, and the papers of the day, the corantos, then the Gazette, then the dailies, were read aloud, argued over, and passed hand to hand. A single copy might have twenty readers; the circulation of the early press understates its public by an order of magnitude. The coffeehouse public is the ancestor of every later reading community, and its sociology, men of trade and affairs debating the news of the day in a commercial room, was new in the world: a public sphere running on printed matter. Governments noticed, and worried; Charles II tried to suppress the coffeehouses themselves and failed.

Taxes on knowledge

Where licensing failed, taxation was tried. The British Stamp Act of 1712 put a duty on every newspaper, every advertisement, and the paper itself, expressly to raise the price of opposition print; the duties were raised repeatedly for a century, and the result was a press divided by price: expensive "respectable" papers, and a heroic, illegal, unstamped radical press, sold in the streets and pursued by informers, whose suppression in the 1830s, after the great untaxed war of Cobbett, Hetherington and their kind, ended in defeat for the state. The advertisement duty and paper duty fell in the 1850s, the stamp in 1855, the paper duty in 1861, and cheap daily journalism, the Telegraph at a penny, was the immediate product. The lesson generalises: the price of print is a political instrument, and the freedom of the press has always been partly a tariff question.

The postal system, the press's logistics

Newspapers also built and rode a physical network. The post, the printing press's twin infrastructure, carried news in and papers out: postal privileges for newspapers were fought over as subsidies; the mail coaches, then the railways, then the telegraph, each tightened the news cycle; and the great railway bookstalls of the nineteenth century, W.H. Smith's empire began there, carried print to the travelling public. By 1900 the daily paper was a node in a planetary system of telegraph, rail and steamship. The network did not begin with the internet; it began with the post road and the press, and the internet's architecture, distribution, timeliness, mass duplication, is the old system at light speed.

Steam, wire and the penny paper

The mass newspaper was a product of three machines arriving together: the steam press to print it, the railway to carry it, and the telegraph to fill it. In 1833 Benjamin Day's New York Sun proved the model: a one-cent daily sold on the street rather than by subscription, aimed at artisans rather than merchants, funded by advertising rather than by party. Circulation followed the technology: the penny papers bought the new cylinder presses, the cylinder presses demanded ever more copies to feed, and the copies demanded ever more

news. The telegraph, from the 1840s, collapsed the geography of news itself; the New York papers founded the Associated Press to share the wire's cost, and a dispatch from Washington or New Orleans became same-day print. Advertising, not the cover price, paid the bills, which fixed the industry's shape for a century and a half: the reader was the product sold to the advertiser, and circulation was the measure of the factory. When the network later dissolved both monopolies, it was this nineteenth-century settlement that ended, as the electronic chapters of this book record.

The coranto and the licence

Between the pamphlet and the daily paper lies a century of institutional invention, and it was fought over line by line. The corantos of the 1620s, single-sheet translations of foreign news printed in Amsterdam and London, taught readers to expect the world weekly; the Civil Wars in England turned news into a weapon, with rival newsbooks for king and parliament; and the state's answer, the Licensing Act, made printing itself a permission until Parliament let the act lapse in 1695, the quiet founding date of press freedom in England. The newspaper as a daily habit, the advertisement as its revenue, the editor as a profession, the coffee house as its reading room: all of it assembled in those decades, and every subsequent argument about the press, sedition, taxation, monopoly, the stamp duties that helped provoke a revolution in America, is legible in them. News was the first content business, and its terms were set before the steam engine existed.

PART V

Iron, Steam, Speed

The press becomes heavy industry: iron frames, steam cylinders, rotary webs and cast lines.

PART V · IRON, STEAM, SPEED

13 · The Iron Hand

For three and a half centuries the printing press was wood, muscle and patience. Around 1800 the wooden press finally gave way to iron, and the change looks modest beside steam. It was not. Iron is what made the press a precision machine, and precision is what the nineteenth century would feed on.



An iron Columbian press with its eagle counterweight: the hand press perfected, around 1815.

The limits of wood

The common press of 1750 was the press of 1450 with refinements: a wooden frame, a wooden screw, a platen that pressed half a sheet at a time. Wood has a physics problem: it flexes, swells, and wears. To get a clean impression the pressman had to make ready for hours, building up weak spots with tissue and pasteboard, and to pull hard twice for every sheet, once per platen-half. The size of the sheet was limited by the force one man could throw into a wooden lever, and the force was limited by the frame's willingness not to crack. Editions stayed in the hundreds; daily printing stayed small; the press stayed a craft.

Stanhope's frame

The first successful all-iron press was built around 1800 for Charles Stanhope, third Earl Stanhope, a politician, scientist and serial inventor. Iron changed every constraint at once. A cast-iron frame does not flex, so the whole sheet could be printed in one pull instead of two. The Stanhope design replaced the brute screw with a compound lever system that multiplied the pressman's force and applied it evenly, so a larger platen could deliver a sharper impression with less effort. Productivity roughly doubled, sheet size grew, and the impression, the actual bite of type into paper, became more even than wood could ever manage. Stanhope, characteristically, did not patent the design; he gave it to the trade, and iron presses spread through the printing houses of Europe and America.

The design school that followed produced the most beautiful presses ever made. The Columbian, invented by the American George Clymer around 1813, crowned its iron frame with a counterweight cast as a great American eagle, its lever ending in a serpent; the Albion, made in London from the 1820s, stripped the ornament to a clean toggle action so smooth that a printer could feel the impression through the handle. These machines are the Stradivarii of letterpress: still working today in the studios of fine printers and universities, still capable of impressions that no offset press can imitate, the type printed with a physical bite you can feel with a fingertip.

Stereotype: freezing the page

The iron age brought a second, quieter invention that mattered as much to the industry's economics: stereotyping, the casting of a whole page of set type into a single solid metal plate. The idea had flickered through the eighteenth century, the Edinburgh goldsmith William Ged demonstrated it in the 1720s and was beaten down by the composing-room interest it threatened, but the industrial version was perfected around 1800 by the Stanhope circle and the French firm of Didot. The process: set the page in movable type as usual, take an impression of it in a mould of plaster or, later, papier-mâché flong, then cast a metal plate from that mould. The plate prints; the type is freed.

Stereotype changed three industries at once. For book printers, it meant a title no longer needed its type kept standing: print the edition, keep the light flong, cast fresh plates for the reprint, melt the old. The reprint, and with it the whole economics of the backlist, was born. For type foundries, it multiplied the market: printers needed less type, but foundries sold the plates' metal and the matrices. For newspapers, later, the flong could be bent into a half-cylinder, which is the key that unlocks the rotary press: curved plates for a round printing surface. The rotary press of the 1840s stands directly on stereotype's shoulders.

The last craft generation

The iron hand press had a long working life, from 1800 deep into the twentieth century, and in one place it never ended at all: the printing of fine books and the craft of letterpress. What it could not do was volume.

Even doubled, a hand press crew produced hundreds of impressions a day, and the nineteenth century's new readers, the cities of the industrial revolution, numbered in millions. The bottleneck was no longer the pressman's skill; it was his arm. The arm's replacement was already being built, not by a printer but by a jobbing engineer who had taught himself clockmaking in a German monastery's shadow. The steam press is the hinge of the whole story, and it begins, fittingly, with a rejection letter.

Workshop: make-ready, the pressman's art

Even the iron press was only as good as its make-ready, the craft of coaxing a perfect impression from imperfect materials. The type in a forme was never perfectly level; the paper never perfectly uniform; the platen's pressure never perfectly even. The pressman's answer was a layered micro-engineering: paste thin tissue under the low spots of the impression, cut away overlays over the heavy spots, adjust the packing of the tympan sheet by sheet, until the forme printed with an even, full, unembossed bite, black without smear, sharp without punch-through. On a fine book, make-ready could take a day per forme. The craft survives wherever letterpress survives, and its ethic, that quality is made in the last hundredth of a millimetre, never left the industry: offset pressmen still speak of makeready, and the word now means the whole setup of a press run.

Baskerville's obsession

The perfection of the iron-age impression had its prophet. John Baskerville of Birmingham, who had made his fortune japanning lacquer ware, turned to printing in the 1750s and rebuilt every element of the process in pursuit of a page of unprecedented clarity: his own type, cut with daring contrast; his own ink, ground finer and blacker; his own presses, rebuilt for accuracy; and paper hot-pressed, ironed between heated copper plates, to a glazed smoothness that took the sharp type without fuzz. The result, his Virgil of 1757 and the great Bible of 1763, astonished Europe and divided it; the English found the pages glaring, the continent found them sublime, and Bodoni and Didot took up the challenge. Baskerville shows the press at a fork: printing as craft nearing its technical summit, just before printing as industry abolished the summit's economics.

The Columbian's eagle

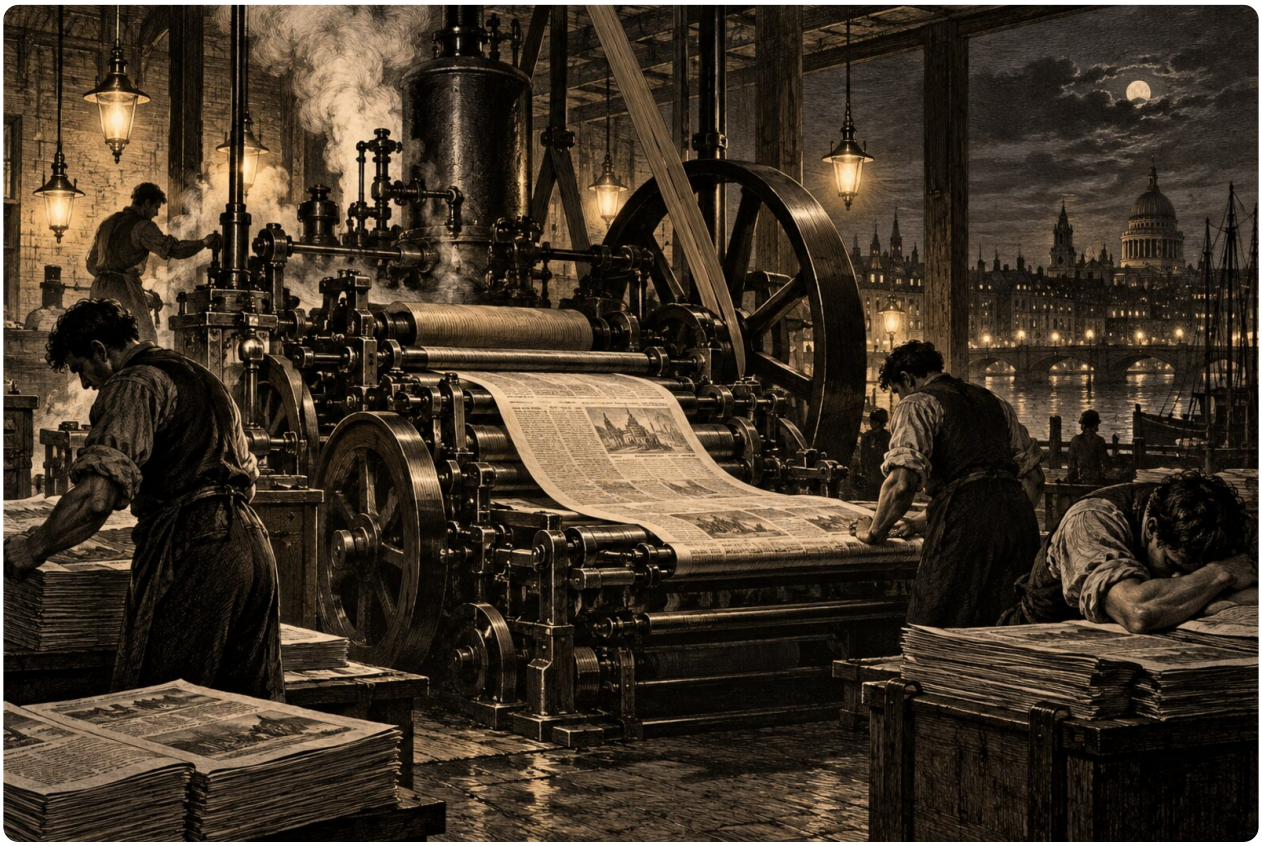
The ornamental iron presses are a reminder that machines have always been advertisements. George Clymer's Columbian of 1813 carried its counterweight as a gilded eagle clutching arrows and an olive branch, with serpents and cornucopias cast into the frame; the English Albion countered with austere functional elegance; the Americans, shut out of Clymer's market by his move to London, built their own Washington press. The iron hand press was the first printing machine to be a designed object, sold on appearance as much as action, and its look, massive, black, heraldic, fixed the popular image of "a printing press" for a century. When later

generations picture Gutenberg's press, it is usually a Columbian they are picturing, a machine three and a half centuries too young.

PART V · IRON, STEAM, SPEED

14 · Steam Reads The Times

In the small hours of 29 November 1814, in the offices of The Times in Printing House Square, London, the future of information changed hands. The pressmen waiting to print that day's paper were shown an already-printed copy, told that the newspaper had been printed by steam, and informed, in effect, that the age of muscle was over. The machine that did it was built by Friedrich Koenig, and the story of how it got there is the story of an industry being born against the will of an old craft.



The night of 28-29 November 1814: Koenig's steam cylinder press prints The Times at 1,100 sheets an hour.

Koenig's long road

Friedrich Koenig was born in 1774 in Eisleben, Saxony, trained as a printer, and taught himself enough engineering to see what printers could not: that the hand press's slow cycle, ink the type, lay the sheet, pull, lift, was a mechanical problem. His insight was to replace the flat platen pressing down on a flat bed with a

rotating cylinder rolling across it: the sheet travels under the cylinder, the impression happens in a moving line instead of a stationary press, and the machine can run continuously. Around 1803 he had a design; he took it to the printers of Germany and Russia and was turned away everywhere. In London he found his partner: Thomas Bensley, a forward-looking book printer, and with Andreas Friedrich Bauer, a precision engineer from Stuttgart who had joined him, Koenig built his machines in a workshop on White Cross Street, in conditions of intense secrecy.

The progression was deliberate. A steam-powered platen press printed a book sheet in 1811, the first page ever printed by steam. Then the full cylinder machine: in 1812 Bensley's shop printed the Annual Register on it, and John Walter II, the proprietor of The Times, ordered two machines, double-cylinder presses able to print both sides' formes in turn. Walter understood what he was buying. The Times was the most powerful newspaper in the world, and its pressmen, organised and militant, had the power to stop it. Walter hid the machines in a separate building. On the night of 28 November 1814 he told his pressroom there would be no paper until morning, and printed the edition of 29 November on the steam machines at 1,100 impressions an hour, roughly four times a hand press crew's rate.

The issue itself carried the announcement, in language any modern technologist would recognise: "Our journal of this day presents to the public the practical result of the greatest improvement connected with printing since the discovery of the art itself." The pressmen's livelihoods were indeed destroyed, in time, as steam spread to every great paper. The Times' rivals had no choice but to follow. Koenig and Bauer returned to Germany and in 1817 founded their own press-building works in a former monastery at Oberzell, near Würzburg. The firm they founded, Koenig & Bauer, is still building printing presses today: the oldest printing press manufacturer in the world.

The twin revolutions

The steam cylinder press created a problem that only another machine could solve. At 1,100 sheets an hour, then 2,000, then more, the demand for paper blew through the rag ceiling. Handmade paper could not scale; a sheet of hand-moulded paper was a craftsman's minute of work. The answer arrived from France by way of English capital: in 1798-99 Nicholas-Louis Robert patented a machine that formed paper on an endless moving wire mesh; the design was financed by the stationers Henry and Sealy Fourdrinier and engineered into a working machine by Bryan Donkin, with the first commercial Fourdrinier machines running at Frogmore, Hertfordshire, in the early 1800s. Paper now came off the machine in a continuous web, as fast as pulp could be poured. The printing press and the paper machine are twins: each is the other's demand and supply. Every later acceleration of print, rotary, web-fed, offset, would be met by the paper machine's own acceleration, and the pair still run in lockstep in every newspaper and packaging plant on earth.

The third leg of the nineteenth century's stool was pulp. Rag paper could not feed a mass press forever, whatever the machine; there were not enough old shirts. The escape came from wood: in the 1840s Friedrich

Gottlob Keller in Saxony patented mechanical groundwood pulp, and in the 1860s the chemical processes followed. Paper became a forest product, cheap beyond all precedent, and the price of the printed word fell to where the penny press could live.

What steam did to print

The cylinder press multiplied output fourfold in a night, and within a generation, with Napier's improvements and ever larger machines, tenfold and more. But its deeper effect was structural. Steam printing needed capital, engines, buildings, distribution; it concentrated the newspaper industry into great urban enterprises with national ambitions, and it made the daily paper, printed in the small hours and read by breakfast, a fixed institution of city life. The press had been a tool of publishers. It was becoming a utility of civilisation, run nightly, like the water and the gas.

"The greatest improvement since the discovery of the art itself"

The Times's own account of its steam night is worth reading closely, because the paper understood exactly what had happened. The editorial of 29 November 1814 told readers that the day's issue "presents to the public the practical result of the greatest improvement connected with printing since the discovery of the art itself": a machine "impelled by two large wheels" driven by steam, feeding itself, printing 1,100 sheets in an hour. The claim was true and the timing was theatre: Walter had the paper printed secretly, held the morning edition back, and confronted his pressmen with the accomplished fact. The compositors and pressmen of The Times had reason for their anger; within two generations their craft would be unrecognisable. But the economics were irresistible: the price of the paper could not fall, and its circulation could not rise, while a human arm drove the press.

Napier, Applegath, and the perfecting press

Koenig's machine printed one side of the sheet at a pass. The improvements came quickly: David Napier, a Scottish engineer, built his Nay-Peer presses with grippers and better inking, then the perfecting press, printing both sides in one passage by running the sheet through two impression points; Augustus Applegath and Edward Cowper, working for The Times, built in the 1820s a four-cylinder machine that printed some 4,000-5,000 sheets an hour, and Applegath's great vertical rotary of 1848 for the Great Exhibition era pushed the number higher still. Each increment came from the same method: replace reciprocating motion with rotation, hand work with feeding gear, and one stream of sheets with many. The printing machine was absorbing the whole grammar of the industrial revolution, power, feed, motion, and applying it to paper and ink.

The monastery factory

Koenig & Bauer's first works, the Kloster Oberzell, deserves its place in industrial history: a suppressed Cistercian convent on the Main, refitted in 1817 as a machine factory, with the church as an assembly hall. The symbolism is almost too neat: the monks' scriptorium become a press factory. From Oberzell the firm shipped cylinder presses across Europe and beyond, to the papers of Berlin, Vienna, Paris and Madrid, and to the book printers of Leipzig; it survived wars, hyperinflation, and the destruction of its factories in 1945, to rebuild into the modern group. The direct line from Koenig's steam cylinder to the banknote presses and packaging giants of today's Koenig & Bauer is the longest continuous thread in the machine side of this book: two hundred and eight years of one company building the press.

The night itself

The drama of 29 November 1814 was staged with a printer's cunning. Walter had the Koenig press installed in secrecy in a neighbouring building, because the pressmen had already wrecked machinery elsewhere and the compositors of The Times were watching for exactly this threat to their trade. On the appointed night the crews stood ready at their hand presses for the usual run, and Walter walked in with the paper already printed: The Times is already printed, by steam. The shock in the room was the future announcing itself. The machine more than doubled output that first night, and within years the double-cylinder successors ran several thousand sheets an hour; The Times's circulation, and its power, climbed with the machine's speed. The secrecy had a sequel the trade remembered: the unions and the speed of the steam press began their long contest that night, and it did not end until the composing rooms themselves were abolished a hundred and sixty years later.

PART V · IRON, STEAM, SPEED

15 · The Rotary Age

The cylinder press of 1814 still printed from a flat bed that had to travel back and forth under the cylinder, stopping and starting with every sheet. The final geometric leap of mechanical printing was to make everything round: type curved onto a cylinder, paper fed as a continuous web, printing as an unbroken rolling contact. With that leap the daily newspaper became a mass product, and with the mass newspaper came the first genuinely planetary news culture.

Hoe and the revolving type

The rotary idea was in the air; Koenig himself had sketched versions. The man who made it work in production was Richard March Hoe of New York, heir to his father Robert's press-building firm. Hoe's

1843 "lightning press", patented in improved form as the type revolving machine in 1846, fixed the flat pages of type, held by a system of wedge-shaped column rules, onto the surface of a great central cylinder; around it, impression cylinders fed sheets, each tended by a boy who laid the paper in. The Philadelphia Public Ledger installed Hoe's machines; the numbers climbed vertiginously: thousands of sheets an hour, then, with more feeding cylinders, ten thousand, twenty thousand. An eight-cylinder Hoe press was a landmark of the industrial city, and the firm of R. Hoe & Company became the American counterpart to Koenig & Bauer, exporting presses across the world.

The type revolving machine had an absurdity at its heart: locking flat pages of movable type onto a curved surface, held by ingenious wedge rules, always threatening to burst. The real solution came from stereotype: cast a papier-mâché flong of the page, bend it into a half-cylinder, cast a curved plate, and bolt plates to the cylinder. Curved stereotype plates made the true rotary press, and rotary plus stereotype became the standard anatomy of newspaper printing for a century. Then came the last geometric gift: the web. If paper could be made in an endless ribbon, the press could print an endless ribbon, and a rotary press fed from a giant roll, printing both sides continuously and cutting and folding the web into finished papers in the same pass, achieved the full form of the newspaper machine. By the 1860s and 1870s web-fed perfecting presses were in service, and by the 1890s Hoe's masterpieces could print, cut, fold and count tens of thousands of complete multi-page newspapers per hour.

The penny press and the mass reader

The machine's social product was a new kind of paper. When the printing of a copy costs a fraction of a penny, the paper can sell for a penny, and at a penny the customer changes: not the gentleman with a subscription but the clerk, the mechanic, the shopgirl buying from the newsboy. The New York Sun (1833) and James Gordon Bennett's Herald (1835) built the model in America: cheap paper, street sales, human-interest news, crime, sensation, and above all advertising, which paid the bills that pennies could not. The same arithmetic produced the Daily Telegraph and later the Daily Mail in London, Le Petit Journal in Paris with a million copies a day by the 1890s, and the great urban dailies everywhere.

Around the mass newspaper grew the machinery of a world information system. The telegraph, arriving in the 1840s, let the evening paper print the day's distant news; the news agencies, Havas (1835), Wolff (1849), Reuters (1851), the Associated Press (1846), organised the wholesale trade in facts; the Atlantic cable of 1866 put New York and London in the same news day. Photography entered the paper through the halftone process in the 1880s and 1890s, which broke a photograph into a screen of dots that relief printing could carry, and the illustrated daily was complete: words, pictures, advertisements, printed by the ton, read by breakfast.

Printing as heavy industry

By 1900 the great newspaper plant was a factory among factories: rolls of paper arriving by rail from groundwood mills in Canada or Scandinavia, engines and then electric motors driving lines of presses through the night, stereotypers casting plates by the hundred, fleets of wagons and then trains carrying the edition out before dawn. The press had become heavy industry, with heavy industry's economics: vast fixed capital, thin unit margins, ruthless time discipline, and a workforce organised into powerful craft unions, the stereotypers, pressmen, machinists and, upstairs, the compositors whose world the next machine was about to make and then unmake. The rotary age also gave the press its modern face in public life: the press baron. Pulitzer, Hearst, Northcliffe and their kind owned what were, in effect, the only mass media in existence, and they used them for politics and war as readily as for news. The rotary press made the daily world legible to millions, and made the opinion of millions a thing that could be manufactured.

Workshop: casting a curved page

The stereotype process that fed the rotary press deserves its step-by-step, because it made the modern newspaper's geometry possible. The compositors set the page in type; the stereotypers beat a damp papier-mâché sheet, the flong, into the forme with a stiff brush, driving it into every letterform; dried, the flong came away as a flexible mould of the whole page. The flong was curved in a casting box and molten stereotype metal poured in: out came a half-cylinder plate bearing the entire page in relief, ready to bolt to the press. After the run, the plates went back to the melting pot and the flongs to the archive, cheap, light, re-castable, so that a second edition at 2 a.m. meant new plates, not new typesetting. The stereotype room of a great daily ran like a bakery: flongs in, plates out, plates in, metal out, all night, every night.

The picture paper

The rotary age also solved the image. Wood engraving, the end-grain boxwood block that could be printed with type, had carried illustration to its summit in the Illustrated London News (1842) and Harper's Weekly, whole visual news services drawn, engraved and printed weekly. Then the halftone arrived: by the 1890s photographs printed directly in the daily paper, and the visual grammar of news shifted from the artist's reconstruction to the camera's evidence. Colour followed: the colour comic supplements of the 1890s, the Yellow Kid's press war between Pulitzer and Hearst, gave both a phrase, yellow journalism, and a new driver of circulation. The modern newspaper's full anatomy, words, photographs, colour, advertising, all printed at rotary speed, was complete by 1900, and its form would hold for a century.

The barons

Mass print made mass politics. Joseph Pulitzer's World and William Randolph Hearst's Journal pushed New York circulation past a million on sensation, stunts and crusades, and their rivalry helped stampede the

country toward the Spanish-American War. In Britain, Alfred Harmsworth, later Lord Northcliffe, built the Daily Mail (1896) into the first paper consciously engineered for the new mass literate lower-middle class, and used its power openly as a political instrument. The rotary press had made the reader a commodity, sold to advertisers, and the newspaper a power of the first rank: the "fourth estate" in full armour. The lesson of the barons has never expired: whoever owns the means of multiplication owns a share of the public mind, and the argument over that ownership, in print then, in platforms now, is one continuous argument.

The press as factory

The mature rotary plant of the late nineteenth century was a factory that happened to print. Web presses took paper from the roll, printed both sides in one pass, and delivered folded, counted signatures at the delivery end; the stereotyping department cast curved plates from flong moulds of the composed pages; duplicate plates meant the same page could print on several presses at once. Output climbed from thousands to tens of thousands of copies an hour. The engineering spread outward from the newspaper: rotary presses for books, for magazines, for catalogues, colour presses laying successive impressions in register for the illustrated weeklies. Each unit of the line existed to keep the cylinder turning, because a rotary press made money only while it ran: the industry's fixation on makeready time, waste and uptime, still the language of pressrooms today, was born here. The printing works had become continuous-process industry, closer in spirit to a rolling mill than to Gutenberg's room, and the men who ran it thought of themselves, accurately, as industrialists.

PART V · IRON, STEAM, SPEED

16 · The Line-Casting Machines

By the 1880s the newspaper's bottleneck had moved upstream. Rotary presses could print a hundred papers for every page the compositors could set. A page of the New York Tribune was set by hand, letter by letter, from the case, at the pace a good compositor had maintained since Gutenberg: about 1,500 letters an hour. The industry's next great machine attacked the composing room itself, and it is one of the most ingenious mechanisms ever built: the Linotype.



A newspaper composing room of the 1890s: rows of Linotypes casting each line of type from molten metal as fast as the keys are struck.

Mergenthaler's assembler

Ottmar Mergenthaler was a German watchmaker who emigrated to Baltimore in 1872, and he approached typesetting as a watchmaker would: as a problem of storing, selecting and re-sorting many small precise parts. His solution, perfected through years of failed prototypes and bankrolled patrons, chief among them the stenographer James O. Clephane who had conceived the commercial dream of the machine, inverted the old system. Instead of casting type and then composing it, the Linotype composes matrices and casts the whole line at once. The operator sits at a keyboard; each keystroke releases a brass matrix, a little female stamp of one letter, from a magazine of channels overhead; the matrices assemble in a line, with expanding wedge-shaped spacebands between the words. When the line is complete, the machine justifies it by driving the wedges until the line is exactly full, carries the assembled matrices to the mould wheel, and casts the line as a single metal slug, a "line o' type", from the same lead-tin-antimony pot Gutenberg would have recognised. The matrices are then lifted to the top of the machine and distributed back into their channels by a toothed bar that reads the pattern of teeth cut in each matrix, so the machine sorts its own letters for the next line. Melt the slugs, and the whole page is metal again.

The machine was first used commercially on 3 July 1886 to set part of that day's New York Tribune. Whitelaw Reid of the Tribune had financed it; the Mergenthaler Linotype Company of Baltimore manufactured it. The performance revolution was immediate: an operator could set six thousand characters

an hour and more, four or five times the hand rate, and the slugs needed no redistribution of type. Newspapers fattened, evening editions multiplied, and the composing room became a battery of clattering keyboards. The Mergenthaler company became one of the great machine-building enterprises of the age, selling tens of thousands of machines worldwide and supplying, in effect, the entire daily press.

Monotype and the book trade

The Linotype's rival came from a civil servant in Washington. Tolbert Lanston's Monotype, patented in 1887 and industrialised in the 1890s, split the job in two: a keyboard that perforated a paper tape with coded holes, and a caster that read the tape and cast individual types, arranging them in lines and pages. Where the Linotype cast a line as one slug, fine for a newspaper column that will be melted tomorrow, the Monotype cast single sorts, so a single letter could be corrected without recasting the line, and the caster could also produce foundry type for hand work. The Monotype found its market in book and journal printing, where corrections and quality mattered; the British Lanston Monotype Corporation, founded in 1897, made it the composing engine of the world's book trade, and its typefaces, Garamond, Bembo, Times New Roman (drawn for The Times of London in 1931 and released by Monotype in 1932), defined the look of the twentieth-century book.

Hot metal's empire

From 1890 to 1970, hot metal ruled: the Linotype and its kin for newspapers and jobbing, the Monotype for books. The system had its own sensory world, the roar of the linotype hall, the lead pots at three hundred degrees, the smell of hot metal and machine oil, and its own sociology: the International Typographical Union, one of the oldest and strongest craft unions, guarding a trade that took years to learn. It also had a hidden fragility. Hot metal is a system for committing text to a rigid physical form, and every correction is a small foundry operation. When a cheaper, lighter way of composing appeared, the empire would collapse with a speed that astonished its masters. But for three generations, the daily world was literally cast in metal every night, on machines whose descendants, in a few composing rooms and museums, still run.

Workshop: the Linotype's round trip

Watch a Linotype through one cycle, because its circulation is one of the most beautiful solutions in machine history. The operator's keystroke lifts a trigger in the 90-channel magazine overhead; a brass matrix slides down a channel to the assembler, joining the line in progress, with wedge-shaped spacebands dropped between words. The operator touches the send lever; the line is carried to the justification block, where the spacebands are driven upward until the line of matrices is wedged to exactly the measure, no hand-spacing, the machine justifies mechanically. The line moves to the mould wheel; a plunger forces molten type metal from the pot into the matrices' faces and the mould behind them; the wheel turns, trimming knives square

the slug, and the finished line of type drops into the galley. Meanwhile the matrices ride the second elevator to the top of the machine, where the distributor bar, cut with a pattern of teeth that matches the tooth pattern on each matrix, carries each matrix along until its pattern lets it drop, back into its own channel. Nothing is filed by a human hand. The machine is a complete materials-handling system for information, built in 1886, and it is no surprise that its inventor was a watchmaker.

The composing room

The linotype hall of a great newspaper was a place apart: hundreds of machines in rows, the roar like a factory's, the heat of the metal pots, the smell of lead and oil, the operators setting straight from reporters' copy at speed, the proof presses in the corner, the compositors "making up" pages from galleys on the stone, the imposing table that gave the whole craft its furniture's name. The trade was unionised to the bone: the International Typographical Union, founded 1852, controlled entry, wages and, critically, jurisdiction over every keystroke. The ITU's strength made composing one of the best-paid crafts in industry, and it made the technological transition of the 1970s a war. When photocomposition and then direct input by journalists arrived, the unions fought to keep the typesetting of advertising and copy as their own; the "bogus" or "reproduction" type-setting, union men re-setting ads that would be thrown away, became the symbol of a craft pricing itself into automation. The end, when it came, was total: the composing room, the loudest room in the building, went silent in a decade.

The faces of hot metal

Hot metal's empire had an aesthetic bureaucracy: the type drawing offices of Mergenthaler Linotype and Lanston Monotype, which commissioned and produced the twentieth century's workhorse faces. Linotype's legibility group, developed with research into newspaper reading, Ionic, Excelsior, Corona, set the news of mid-century; Monotype's program under Stanley Morison revived the great historical faces, Garamond, Bembo, Plantin, Baskerville, Poliphilus, and commissioned new ones, Perpetua, Gill Sans, and, for The Times in 1931-32, Times New Roman, drawn by Morison with Victor Lardent and released generally in 1932. Times New Roman may be the most used typeface ever made, the default voice of the typed and printed century. The hot-metal houses thus did for the twentieth century what Griffo did for the sixteenth: they drew its letterforms, and their revivals still set a large share of the world's books.

Etaoin shrdlu

The line-caster created its own culture, and its own accidental monument. The Linotype keyboard was not a typewriter's: its keys ran down the left in order of letter frequency, ETAOIN SHRDLU, and a compositor who made an error finished the line by running a finger down the rows to eject it whole rather than stop to correct, because a half-set line risked squirting molten metal. Occasionally the botched line escaped the

hellbox and reached print, and etaoin shrdlu appeared in the paper, a ghost in the machine visible to millions. The hot-metal composing room was loud, hot, exacting and unionised, one of the aristocracies of industrial labour, and it died within a decade: when the New York Times ended hot-metal production in July 1978, the ceremony was broadcast, the last line cast to cheers, and a five-hundred-year-old way of making text passed, with surprising speed, from a skilled trade to a museum exhibit. The machines went for scrap by the thousands; the survivors are now loved by a letterpress revival their inventors could not have imagined.

PART VI

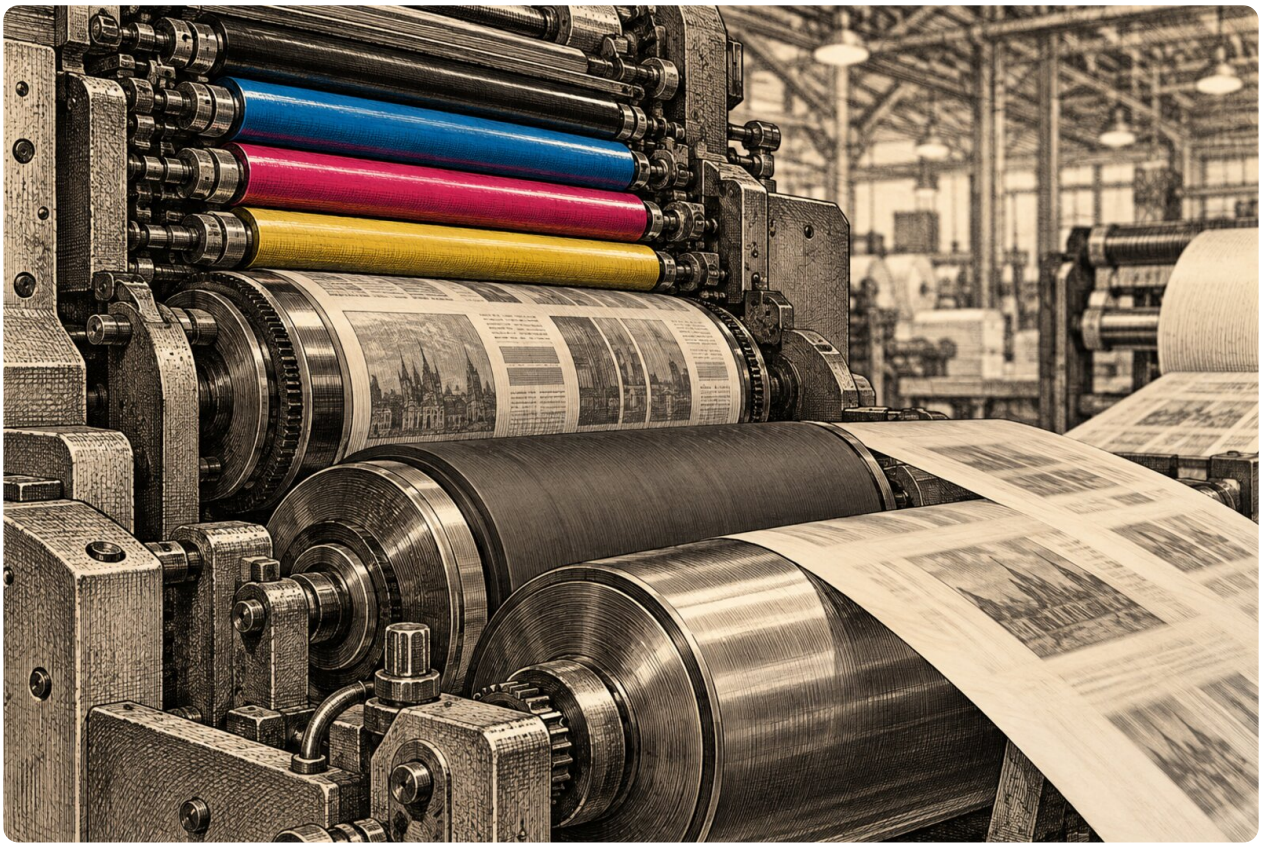
Light, Chemistry and the Second Revolution

Grease, water and light: lithography, offset and the photographic page.

PART VI · LIGHT, CHEMISTRY AND THE SECOND REVOLUTION

17 · The Stone of Solnhofen

Everything described so far is relief printing: the raised surface takes the ink. In 1796, in Munich, a broke young playwright discovered that you can print from a surface with no relief at all, using nothing but the mutual hostility of grease and water. Lithography, "stone writing", is the press's second birth: the invention of chemical printing, and the distant parent of the offset process that would come to dominate the industry.



An offset printing unit: plate, rubber blanket and impression cylinders in train, the chemistry of grease and water at rotary speed.

Senefelder's accident

Alois Senefelder was an actor's son from Prague who wanted to publish his own plays cheaply and could not afford type. Experimenting with etching on the fine limestone quarried at Solnhofen in Bavaria, the same stone that preserves the Archaeopteryx, he noticed the fact that founded the industry: if you write on the polished stone with a greasy ink and then wet the surface, printing ink rolled over it sticks to the greasy writing and is repelled by the damp stone. No engraving, no relief, no intaglio: a flat surface divided

chemically into image and non-image. He spent years systematising the discovery, published his complete manual of the art in 1818, and died in 1834 having seen his process spread across Europe.

Lithography's gift to the press was the image. Relief printing could carry illustrations only as woodcuts and engravings bolted alongside type; the stone could carry anything a crayon could draw, freely, tonally, in the artist's own hand. Through the nineteenth century it became the medium of music publishing, maps, business forms, art reproduction, and above all the poster: chromolithography, printing in successive colours from successive stones, filled the walls of Paris with the posters of Chéret and Toulouse-Lautrec and gave the industrial city its first colour-saturated public imagery. It also quietly invented the modern concept of planographic printing: the print as a photograph-like transfer rather than an embossed bite.

From stone to plate

The stone was a dead end as a production surface, heavy, fragile, and flat-bed slow, but the chemistry was immortal. Zinc and aluminium replaced limestone; the flat stone became a thin grained metal plate wrapped around a cylinder; and the plate's perfect surface let lithography migrate onto rotary machinery. The remaining problem was contact: a hard plate printing directly on paper wears fast and demands a perfect surface. The fix came, as in so many printing stories, by accident, on a rotary press in Nutley, New Jersey, in 1904. Ira Washington Rubel, a printer of paper bags and labels, noticed that when his press's cylinder missed a sheet, the image printed onto the rubber-covered impression cylinder, and the next sheet then received the image twice, once from the plate, sharp and wrong-signed, and once, offset, from the rubber: and the offset impression was noticeably better, softer, cleaner, kinder to rough paper. Rubel did what inventors do: he built a press to do the mistake on purpose, with a rubber-blanket cylinder between plate and paper. Offset lithography was born.

Offset's long takeover

The offset press triangulates the process: the plate, damped and inked, prints onto the rubber blanket; the blanket prints onto the paper. The rubber conforms to any paper, the plate never touches the sheet and lasts far longer, the image is right-reading on plate and blanket alike, and the press can run at rotary speeds. Through the first half of the twentieth century offset grew at the edges, labels, tin printing, posters, while letterpress kept books and newspapers. After the Second World War, with better plates, better presses, and photographic platemaking, the balance broke: offset was cheaper per impression at scale, kinder to halftone photography, and free of hot metal's mass of lead. By the 1960s and 1970s it had absorbed the book trade; by the 1970s and 1980s, with web offset newspaper presses and photo-composed pages, it took the newspapers too. Senefelder's grease-and-water trick, multiplied by Rubel's rubber blanket, is today the standard method by which the world's books, magazines, cartons and newspapers are printed: the descendant of a playwright's accident on Bavarian limestone.

Workshop: drawing on the stone

Lithography's workshop is the opposite of the type foundry: no metal, no mould, just stone, grease and water. The artist grinds a slab of Solnhofen limestone level with sand and water, then draws directly on it with a greasy crayon or liquid tusche; the drawing sinks its grease into the stone's open pores. The stone is etched with a weak gum-arabic and acid bath that fixes the image chemically, desensitising the blank stone to ink; it is then kept damp while the printer rolls on oil-based ink, which the greasy drawing accepts and the wet stone refuses. Paper is laid, the stone passes through the scraper press, and the impression comes away. Colour work means a stone per colour, drawn in registration; the great chromolithographic houses used a dozen or more stones for a single poster, and the registration craft, each colour landing exactly on the last, was their living. The chemistry is the whole secret: image and non-image differ not in height but in appetite.

The poster city

Chromolithography painted the industrial city. From the 1860s, Jules Chéret's Paris posters, then Toulouse-Lautrec, Mucha, and a thousand commercial hands, turned hoardings into an open-air gallery; the poster became the first truly mass visual advertising, and the trade that produced it, large-format stones, steam litho presses, specialist houses, was a major branch of printing in its own right. The poster's descendants are obvious; less obvious is that lithography also carried the century's practical colour: sheet music covers, maps, trade cards, seed catalogues, box labels, cigarette cards. Before the colour magazine or the colour newspaper, the city already lived in printed colour, thanks to the stone and its metal-plate successors.

The tin and the tube

Lithography also colonised surfaces paper never saw. Printing on tinplate, for biscuit tins, tobacco boxes and later the whole canned-goods shelf, was an offset process avant la lettre: the image printed from stone or plate onto an intermediary and then onto the metal, because metal takes no direct impression kindly. Transfer printing decorated ceramics; the litho-decorated enamel sign covered the railway stations of the world. These trades look like footnotes; industrially they were the rehearsal for offset's rubber blanket and for the press's modern dominance of packaging. The lesson repeats: in printing, the side trades invent what the main trade later adopts.

The chromolithographic century

Lithography's first century was a slow conquest of everything letterpress could not do well. Music printing moved to the stone early, because notation drew better than it composed; maps followed, and labels, certificates, banknotes, playing cards and the whole chromatic overflow of Victorian commerce. Chromolithography, colour built up stone by stone, a dozen or more impressions in register, produced the saturated advertising cards, art reproductions and packaging of the century's second half, and in Paris the

process climbed to art: Jules Chéret's posters turned the boulevard into a gallery, and Toulouse-Lautrec made the lithographic poster a major form. The trade grew vast and nearly invisible, its product everywhere and its name nowhere. But lithography on stone was heavy, slow and skilled; stone gave way to zinc and aluminium plates, and the flatbed gave way, after Rubel's discovery, to the offset cylinder. By the mid-twentieth century the offset litho press, plate, blanket, impression, had absorbed nearly all of lithography's old trade and most of letterpress's too, and 'litho', unqualified, came to mean the process that had begun with a laundry list written on a stone.

PART VI · LIGHT, CHEMISTRY AND THE SECOND REVOLUTION

18 · Light Sets the Type

The twentieth century's decisive change to the press was not in the pressroom but in what the pressroom received. Composition and platemaking went photographic: text became light written on film, plates became photographs etched in metal, and the half-millennium reign of cast metal type ended in less than a generation. The press that Gutenberg made of lead became, at last, a machine for reproducing light.



The halftone under the loupe: continuous tone translated into dots, the sampling trick that let presses print photographs.

The halftone: photography learns to print

Relief and lithographic presses print ink or no ink; they cannot print grey. The photograph is all grey, and for fifty years after photography's invention the daily press could not print it. The halftone screen solved the problem by translation: photograph the original through a ruled glass screen, and the greys become a field of dots, large dots in the shadows, pinpoints in the highlights, that trick the eye at reading distance. Patents accumulated through the 1850s to 1880s; the practical process arrived in the 1880s and 1890s, and the illustrated daily was born. Every photograph in every newspaper and magazine of the twentieth century is a halftone, a picture coded as texture so that a binary machine can carry it. The halftone is also, in disguise, the first great act of sampling, the conversion of a continuous world into dots for a machine, which is the conceptual hinge between the nineteenth-century press and the digital one.

Phototypesetting: the letter as light

If a picture can be photographed for the press, so can a letter. Phototypesetting machines, maturing from the late 1940s, carried type as photographic negatives, fonts on glass discs or film strips, and composed by exposing character after character onto photosensitive paper or film, at speeds hot metal could not approach and with no lead, no pot, no slug. The composing room changed its air: out went the roar of the line-casters, in came the quiet hum of exposure units and the darkroom. For the printers it was cheaper and faster; for the compositors' unions it was extinction, fought bitterly in the newspaper strikes of the 1970s from London to New York.

The generational change completed itself with the computer. Digital typesetting, type stored as numerical outlines, composed on screens, output to film, arrived through the 1970s and 1980s, and in 1984-85 three products fused into a revolution: the Apple Macintosh, the LaserWriter printer, and Adobe's PostScript page-description language, with Aldus PageMaker composing whole pages on a screen. Desktop publishing put the composing room on a desk. Linotype and Monotype, the foundry-machine empires of 1886, shrank into digital type businesses; Compugraphic and the phototype giants vanished; and an occupation of half a million skilled hands, the compositor, disappeared from the industrial statistics in barely twenty years. The press downstream cared little: it had been receiving its image on film for decades. What it received now was film made by computers, and soon, with computer-to-plate, no film at all.

The meaning of the change

It is worth stepping back, because this is the moment the item of this book mutates. From 1450 to 1950, "the printing press" was a foundry product: a machine for multiplying cast-metal formes of text. After 1950, the foundry evaporated out of the process, and the press became a reproductive machine fed by light and then by data. The type did not vanish; it dematerialised, and its design, the punchcutter's art, passed to a new craft of

digital type founders drawing curves on screens. The next part follows the dematerialisation to its end: presses that print not from formes or plates at all, but straight from the file.

The dot's arithmetic

The halftone deserves its own look, because it is the ancestor of every pixel. A halftone screen divides the image into a grid of cells, each cell printing one dot; the dot's size carries the tone, coarse screens of 65 to 85 lines per inch for newsprint, 133 to 175 for fine book work, 300 and beyond for the best. Rotate the screens for each colour at precise angles, 30 degrees apart, and the dots interleave into rosettes instead of moiré; look at any colour magazine picture through a linen tester and the rosettes are there, the fingerprint of process colour. The whole of four-colour printing rests on this: three inks and black, screened at angles, synthesise the visible world from dots. Digital sampling, display pixels, even the dither of an inkjet, are the halftone's children, and the child's logic is the parent's: a binary machine, ink or no ink, made to perform a continuous world.

Wapping: the last battle of hot metal

The collision between the new composing and the old unions had its set-piece battle. In January 1986 Rupert Murdoch's News International moved its London papers overnight from Fleet Street to a secretly built plant at Wapping, staffed by electricians' union members running computer-to-plate photocomposition, and dismissed some five thousand print workers. The year-long strike that followed, mass pickets, police charges, the end of the closed shop in British national newspapers, broke the power of the print unions and restructured an industry: papers grew fatter, colour came in, costs fell, and Fleet Street's identity as the home of the press ended within a few years. Wapping is remembered as a labour story; it was equally a technology story, the press completing its transition from foundry to electronics, with the men of the foundry paying the price.

The craft diaspora

Where did the compositors' knowledge go? Partly into the new roles, the paste-up artists and scanner operators of the offset age, and then the desktop operators and pre-press technicians; partly out of the industry entirely. Yet the craft's standards survived the craft: the typographic conventions the computer inherited, measures, leading, hyphenation and justification rules, ligatures, quotes, were all composing-room law, encoded into PostScript, into desktop software, into the digital fonts that still bear the hot-metal names. The Linotype operator is gone; the line he justified remains, set now by an algorithm that enforces, more or less well, the same discipline. Machines retire; their rules persist.

The machines of light

Phototypesetting had its own machine genealogy, and it ran fast. The Intertype Fotosetter of 1950 put a camera inside a line-casting machine, photographing matrices instead of casting them; the Lumitype-Photon, developed in France by Rene Higonnet and Louis Moyroud from the mid-1940s and commercialised in the 1950s, carried fonts on a spinning glass disc and flashed characters onto film at speeds metal could never reach. The second generation replaced the spinning disc with a cathode-ray tube, the letter drawn by an electron beam, and speeds climbed into thousands of characters a second. Each generation stripped mass out of composition: first the pot of molten lead went, then the mechanical matrix, then the machine itself, until composition was a program and the font a file. The foundries' assets, a century of type design, survived the transition better than their machines: the great libraries of Times, Helvetica, Garamond and their kin were redrawn as outlines and licensed as software, and the punchcutter's five-hundred-year craft became a design discipline practised on screens, which is its present form.

Part VI · Light, Chemistry and the Second Revolution

19 · Gravure, Flexo, Screen

Three great printing processes never get their portraits painted. Letterpress had Gutenberg, lithography had Senefelder, offset had its accident in Nutley; but the gravure cylinder that printed the Sunday magazine, the rubber plate that printed the bread bag, and the silk screen that printed the T-shirt, the poster and the circuit board did their work in the trade's background, unnamed on the title page of the visible world. They are the quiet processes, and no honest account of the press as an industry can leave them out, because between them they carry most of what the modern world actually prints.

The ink in the hollows

Every process so far in this book prints from a surface: the raised face of type, the grease-marked plane of the stone, the rubber blanket's chemistry. Gravure prints from a void. The image is engraved or etched into a copper surface as millions of tiny recessed cells; the whole cylinder is flooded with thin ink, a steel doctor blade wipes the surface clean, and the paper is pressed against the cells and pulls the ink out of the hollows. It is intaglio, the third great family of printing, and its logic is the reverse of relief: where letterpress prints what stands up, gravure prints what is dug out.

The craft descends from the engraver's burin and the etcher's acid, and its photographic form arrived with the same nineteenth-century marriage of light and chemistry that produced the halftone. Karel Klíč, a Czech

painter working in Vienna, brought the photogravure to commercial viability in 1879, building on Talbot's earlier experiments: a copper plate grained with resin dust, a carbon tissue carrying the photographic image, acid biting the tones into the metal in differing depths. Deep cells hold more ink and print darker; shallow cells print pale. Gravure therefore renders tone not as dots of varying size, like the halftone, but as wells of varying depth, and the result has a velvety continuous richness that no relief process could touch. For a century it was the connoisseur's process for art books and the workhorse's process for long runs.

The workhorse version came when the plate wrapped itself into a cylinder. Rotogravure, gravure printed from an etched cylinder on a web of paper, married intaglio quality to rotary speed, and through the twentieth century it owned a particular kingdom: the high-circulation illustrated magazine and the Sunday newspaper supplement, where millions of copies of the same rich photographs had to be printed fast. The Library of Congress's collections of First World War newspaper pictorials survive as rotogravure sections, printed by exactly this route. Gravure's economics were always polar: the cylinder was expensive to engrave and nearly immortal in the run, so the process rewarded enormous editions and punished small ones. When magazine circulations shrank, gravure's kingdom shrank with them. It survives where runs remain huge and substrates awkward: packaging films, gift wrap, wallpaper, decorative laminates, the wood-grain print on a furniture panel.

The process that printed the pantry

Flexography began as a joke at its own expense. In 1890 the Liverpool firm of Bibby, Baron and Sons patented a rotary press printing with rubber plates and a water-based aniline dye ink; the ink smeared so readily that the trade called the machine Bibby's Folly. The idea was sound and the chemistry was not yet: a flexible relief plate that could wrap around a cylinder and print on surfaces too rough, too soft or too absorbent for anything else. Through the early twentieth century the aniline press, named for its dye inks, ground on in the lowliest corner of the trade, printing paper bags, wrapping paper and gummed tape, until better inks, better plates and, decisively, the engraved anilox roller, which meters ink to the plate in a precise, microscopic film, turned a smearing novelty into a precision process. Renamed flexography in 1952, it inherited the entire world of packaging.

That inheritance is the point. Walk down a supermarket aisle and nearly everything flexible that is printed, the crisp packet, the bread bag, the frozen-food film, the corrugated shipping case, the label, the paper cup, is flexo's work. It is relief printing reborn for the polymer age: photopolymer plates imaged digitally, solvent or water or UV inks drying in seconds, webs of film running at hundreds of metres a minute. Flexo asks no prestige and gets none; it is absent from the coffee-table histories. But measured by the area of printed surface the average person touches in a day, flexography is very likely the dominant printing process on earth, the anonymous hand on the pantry shelf. The press's oldest family, relief, having lost the book and the newspaper, quietly took the package as compensation.

The sieve that prints on anything

The third quiet process is the humblest of all: a stencil and a sieve. Screen printing forces ink through a fine mesh, originally silk, stretched on a frame; where a stencil blocks the mesh, no ink passes, and where the mesh is open, a squeegee pushes a thick film of ink straight onto the surface below. Stencil printing through fabric has Asian roots reaching back a thousand years, refined in Japan into an art of delicate paper stencils for textiles; the industrial process arrived with Samuel Simon's Manchester patent of 1907 and found its American century in signage, posters and textiles. Because the ink film is thick and the pressure trivial, screen prints where no other process can: on glass, metal, ceramics, wood, fabric, bottles, instrument panels, and surfaces that are not flat at all.

Its two great chapters could hardly be less alike. The first is cultural: in the 1960s the screen print became the medium of the poster and the art multiple, the thick flat colour of the concert bill and Pop Art, the process that put an image on every T-shirt on earth. The second is industrial and invisible: screen printing is the precision deposition tool of electronics, printing the conductive pastes, resist layers and solder masks of the circuit board, the electrodes of the solar cell, the membrane switch, the thick-film sensor. The same sieve that printed the rock poster prints the photovoltaic panel. When the next chapter's story reaches printed electronics, it is worth remembering that the oldest stencil is still one of the industry's sharpest instruments.

Why the quiet processes matter

The visible history of printing is written in its prestige products: Bibles, newspapers, novels, posters. The material history is written in its tonnage, and there the quiet processes rule. Gravure took the long illustrated run; flexo took the package; screen took the object that would not lie flat under a press. None of them displaced the famous processes; they annexed the territories the famous processes could not serve, the film, the foil, the corrugated board, the curved surface, the electronic substrate. Together they make the same point this book has argued from the beginning: the press is not one machine but a principle, deposit a precise pattern of material on a surface, cheaply, at scale, and the principle is indifferent to whether the surface is a page. The world's most influential printing is the printing nobody reads.

The package economy

Flexo's kingdom deserves one more look, because it is where the press now earns its living. The corrugated shipping case is printed by the hundred billion a year, a flexo product so ordinary that the world's trade literally moves inside it; the flexible film pouch displaced the tin can and the glass jar across whole aisles of the supermarket on the strength of flexo's ability to print thin, extensible plastic at speed; the label, pressure-sensitive, shrink-sleeved or in-mould, is a flexo-and-digital duopoly. The process's modern form is high technology in overalls: photopolymer plates imaged by laser, ceramic anilox rolls engraved with billions of laser-cut cells, automatic register and viscosity control, LED-UV curing. Nothing about it appears in a

museum of the book, and everything about it appears ten times a day in the reader's hands. The printing press of the twenty-first century is, by volume, a machine for printing packaging, and its ancestry runs through Bibby's Folly, not through Mainz.

PART VII

The Electronic Page

Xerography, digital presses and the network the press made possible.

PART VII · THE ELECTRONIC PAGE

20 · 10-22-38, Astoria

The humblest caption in the history of printing is a notation written in ink on a glass slide in a rented room above a bar in Queens, New York: "10-22-38 ASTORIA". It is the first xerographic copy ever made, and from it descends the machine that did more than any other to put a press in every office: the photocopier, and behind it the laser printer, the press's smallest and most numerous descendant.

Carlson's dry copy

Chester Carlson was a patent attorney in New York, trained in physics, and his problem was practical: patent specifications had to be copied, and copying was slow, wet, expensive drudgery. Carbon paper, the mimeograph, the photostat: every existing answer was a compromise. Carlson's reading in physics suggested another road. Certain materials, sulphur among them, hold a static electric charge in the dark and lose it where light falls. Expose an image onto a charged plate, and you have a pattern of charge matching the image; dust it with a powder that clings to the charge, and you have a visible picture; press the powder onto paper and fix it with heat, and you have a copy, made dry, from any original, in a couple of minutes. On 22 October 1938, in Astoria, with an unemployed Austrian physicist named Otto Kornei as assistant, Carlson made the process work, copying the date and place onto a waxed paper. He called it electrophotography; the world would call it xerography, dry writing.

The industry wanted nothing to do with it. Carlson shopped the invention for years; twenty companies, including the giants of office equipment and photography, turned it down. It was the Battelle Memorial Institute in Columbus, a research foundation, that took it up in 1944, and a small photographic-paper company in Rochester, the Haloid Company, that bet the firm on it. After years of development the bet paid off beyond all precedent: the Xerox 914 of 1959, the first plain-paper office copier, became one of the most successful single products in American industrial history, and Haloid became Xerox. The office copier democratised the press's essential act, multiplication, moving it from the print works to the corridor outside every manager's office. Memos, manuscripts, homework, samizdat: the clandestine literature of the Soviet Union was copied on machines that party officials guarded like weapons, because they were.

The laser and the last mile

The copier copies what exists. The next step was to let the computer print what did not yet exist: in 1969-71 Gary Starkweather at Xerox's Palo Alto Research Center married the laser to the copier's engine, scanning a laser beam modulated by digital data across the photoreceptor, and the laser printer was born. Xerox built

the big machines; the mass market arrived with the Canon-engineered desktop engines of the early 1980s and, decisively, the Apple LaserWriter of 1985, which with PostScript made the desktop a print shop. Today the laser and inkjet printer, the personal press, is one of the most common machines on earth, and office and consumer printing consumes a river of paper and toner that remains one of the largest segments of the entire printing ink business. Carlson's slide belongs to the same lineage as Gutenberg's mould: both are devices for making many copies of one pattern. The difference is that the copier's pattern can be anything, made by anyone, in an afternoon.

The counterpoint

There is a sobering symmetry here. The press put copying into factories; the copier and desktop printer pulled a small part of it back into offices and homes. For a moment it looked as if printing itself might decentralise completely, that the paperless office, a phrase born in the same Xerox PARC milieu, would follow the copier as the copier followed the press. It did not happen that way. The world's consumption of printing and writing paper kept rising into the 2000s before digital media finally bent the curve. The press's story in its fifth century is not replacement but relocation, and the relocation continues.

The 914 and the Rochester bet

The Xerox 914, named for the size of the paper it took, was a machine the size of a desk that weighed over 600 pounds, jammed, occasionally caught fire, and printed seven copies a minute, and it changed the office forever. Haloid's president Joseph Wilson had bet the company on Carlson's patents; the development took fifteen years, new photoconductors, selenium drums, corona charging wires, toner, fusers, and a service model, renting machines and charging per copy, that made the economics of copying match the economics of printing: the first copies pay for the machine. By the mid-1960s Xerox was one of the great American growth companies, and the word Xerox had become, to the despair of its lawyers, the verb for copying. The 914's true descendant count is invisible: every office laser printer is a xerographic press, and there are hundreds of millions of them.

The guarded machine

The copier's power showed most sharply where it was forbidden. In the Soviet Union and its satellites, duplicating machines were registered, locked, and controlled by the state precisely because they were presses: the samizdat literature, retyped and photographed and copied in flats and offices, was a shadow publishing industry, and possession of an unregistered duplicator was a crime of the first order. The state understood what the American office took for granted: cheap multiplication is political power. The Zenger jury's question, who may print, had become, in the twentieth century, the question of who may copy. The answer,

in the free world, was everyone, and the copier, then the desktop printer, then the phone camera, kept widening it.

The office paper river

The copier and the laser printer created a wholly new branch of the paper industry: cut-size office paper, standardised, bright, wrapped in reams, sold through office supply chains in quantities that came to rival entire traditional grades. The "paperless office", predicted from the 1970s, inverted: cheap copying and printing made offices use more paper, not less, for decades, until networked screens finally bent consumption down in the 2010s. The episode is a standing lesson in technology forecasting: making reproduction cheaper increases reproduction, and the press's own law, cheaper copies, more copies, held for the office as for everything else until the medium itself changed.

PART VII · THE ELECTRONIC PAGE

21 · Presses Without Plates

Every press since Mainz begins the same way: make a fixed image carrier, a forme, a stone, a plate, and print from it as long as the run lasts. The cost of that carrier is the industry's oldest tax, and it dictates the industry's oldest law: printing is cheap per copy only if you print many copies. Digital printing abolishes the carrier. Each impression is generated fresh from data. The law of the long run breaks, and with it breaks the whole economics of the printed object.



The modern digital hall: presses without plates, every sheet generated fresh from data.

Landa and the E-Print

The announcement came at the IPEX exhibition in Birmingham in 1993: Indigo, an Israeli company founded in 1977 by Benny Landa, showed the E-Print 1000, the first digital offset colour press. Its trick was liquid electrophotography: a charged photoconductive drum written by a laser, developed with a liquid toner, ElectroInk, that offset-transferred to a blanket and then to paper, with the image erased and rewritten for every single impression. Each sheet could be different. Landa, who would be called the father of commercial digital printing, had spent a decade on the physics; in 2002 Hewlett-Packard acquired the company, and HP Indigo presses became the backbone of the digital colour printing industry, with thousands installed worldwide.

The other great digital family is inkjet: no charge, no drum, just microscopic nozzles firing droplets of ink on demand. Inkjet grew from the desktop printer upward, through wide-format graphics, into industrial presses; today's high-speed inkjet webs print books, statements, packaging and newspapers' remnants at hundreds of metres per minute. Toner and inkjet between them define digital printing, and both share the founding property: the image is data until the instant it is ink.

The economics of one

What changes when the carrier disappears? Everything about the run. There is no make-ready, no plates to amortise, no waste run-up to colour; the thousandth copy costs what the first did, so the sensible edition is exactly as large as demand, down to an edition of one. Three industries were rebuilt on this fact. First, short-run and on-demand book printing: the whole backlist of publishing, hundreds of thousands of titles that could never justify an offset run, became permanently available, printed when ordered, and self-publishing acquired an industrial base; a book is now, optionally, a file with a price. Second, variable-data printing: every copy different, statements, bills, direct mail personalised to the recipient, labels serialised, packaging localised, textbooks customised; the printed object learned to address one person at a time. Third, speed itself: no plates, no drying delay, order-to-delivery in days or hours, and print became a branch of logistics as much as of manufacture.

The press builders adapted or were absorbed; the digital press hall of today, an Indigo or a production inkjet line humming beside a CNC cutter, looks more like a data centre's cousin than like a newspaper plant of 1950. Yet the lineage is intact. The digital press is not a repudiation of Gutenberg's system but its final abstraction: the forme made evanescent, the matrix made mathematical, the press made a peripheral of the network. The fixed pattern survives as the PDF; the type metal survives as the font file; the pressman's make-ready survives as colour management. Strip away five centuries of engineering and the machine is still doing the one thing: making identical meaning, on demand.

Nanography and the next carrier

The man who broke the carrier returned to improve what replaced it. Benny Landa's second company, Landa Corporation, unveiled nanographic printing at drupa 2012: jets of nano-pigment water-based ink ejected onto a heated blanket, where the water evaporates and the ultra-thin ink film transfers dry to the paper, promising offset-class quality and substrate freedom with digital flexibility. The technology's development proved slower and harder than its spectacular debut, but its logic is the industry's logic: shrink the ink film, free the image from the surface, print anything on anything. The next chapter follows that logic beyond paper entirely.

ElectroInk and the printed pixel

The Indigo press's ElectroInk deserves a technical paragraph, because it solved the hardest problem in digital printing: making an electrostatic image print like ink. Conventional dry toner prints as a powder fused to the surface; fine, but the image sits on the paper and cracks at folds. ElectroInk suspends pigment particles of a few microns in a carrier oil; written by laser onto a charged drum, the image develops as a liquid film, transfers to a heated blanket where the carrier evaporates and the resin melts, and then transfers again to paper as an ultra-thin plastic layer that behaves like offset ink, following the paper's own surface. The drum is

re-imaged for every revolution, so every sheet can differ entirely. Inkjet went the other way: no intermediate, droplets of a picolitre or two fired from arrays of nozzles, thermal or piezoelectric, thousands of times per second, built up into the image directly. Between liquid toner and jettable ink, the press shed its last mechanical memory.

The mathematics of the edition of one

Print-on-demand rewrote the publisher's spreadsheet. Offset's curve is a falling unit cost with volume, with a floor set by make-ready: a 500-copy offset book might cost several times more per copy than a 5,000-copy run. Digital's curve is nearly flat: the first copy costs about what the thousandth does, more per copy at high volume, less at low. The crossover sits today in the hundreds to low thousands of copies, depending on the book; below it, digital wins. The consequence transformed the economics of the backlist and the small publisher: no warehouse, no pulpings, no out-of-print. The Espresso Book Machine even put the factory in the bookshop, printing and binding a paperback from a file in minutes. The codex became, in principle, a catalogue of files with physical instances summoned as needed.

Every copy an individual

Variable data printing, the digital press's other gift, created products with no analogue precedent. TransPromo statements printed each customer's bill with marketing tuned to their account; direct mail addressed not "the householder" but the recipient by name, offer and history; labels and cartons carried serial numbers, QR codes, regional variants and security features unique to each item; photobooks, the gift market's staple, exist only because every copy can be one person's own. Print thus absorbed the internet's promise of personalisation into the physical object. The press that began by making every copy identical ended by making every copy unique, and the two capabilities, uniformity and variation, now coexist on the same machines.

Inkjet: the other digital

Electrophotography had a rival from the start, and by the 2010s the rival was winning the volume game. High-speed inkjet web presses, machines from Screen, Ricoh, Canon and HP running paper at hundreds of feet per minute, took over the transactional heartlands: statements, bills, direct mail, and increasingly books, where inkjet lines now print a substantial share of trade paperback volume in short runs timed to demand. The inkjet head is the press reduced to its essence: thousands of nozzles firing droplets picolitres in size, no plate, no blanket, no contact, the image existing only as data until the instant it lands. Landa's nanography took a third path, jetting a polymer-pigment emulsion onto a heated blanket and transferring a dry film to the sheet at B1 poster format, an attempt to give digital the look and economics of offset. The press's newest

generation is thus not one machine but a family of deposition engines, and its frontier is not speed any longer but cost per page at ever shorter runs, the economics of one, again.

PART VII · THE ELECTRONIC PAGE

22 · The Press in the Age of Its Own Child

In the 1990s the press met the medium it had been anticipating for five centuries: a network that transmits text and image to anyone, instantly, at zero marginal cost per copy. The internet is the printing press's child in a strict sense, it does electronically what print did mechanically, and its arrival broke the press's oldest businesses while confirming its deepest idea.

What the network took

The newspaper industry was hit first and hardest. Its economics had always rested on a double monopoly: the only mass text medium, and the only mass classified marketplace. The network dissolved both. Classified advertising, the river of gold that paid for reporting, migrated online in barely a decade; display advertising followed the audience to search and social platforms; and the printed daily, already weakened by television, entered a decline that has closed thousands of papers and cut newsroom employment by a large fraction in the United States alone. Newsprint demand, once the paper industry's proudest grade, collapsed; mills converted or closed; the great web-offset plants of the 1990s became stranded assets. Magazines followed the same curve. Even the telephone directory and the encyclopedia, two of print's oldest mass products, simply ceased to exist in their physical form, the encyclopedia replaced by a volunteer-built network text larger than any press-run work in history.

Book publishing was hit differently, and the difference is instructive. The ebook, forecast in the early 2010s to bury the printed book, instead plateaued: in the English-language trade it settled at a substantial minority of unit sales, and the printed book kept the majority. The codex, the five-hundred-and-fifty-year-old format of folded, bound sheets, proved to have properties the network could not replicate: ownership without licence, reading without battery or surveillance, presence as furniture and gift, and a browsing physics that many readers simply prefer. The book did not die. It became, for the first time, a chosen medium rather than the only medium.

What the network confirmed

Yet the deeper verdict of the internet age is that Gutenberg's wager was right. The network's founding assumption is the press's: that the world's default relationship to information should be many identical copies, everywhere, for almost nothing. Every property of the online world that seems native to it, the viral text, the fixed and citable page, the editor's craft, the flame war over falsehood, the law's struggle with

expression, ran first in print. The Reformation pamphlet is the prototype of the viral post; the coranto of the push alert; the index, the catalogue and the footnote of the search engine; Areopagitica of every argument about platform moderation. When scholars date the information revolution, the honest ones date it twice: once to 1450 and once to the network, and the second revolution reads like the first with the latency removed.

There is also a material continuity the network conceals. The internet runs on printed things: every server, phone and fibre repeater is built with printed circuit boards, made by photolithographic processes that are Senefelder's chemistry carried into silicon; and the semiconductor itself, the substrate of the entire digital world, is manufactured by optical lithography, the most precise printing process ever devised, printing transistor patterns measured in nanometres. The press did not merely precede the electronic world. It manufactures it.

The press that remains

What is left to the press after its child's triumph? Everything the network cannot carry: the physical surface of the world. The packages on the supermarket shelf, the labels on the bottle, the carton, the ticket, the banknote, the ballot, the wallpaper, the ceramic tile, the textile, the book you choose to own. The industry's centre of gravity has moved decisively from communication to packaging and functional print, as the next part of this book details. The press began by printing scripture for a world that could not read; it ends, in this account so far, printing the skin of the industrial world for a world that reads on glass. The item endures; the purposes rotate.

Newsprint's collapse in numbers

The scale of the newspaper's fall deserves concrete figures. In the United States, weekday print circulation, which peaked around 60 million copies in the early 1990s, fell by more than half in three decades; newsroom employment fell from over 70,000 journalists at its peak to roughly a third of that by the 2020s; thousands of local papers closed or merged. Newsprint demand in North America fell from over 12 million tonnes a year around 2000 to a small fraction of that two decades later, and the great newsprint machines of the boreal belt were converted to packaging grades or scrapped. The pattern repeated across Europe, Japan, and every high-income market, with India among the few large markets where print circulation continued to grow. The web offset press, the proudest machine of 1970, became the textbook stranded asset.

The encyclopedia's end

No product death tells the story more cleanly. The Encyclopaedia Britannica, in print since 1768, a crown of the reference trade, published its last print edition in 2010, 32 volumes, after the encyclopedia's function had migrated first to CD-ROM and then to the network, where a volunteer encyclopedia overtook it in both size

and use. The reference book, the directory, the timetable, the mail-order catalogue, the phone book: an entire category of print, the information you look up rather than read, proved to be software. Print's survivors are the things it does better than screens, and "looking things up" is no longer one of them.

Printing transistors

The press's strangest modern descendant deserves its due: the semiconductor industry. A chip is made by photolithography: coat the silicon wafer with photosensitive resist, project the circuit pattern onto it through a mask, develop, etch, repeat, dozens of layers, each aligned to nanometres. The process is printing in every essential, an image carrier, a photosensitive surface, development chemistry, registration, and it descends directly from the photo-engraving and offset platemaking trades; the word "lithography" the fabs use is Senefelder's word. Extreme ultraviolet lithography, the current frontier, prints features measured in atoms with machines that are the most complex ever sold. The information age runs on printed hardware: the press manufactures the machines that were supposed to replace it.

The closures, counted

The contraction is measurable, and it is worth measuring rather than gesturing at. Northwestern's Medill School, tracking the American local news landscape, counts nearly 2,900 newspapers closed since 2005, more than two a week, leaving the country on a trajectory to have lost a third of its papers within two decades; whole counties have become news deserts with no daily or weekly paper at all. Pew's newsroom employment series tells the matching story inside the surviving buildings: a quarter of the nation's newsroom jobs gone between 2008 and 2020, with newspaper newsrooms hit hardest. The press did not lose the argument; it lost the classifieds, and with them the cross-subsidy that had paid for the reporting. What the network offered the reader for free, it charged the newspaper everything to provide.

PART VIII

The Industry of the Press

The builders, the hidden industries, the segments and the dependence, today.

PART VIII · THE INDUSTRY OF THE PRESS

23 · The Press Builders

The industry that builds printing presses is small, ancient and concentrated: a handful of firms, mostly German and Japanese, whose machines are among the largest and most precise capital goods on earth. A modern newspaper or packaging press line can weigh hundreds of tonnes, run paper at highway speed, and hold registration, the alignment of successive colour impressions, to a fraction of a hair across a web a metre wide. This chapter is their story and their market.

Würzburg: the oldest press-builder

Koenig & Bauer, founded in 1817 by Friedrich Koenig and Andreas Friedrich Bauer in a secularised monastery at Oberzell near Würzburg, is the world's oldest printing press manufacturer, a direct descendant of the machines that printed The Times by steam in 1814. Two centuries on, the group builds sheetfed and web offset presses, flexo and die-cutting lines for packaging, presses for metal decoration, glass and coding, and, in a niche it dominates almost totally, banknote printing: the great majority of the world's currencies are printed on Koenig & Bauer banknote presses, through the firm's banknote solutions unit, the descendant of Giori's intaglio line. The company is listed in Frankfurt; its recent annual reports describe a group with revenue around 1.3 billion euros, refocused on packaging and special applications as classic newspaper printing has declined. A firm that began with steam now sells machines that print the money of states and the cartons of the world's food.

Heidelberg: the sheetfed empire

The most famous name in press-building comes from a foundry in Frankenthal. The firm that became Heidelberger Druckmaschinen AG grew from a bell foundry, took the name of its assembly town, Heidelberg, and in the twentieth century built its name on two machines: the Tiegel platen, the "Heidelberg windmill" of the jobbing printer, and above all the Speedmaster family of sheetfed offset presses, introduced in the 1970s, which became the standard machine of the world's commercial printers. Heidelberg's revenue peaked near four billion euros in the early 2000s; the digital shift halved the industry, and the company spent fifteen years restructuring into a narrower, more digital and packaging-oriented business, with revenue around 2.3 billion euros in recent financial years. Its Wiesloch-Walldorf factory remains the largest printing press plant in the world, and its brand is still the default noun for a small offset press in half the languages of the trade.

The other houses

The rest of the map is quickly drawn but rich in consequence. Komori, founded near Tokyo in 1923, is the leading Japanese press-builder, strong in sheetfed offset, security and currency printing. Manroland, from the 1845 Augsburg firm and the 1871 Faber & Schleicher "Roland", built the great newspaper webs of the twentieth century; after insolvency in 2011 its sheetfed business went to Britain's Langley Holdings (manroland Sheetfed) and its web business became manroland Goss, later folded into the American Goss tradition it had merged with, the Hoe-descended house of newspaper presses. Bobst of Lausanne, founded 1890, rules the finishing and printing of folding cartons; Windmöller & Hölscher of Lengerich leads in flexographic presses for flexible packaging; Gallus and Nilpeter in labels; RMGT (Ryobi MHI) in compact sheetfed. The Italian and German gravure builders serve the packaging and decor trade. And on the digital flank stand the newcomers who are now incumbents: HP with Indigo, Canon with its production lines, Fujifilm, Screen and Ricoh in inkjet, and Landa.

The market they serve

The printing machinery market is a mature, cyclical capital-goods market: industry estimates put annual sales of printing equipment in the range of fifteen to twenty billion dollars, with growth concentrated in packaging presses and digital machines and decline in everything tied to newsprint and commercial paper. The geographic logic has shifted east: China is now both a major market and a rising maker of mid-range presses. What has not changed in two centuries is the industry's shape: a few specialist houses, each a century and more deep in the craft of moving webs and sheets at speed, selling to printers who will run the machines for twenty or thirty years. The press is one of the longest-lived capital goods in the industrial world, which is why its builders sell, above all, trust.

Anatomy of a modern press line

Stand beside a contemporary press line and the item's scale lands. A web offset or flexo packaging line is a hundred metres of machinery: unwind stands holding paper or film rolls of over a tonne, infeed and tension control, printing units, one per colour, each a tower of plate, blanket or anilox and impression cylinders, drying or curing tunnels between them, chill rollers, register cameras reading printed marks a tenth of a millimetre wide and correcting alignment continuously at full speed, and at the end a folder, sheeter, die-cutter or rewinder delivering finished product. Speeds run to 10-15 metres per second, the web moving at the pace of a car on a city street while four or eight colours align within a hair. A large sheetfed offset press prints 15,000-18,000 sheets an hour; a modern corrugator flexo line prints, slots and folds boxes by the tens of thousands. The purchase price of such a line runs from millions to tens of millions of euros, amortised across a working life of decades, which is why the builders' order books move with the credit cycle and why their service revenues matter more each year.

The money printers

Security printing is the industry's closed room. Banknotes are printed by a small circle of state works and private firms on machines almost no one else operates: intaglio presses that lay ink so thick you can feel the engraving with a fingertip, plus letterpress numbering, offset backgrounds, and an armoury of features, threads, foils, watermarks, optically variable inks, windows. Koenig & Bauer's banknote unit, heir of the Swiss firm Giori whose intaglio machines became the world standard, supplies the great majority of the world's banknote printing works; De La Rue of Britain prints notes and passports for dozens of countries; state printers like the US Bureau of Engraving and Printing, the Bundesdruckerei and Orell Füssli complete the circle. The trade's economics are unlike any other branch of print: the customer is sovereignty itself, and the product is the physical credibility of money.

The second life of machines

Printing presses almost never die; they migrate. The used-press market, brokers, dismantlers, riggers, exporters, has carried two generations of offset capacity from the rich world to the growing one: a 1990s Speedmaster retired from a German commercial house may spend its second twenty years printing books in Chennai, Lagos or Lima. The trade in used iron explains much of the world's printing geography: the newest machines cluster where labour is dear and capital cheap; the hand-me-downs where the reverse holds. Gutenberg's press had no second hand market because it had no serial numbers; the modern industry is a cascade of machines flowing downhill in wealth and uphill in age, and the cascade is one of the quiet mechanisms by which print technology finally reached everywhere.

The other houses

Around the two Germans the industry narrows to a short list. manroland Goss, the merger of Roland of Offenbach and Goss of Chicago's web heritage, builds the big newspaper and commercial web presses from Augsburg. The Japanese houses, Komori and RMGT (Ryobi Mitsubishi), hold strong positions in sheetfed and packaging presses, Komori with a security-printing line of its own. Bobst of Switzerland owns the converting end: the die-cutters and folder-gluers that turn printed sheets into boxes. The Chinese builders, led by giants such as Masterwork, climb steadily upmarket as the industry's manufacturing gravity shifts east. The digital vendors form their own tier: HP with Indigo, Canon with its cut-sheet and inkjet lines, Ricoh, Konica Minolta, Fujifilm, Screen with high-speed inkjet webs, and Landa with nanography. Between them all, the world's annual output of new presses is a business of only a few billion euros: astonishingly small for the industry it equips, which is the surest sign of how long a well-built press lives, and why the builders survive on service, parts and consumables rather than on iron.

PART VIII · THE INDUSTRY OF THE PRESS

24 · The Hidden Industries

A printing press does not print. It is the centre of a web of industries that feed it: ink, paper, plates, blankets, rollers, chemicals, spare parts. These supply industries are mostly invisible to the public and several of them are larger than the press-building industry itself. The item at the heart of this book is, in industrial truth, a standing order placed by the world's printers with a dozen other industries.

Ink: the original printing industry

Printing ink is the oldest of the allied trades, it predates the press by millennia, and it remains a global industry of around twenty billion dollars a year by the main market estimates. Its structure has been remarkably stable: a few multinational groups, DIC/Sun Chemical and Flint Group at the top with sales in the range of three billion dollars each in graphic arts, followed by Toyo Ink, Sakata INX, Siegwerk and hubergroup, supply a fragmented world of printers. The product is a precision colloid: pigments ground to micron fineness in varnish systems tuned to each process, oxidising oil varnishes for sheetfed offset, solvent systems for gravure and flexible packaging, UV-curing chemistry for high-speed sheetfed and labels, water-based flexo inks for the corrugated box. Ink is where printing meets chemistry, regulation and, increasingly, sustainability: food-contact rules govern packaging inks, and the industry's current technical frontier is de-inkable, recyclable, low-migration chemistry for a circular paper economy.

Paper: the press's twin

The paper industry dwarfs everything else in the book: a global market of several hundred billion dollars and the true twin of the press since the Fourdrinier machine. Its modern geography tells the industry's story in one map. Newsprint, the grade built for the daily press, has collapsed with the newspaper; printing and writing papers are in managed decline in the West; and the industry's growth grades are precisely the ones the modern press prints most: containerboard and cartonboard for packaging, tissue, and specialty papers for labels. The great Nordic and North American newsprint houses have converted to packaging or closed; Asia, above all China, now makes and consumes the largest share of the world's paper. When this book's sister volumes speak of the paper industry as its own item, this is the hinge: paper is where the press's past and future visibly trade places.

Plates, blankets, rollers, and the craft of spares

Between ink and paper stands a set of unglamorous, indispensable industries. Offset printing plates, grained and coated aluminium imaged photographically or by computer-to-plate lasers, are a business of billions, historically ruled by Kodak, Agfa and Fujifilm, and now contended by Chinese makers as the West's plants consolidate. Printing blankets, the rubber-cloth transfer skins of the offset press, are a specialist product of a few firms, Continental, Trelleborg's former line, Meiji, Kinyosha, engineered to release ink and absorb the smash of the nip. Ink rollers, chromed, rubbered and ceramic anilox, doctor blades, fountain solutions, wash-up chemistry: each is a niche industry with its own chemistry and patents. And beneath them all lies the after-market: a press lives for decades, and the trade in spare parts, service, retrofits and used machines is an economy in itself, with Heidelberg and Koenig & Bauer making a large share of their revenue from service rather than new iron. The press is never bought once; it is married.

Why the hidden half matters

The hidden industries explain the visible ones. The consolidation of the plate and ink trades foretold the consolidation of printers; the conversion of paper mills foretold the packaging age; the used-press market carried offset printing into Africa and South Asia, where second-generation Speedmasters still print much of the world's books. Follow the supply chain and the map of the press's world appears: pigment from the chemical belt, aluminium from the smelters, blankets from two or three factories, paper from the boreal forests and the eucalyptus plantations, machines from Würzburg, Heidelberg and Tokyo, and, at the end of every line, a printed thing in someone's hand.

Workshop: how offset ink is made

An offset ink begins as a varnish: linseed or soy oil cooked with hard resins, or modern hydrocarbon resins in mineral or vegetable oils, engineered for tack, the stringiness that lets the film split cleanly from roller to plate to blanket to paper. Into the varnish goes pigment, carbon black, phthalo blue, diarylide yellow, rubine red, wetted and then ground on three-roll mills, where the paste passes through steel rollers rotating at different speeds until the pigment is dispersed to a few microns; the fineness is checked on a grind gauge, a micrometre-scale channel, as it has been for a century. Driers, cobalt or manganese salts, catalyse the oxidation that hardens the film. The ink must do contradictory things: tacky enough to transfer, short enough not to fly, stable on the rollers for hours, hard on the sheet in seconds, and, on packaging, inert enough to touch food from a film's thickness away. Ink making is dispersion chemistry with a 570-year-old lineage from Gutenberg's lampblack varnish.

The anilox: flexo's measuring cup

Flexography, the relief process that prints the world's flexible packaging and corrugated boxes, rests on one hidden component: the anilox roller, a steel or ceramic cylinder engraved with millions of microscopic cells that meter the ink film to the printing plate. Cell count, cell volume and engraving geometry decide how much ink the plate receives, and the anilox is to flexo what the screen is to litho: the precision organ that made the crude process fine. Flexo's plates, once rubber, now photopolymer, are made by washing away unexposed polymer, a descendant of photo-engraving; its inks run from solvent to water to UV. The process that once printed bread bags in blurry type now prints the full-colour skins of the world's consumer goods.

The loop of the sheet

The industry's material loop deserves an honest paragraph. Paper is the most recycled major material in the industrial world: in Europe, around three-quarters of paper is collected for recycling, and old newspapers and cartons re-enter mills as furnish. Deinking, flotation and washing that strip ink from fibre, is its own chemical art, and the ink industry now designs for it: prints that release their ink cleanly, mineral-oil-free formulations, barrier coatings that keep fibre recyclable. The environmental ledger of print is mixed, forests, mills, solvents, energy, but the loop of the sheet is a real one, and the oldest mass medium is also among the most circular.

Paper: the substrate industry

The press's appetite forced its largest hidden industry. For four centuries paper was made from rags, and the supply of rags set a hard ceiling on the supply of print; the nineteenth century's reading millions broke the ceiling twice, first with groundwood pulp, the Keller-Voelter grinder process of the 1840s that shredded whole logs into cheap, weak, fast-yellowing fibre, the newspaper's fibre, and then with the chemical pulps, Tilghman's sulfite process patented in 1867 and the kraft process after it, which cooked the lignin out of wood and left strong cellulose. The Fourdrinier machine industrialised the output: a wire belt, suction, steam-heated drying cylinders, a continuous ribbon of paper kilometres long. Today's paper industry is one of the world's great continuous-process industries, mills the size of towns running machines wider than a house at highway speed, and printing and writing grades are no longer its centre: packaging board is, the containerboard of the e-commerce economy, while newsprint shrinks to a specialty. The press and the paper machine grew up as twins, and the twin has followed print's centre of gravity from the page to the parcel.

The consumables

Around the press stands a whole economy of things that are consumed in the act of printing. The offset plate, anodised aluminium coated with a light-sensitive polymer, imaged in the platesetter and worn out in the run. The rubber blanket, engineered fabric and elastomer, the offset process's namesake, replaced on a

schedule. The fountain solution, the dampening chemistry that polices the grease-water frontier on the plate. The rollers, the washes, the powders, the tapes. And after the press, the finishing trades: folders, gatherers, binders, trimmers, laminators, die-cutters, a second factory downstream of the first. None of these industries prints anything, and none of printing happens without them; the item of this book is the apex of a supply pyramid most readers never see.

Ink: the chemistry that carries the word

The press's second consumable is the oldest chemical product still in daily industrial use. Gutenberg's own ink was already a sophisticated material: not the watery writing ink of the scribes, which runs off metal, but a stiff, tacky varnish of boiled linseed oil carrying lampblack, essentially a paint engineered to wet the type, transfer to the sheet, and then harden by oxidation into permanence. Every subsequent process re-derived its own ink: litho inks balanced against the fountain's water, heatset inks dried in ovens at the web's speed, coldset news inks drying by absorption alone, UV inks cured by light in a fraction of a second, flexo's thin film inks for film, conductive silver inks for circuits. An ink is a fluid machine: pigment for colour, vehicle for carry, driers and additives for timing, all tuned to one press, one substrate, one speed. The industry that makes it is correspondingly concentrated and correspondingly huge, a handful of global groups, led by DIC and Flint, supplying tens of billions of dollars of engineered fluid a year, and its laboratories hold much of printing's real know-how. The history of the press could be written as a history of ink, and the ink's story would contain all the others.

PART VIII · THE INDUSTRY OF THE PRESS

25 · What the World Prints

Measured by money, printing is one of the largest manufacturing industries on earth: the main industry studies put the global print market in the high hundreds of billions of dollars annually, with some estimates approaching a trillion when packaging and all print products are counted. Almost none of that money is in the products the word "printing" first brings to mind. The industry's centre of mass has moved from words to wraps.



Print's centre of gravity today: a supermarket aisle, every surface printed.

The segment map

Break the market down and a clear order emerges. Packaging is the largest and the only durably growing segment: folding cartons, corrugated boxes, flexible films, labels, printed on flexo, gravure, offset and digital presses by the trillion impressions, and driven by the relentless growth of packaged food, e-commerce and branded goods. Labels alone, a niche in 1950, are now a major industry, every bottle, jar and parcel a small printed surface with its own legal and marketing payload. Commercial printing, the brochures, catalogues, forms, calendars and business documents that once defined the industry, has been eroding for two decades under digital media. Publishing print, books, magazines, newspapers, divides internally: newspapers and magazines in steep structural decline; books stable to gently growing, an island of resilience. And around these lie the specialist realms: security printing of banknotes, passports and tax stamps, a small, secretive, high-value trade; decorative and industrial printing, wallpaper, laminates, ceramics, textiles; and the fastest-growing frontier, functional printing of electronics, sensors and displays, which the last part of this book visits.

The tonnage follows the same migration. Global print volume is measured in the tens of trillions of A4-equivalent impressions a year, and the volume declines even where value holds, because the industry prints fewer reading pages and more package surfaces. The modern press's typical product is not read at all; it is ripped open and thrown away. The industry of the word has become, by tonnage, an industry of packaging.

The geography

The map of print has followed the map of manufacture. Asia-Pacific is now the largest printing region, with China the single largest national market, built on its position as the world's packaging workshop and on a domestic book and newspaper industry of continental scale. North America and Western Europe remain the high-value markets, dominated by packaging, labels, security and speciality work as their publication printing drains away. India is among the fastest-growing major print markets: a vast newspaper readership still growing in regional languages, a book trade among the world's largest, and a packaging industry riding the same retail and e-commerce expansion as China's before it. The item has come home in a certain sense: the civilisation that taught the world paper is now one of the growth engines of the press.

The shape of the trade

The printing industry itself, hundreds of thousands of establishments worldwide, remains strikingly unconcentrated: a few multinational packaging and security giants, a stratum of national champions, and a long tail of small commercial printers serving local markets. Consolidation has been the constant for thirty years and has not changed the shape: printing is a local service grafted onto a global supply chain, because printed goods are cheap to make and surprisingly dear to ship, and because print buyers buy trust, turnaround and colour consistency as much as impressions. The industry's profitability rests where it has rested since Aldus: not in the presswork, which is a commodity, but in the services wrapped around it, pre-press, finishing, logistics, and the management of the customer's whole printed estate.

The corrugated economy

The humble corrugated box deserves its own look, because it is now the press's largest single product family. Corrugated board, fluted kraft paper sandwiched between liners, printed flexo or by high-gloss offset-laminate for display boxes, carries the goods of the entire economy: produce, appliances, and the avalanche of e-commerce parcels. Every online order travels in a printed box; the growth of the parcel is printed, literally, on the industry's books. The box plants, sheet feeders, corrugators, flexo folder-gluers, die-cutters, are printing factories even when their product is a brown shipping case, and the sector's consolidation, giants like International Paper, WestRock, Smurfit Kappa, DS Smith, has made packaging the first branch of print dominated by global groups. The press's centre of gravity now sits in a corrugator hall.

Security: the printed state

Banknotes, passports, postage and revenue stamps, tax labels, certificates: security printing is the press as an arm of sovereignty. The features read like a history of the whole craft weaponised: the intaglio plate whose raised ink you can feel, a direct descendant of the copperplate; the watermark, Fabriano's invention; the rainbow of offset background guilloches, patterns too fine to re-originate; letterpress numbering, the last

mass use of the oldest process; and the modern layers, threads, foils, holograms, windows, optically variable inks, UV and IR inks, microtext printed at the limit of the eye. Counterfeiting is the adversary, and the features' evolution is an arms race between two printing industries, the state's and the forger's. The banknote is the most engineered printed object in ordinary hands, and the cashless future, if it comes, will retire one of the press's oldest products.

India's print economy

Because this is an Industries of India study, the country gets its paragraph here, without forcing the founding story onto it. India's print market is one of the world's largest and fastest-growing, by most estimates in the tens of billions of dollars: a newspaper industry that still grows in the regional languages even as the Western press declines, with dailies printed nightly in dozens of cities; a book trade among the largest in the world, anchored by educational publishing, the school textbook being the Indian press's bread and butter; and a packaging sector expanding with retail and e-commerce. The press came to India in 1556 with the Portuguese at Goa, the first printing press in Asia outside the Philippines' orbit, and the missionary presses of Goa, then the Serampore press of Carey and his successors, printed scripture and grammar in a dozen Indian scripts, doing for those scripts what Caxton did for English. The item's Indian chapter, the mission presses, the nationalist press of Tilak and Gandhi, where the press was quite literally an instrument of independence, the modern packaging boom, is a book of its own in this series' future, and it will be written on the foundation laid here.

The segments, named

The industry's own statistical language divides its output into segments worth naming plainly, because the aggregate hides them. Packaging and labels, the largest and growing: corrugated cases, folding cartons, flexible films, pressure-sensitive labels, shrink sleeves, in-mould labels. Publishing: books, the resilient segment, newspapers and magazines, the shrinking ones. Commercial print: the brochures, catalogues, direct mail, reports and calendars of business communication, eroded by the network but persistent. Advertising print: posters, point-of-sale, signage and the wide-format world. Security print: banknotes, passports, stamps, tax labels, identity documents, the smallest and most guarded segment. And functional print: the printed electronics, sensors and industrial deposition of the next chapters. Each segment runs its own process mix, offset for cartons, flexo for films and corrugated, gravure for long-run films and decor, digital for labels and short-run everything, screen for the thick and the curved, and the capital, the margins and the futures differ accordingly. 'The printing industry' is these six businesses sharing a name.

PART VIII · THE INDUSTRY OF THE PRESS

26 · Dependence

How much does humanity depend on the printing press? The question cuts two ways. In its classic form, the press as the machinery of reading, the dependence is total but invisible, embedded in the foundations of modern life. In its modern form, the press as the machinery of surfaces, the dependence is physical, daily, and almost entirely unnoticed. Both deserve an accounting.

The reading machine

Begin with the obvious: mass literacy is a product of the press. A civilisation in which books cost years of wages cannot be a civilisation of readers; one in which a book costs an hour's wages cannot avoid becoming one. The curve of European literacy rises with the curve of printed volume from the sixteenth century onward, through schoolbooks and catechisms, the cheap Bible, the chapbook and the novel, the penny newspaper and the free library, until, by the twentieth century, the reading public was simply the public. Everything built on that public carries the press inside it: universal schooling, whose textbook is a press product; modern science, whose unit of progress is the published paper; law and administration, whose statutes, forms, files and records presume print; representative government, whose campaigns, ballots and newspapers presume it; the market economy itself, whose contracts, ledgers, money and labels are printed things. When the presses of a country stop, as in wars and blockades, the failure is felt not as nostalgia but as institutional paralysis.

The dependence also has a negative face, and honest accounting must show it. The press is the first machine that made mass persuasion cheap, and every later technique of the mass manufacture of consent, propaganda, advertising, the engineered moral panic, the totalitarian newspaper, was invented on it. The same industry that printed the Encyclopédie printed the forgery; the same press that carries the ballot carries the smear. Dependence on the press is dependence on an amplifier, and an amplifier has no opinions.

The surface machine

Now the physical accounting. Wake in the morning and count the printed things before you leave the house: the cereal box, the milk carton, the medicine blister and its leaflet, the newspaper if you still take one, the banknotes in your wallet, the label in your shirt, the cover of the paperback on the table, the postage stamp, the bus ticket, the wallpaper. All of it came off a press in the last months, most of it in the last weeks. Global packaging is the largest single use of print; food cannot be branded, dated, traced or sold by law without it; commerce cannot label, ticket or receipt without it; the state cannot tax, identify or pay without it. The supply chains of the modern world are annotated in ink: remove the press, and the goods still move, but anonymously, illegally, and briefly.

The strangest dependence is the one on the press's descendant processes. Every microchip is printed, by photolithography, with the press's chemistry at nanometre scale; every circuit board, display and solar cell

passes through printing processes; the membrane keyboard, the RFID tag, the glucose test strip, the printed antenna, all are products of the functional printing industry that is the press's newest organ. A world that believes it has gone digital is, in fact, more thoroughly printed than ever, because the digital world itself is manufactured by the press's descendants. Gutenberg's machine now prints the machines.

The arithmetic of the page

A final measure. The global print industry turns over in the high hundreds of billions of dollars a year; it prints on the order of forty trillion A4-equivalent impressions annually; it employs, directly and in its supply industries, millions. And it does this for a unit price that has fallen roughly a hundred-thousand-fold since the fifteenth century: from a scribe's year for a book to a machine's second for a page. No other industry that old is still that large. The dependence is not on an antique. It is on one of the founding utilities of the modern world, running still.

The textbook and the school

Universal schooling is a printing industry outcome. The common school needed the common textbook: identical, cheap, correct, supplied to every child in a system, and only the press could manufacture it. From the New England Primer to the national textbook systems of the nineteenth century, from the great educational houses to the state textbook boards of the twentieth, schooling scaled exactly as print scaled. The textbook's economics, enormous adoption runs, state contracts, multi-year cycles, created a distinct branch of publishing, and in much of the world, India included, educational printing is still the book industry's largest single market. Every literate child of the last two centuries was taught by the press as surely as by any teacher.

Money and the ballot

Two state functions stand wholly on the press. Paper money is printing: the note is a press product from paper to plate to numbering, and the state's monopoly on its printing is one of the defining privileges of sovereignty, as the Chinese discovered with the first printed currency a millennium ago. The ballot is printing too: the secret, uniform, mass-produced ballot, the "Australian ballot" adopted in the late nineteenth century, required standard printed forms no hand could vary, and every election since has been a print run with rules. When a democracy votes, it votes on the press's product; the integrity of the object and the integrity of the process are literally printed together.

The form

Finally, the most ordinary dependence of all: the blank form. Printed applications, licences, receipts, ledgers, waybills, prescriptions, the form is the state's and the firm's interface with the person, and for three centuries

it existed only because a press could print a million identical blanks. The digital form inherits the pattern, but the paper form persists wherever signatures, evidence or infrastructure gaps require it. The form is proof that the press's deepest product was never reading matter as such: it was standardisation, the identical interface, and the modern world runs on it.

The dependencies, named

Dependence deserves its inventory, because it is easy to wave at and better to count. The world's newspapers depend on a handful of newsprint mills and a concentrated ink supply; a mill closure in Scandinavia or North America moves prices on another continent within weeks. Security printing depends on chains that are deliberately narrow: the cotton-linen paper of banknotes made by a small number of mills under state-grade secrecy, the intaglio presses of one dominant maker, the currency inks of one Swiss house, because trust, in money, is manufactured by controlling who can manufacture. Book publishing depends on a shrinking number of large book printers and on the logistics of paper; a single mill's conversion from white paper to board can tighten the whole trade's production schedules. Digital printing depends on proprietary inks, toners and printheads, sold on the razor-and-blade model, which is why a digital press's true price is measured in click charges, not in iron. And the whole industry depends on skills: the press engineer who can hold register on a six-colour web is a scarcer resource than the press, and the pipeline that trains him has narrowed as the prestige industries shrank. None of this is fragility exactly; it is concentration, and concentration is what dependence looks like before it is tested.

PART IX

The Press After Paper

Functional printing, the third dimension, and the codex that refuses to die.

PART IX · THE PRESS AFTER PAPER

27 · The Functional Future

The press's next centuries are already visible, and they look less like books than like anything else. Printing is migrating from communication to manufacture: the same logic, deposit a precise pattern of material onto a surface, cheaply, at scale, is being applied to electronics, energy, medicine and matter itself. The press is becoming a way of making things, which, in truth, is what it always was.

Printed electronics

Functional printing replaces the image with the device. With conductive inks, silver nanoparticles, carbon nanotubes, conducting polymers, a printer can lay down circuits, antennas, sensors, heaters, displays and photovoltaic layers on paper, plastic or fabric, roll to roll, at a fraction of the cost of the silicon fab. The products are already ordinary: the printed silver grid in a car's rear-window defroster, the membrane switches in appliances, RFID antennas printed by the billion for logistics tags, glucose test strips for diabetics, electroluminescent lamps, printed temperature loggers on vaccine cartons. The frontier runs to printed solar cells, flexible displays and smart packaging that senses, remembers and talks. Market estimates for printed and flexible electronics run in the tens of billions of dollars and climbing, the press's fastest-growing descendant industry.

The third dimension

Additive manufacturing, 3D printing, is the press's boldest child: printing in depth, depositing material layer on layer until the pattern becomes an object. The kinship is not rhetorical. Inkjet technology is one of its core engines, binding powders and jetting resins; the industry's founding patent family, filed at MIT in 1989 and granted in 1993, named the powder-and-inkjet process plainly: three-dimensional printing. The 3D printer generalises the press's founding act: a digital pattern made material, in as many copies as needed, at the point of need. Where Gutenberg freed text from the scribe, additive manufacture frees form from the mould; the economics rhyme, the short run against the mass run, and the industries are converging in packaging prototyping, dental and medical devices, aerospace parts and construction experiments.

Ink as medicine

At the far edge, the ink becomes living. Bioprinting jets suspensions of cells in hydrogel "bio-inks" into patterned scaffolds: skin grafts, cartilage, tissue models for drug testing, and, on the research horizon, printed vascularised organs. The press that began by multiplying scripture now multiplies tissue. Closer to the

present, printed pharmaceutical doses and microneedle patches are in development and early use. These are young industries, and this book flags them honestly as such: the volumes are small, the forecasts are forecasts. But the direction of five hundred and seventy years is unmistakable. Each generation of the press prints a new class of thing: words, then images, then money and packaging, then circuits, then matter, then life.

The limits

The future has constraints, and the industry knows them. Functional printing trades precision for scale against a silicon industry that improves relentlessly; 3D printing remains slow and material-limited against the mould and the lathe for mass goods; bioprinting faces biology itself, the hardest material of all. The press's future segments will grow exactly where the item's ancient economics hold: many small identical or customised patterns, made cheaply, near the point of use. That is a large territory. It is not the whole of manufacturing, and the honest forecast is a press that is everywhere and visible nowhere, an infrastructure of deposition humming inside the world's factories, as invisible and as essential as the printing of cartons is today.

Printing the sun

Printed photovoltaics show both the promise and the discipline of functional printing. Organic and perovskite solar cells can, in principle, be printed roll to roll like a newspaper, inks of light-absorbing polymers or perovskite precursors laid on flexible films, with printed electrodes, promising solar power at packaging-line cost and weight. Research lines in Australia, Germany and elsewhere have printed full cells and modules; efficiencies and lifetimes still trail silicon, and the industry forecasts, this book repeats the rule, are forecasts. But if the economics close, the press becomes an energy industry, printing power by the kilometre. The same logic applies to printed batteries, printed displays and printed sensors: the pattern is electricity itself.

Printing the built world

The construction experiments take the press vertical. Large-format additive systems, gantry printers extruding concrete, have printed houses, bridges and barracks in days, with the printer as a portable factory. The analogy to the press is exact: the digital pattern made material, locally, without moulds or shuttering. The industry's honest state: demonstrations multiply, standards and economics lag, and the forecast is a niche that grows where its economics fit, remote sites, bespoke forms, speed, rather than a replacement for the trowel. But the direction rhyme with 1450 is real: a machine that turns a file into a thing, on site, on demand.

The forecast caveat

A book that has just narrated five hundred years of confident obsolescence owes its futures a discipline. Print has been declared dead since 1455, for scribes, then for hand presses, then for newspapers, then for books, and each declaration was at best half right. The functional futures described here, printed electronics, additive manufacture, bioprinting, will likewise arrive partially, later and stranger than forecast. What will not change is the item's core act, and the industry's core skill: depositing matter in precise patterns at scale. However the segments rotate, that skill has been in continuous demand for five and a half centuries, and there is no forecast in which it stops.

The lithography that prints the world

One descendant of the press deserves its own paragraph in any honest future, because it already prints the substrate of modern life. Semiconductor manufacturing is photolithography: a pattern imaged in light onto a photosensitive resist, developed, etched, doped, repeated in scores of layers at nanometre scale. The stepper and the scanner are printing machines in every functional sense, and their extreme-ultraviolet generation prints features measured in atoms from mask to silicon with optics of impossible precision. Senefelder's chemistry, grease against water on a stone, has become light against resist on a wafer, and the cheapest powerful computers in history rest on the same principle as the cheapest books: pattern once, replicate millions. The press's oldest idea is also the digital world's deepest manufacturing secret.

PART IX · THE PRESS AFTER PAPER

28 · The Persistence of the Book

Every account of the press's future must reckon with a stubborn fact: the oldest product is still alive. The printed codex, folded sheets bound at the spine, invented in late antiquity and industrialised by Gutenberg, has survived radio, cinema, television, the computer and the smartphone. The persistence is not sentiment. It is the performance of a superbly engineered object, and it closes this book's loop.

The format that refused to die

The obituaries of the printed book have been written continuously since the nineteenth century. The phonograph, the microfilm, the computer, the CD-ROM, and finally the ebook were each going to replace it. The ebook came closest: between 2008 and 2014 it took a visible bite of trade book sales in the English-speaking world, and then stopped growing. The printed book stabilised and, in many markets, grew modestly; in the United States and Britain, print still accounts for the large majority of trade book units sold. The reasons are not mysterious on inspection. A printed book is a complete, self-contained technology: it

needs no power, no account, no licence, no update; it is ownable, lendable, giftable, resalable, shelvable; it displays its own progress bar in the thickness under the thumb; it survives being dropped in the bath. And it carries social data that no file can: a personal library is an autobiography in objects.

The book's survival also rests on the press's own reinvention. Digital printing and print-on-demand removed the last economic weakness of the codex, the long run: a title can now exist in permanent availability without a warehouse, printed copy by copy at the point of order. The book trade's backlist, once a graveyard of out-of-print titles, is effectively immortal. The press learned to print the edition of one, and the book learned to live forever.

The letterpress afterlife

One more survival deserves note, because it is the survival of the machine itself. Letterpress, the relief printing of Gutenberg, Stanhope and Clymer, commercially extinct by 1990, has undergone a craft revival: small studios and university shops around the world print books, broadsides and wedding suites on restored hand presses and Vandercooks, with a market that pays a premium precisely for the bite of type in paper, the tactile evidence of the machine. The Adana, the Albion, the Heidelberg windmill, the Linotype: the retired machines of the industrial age have become the instruments of an artisan one. This is not nostalgia as industry; it is the item's oldest form persisting as an art, the way hand-thrown pottery persists beside the kiln lines of industry. The first printing technology is now a medium of choice rather than necessity, and it teaches the machine's newest students what the item actually is: not a way of making copies, but a way of making marks that last.

The loop closed

From the Diamond Sutra to the print-on-demand paperback, the item has kept its promise: identical meaning, materialised, at falling cost, for anyone. The forms rotated, wood block, cast type, iron, steam, rotary, offset, toner, inkjet, but the promise held, and the book, the press's first mass product, remains its most loved one. Whatever the press becomes next, the codex has already made the argument for its survival: some patterns are worth keeping in matter.

The physics of the codex

Why did the codex win and keep winning? Because as an information machine it is superbly designed. Random access: any page is two hand-movements away, no scrolling, no seeking. Durability: the bound book is a shock-mounted, dust-sealed archive with a five-hundred-year service record. Bandwidth: two facing pages present more simultaneous information than any phone screen. Interface: the book teaches its own operation to a four-year-old. And manufacture: folded, sewn or glued sheets are a one-machine product, cheap enough for the pocket of a labourer since the nineteenth century. Technologists who predict the book's death

consistently underrate the object because they compare it to screens feature by feature; the book is not a screen's rival but a different answer to a different problem, the keeping and handling of long text by humans.

The market for the first books

The Gutenberg Bible's journey from product to relic maps the press's own canonisation. In the nineteenth century the book was collected as the first fruit of printing; complete copies passed between the great libraries at prices that rose with each sale. When the General Theological Seminary's copy sold at Christie's New York in 1978 it fetched a record price for a printed book; a leaf from a broken copy sells today for a respectable car's price, and the "Noble Fragment" leaves of a copy dismantled in 1921 are traded singly. The market's verdict is the culture's: the first book of the press is a foundational artefact, and the institutions that hold copies, Mainz, the Vatican, the British Library, the Library of Congress, the Morgan, Göttingen, treat them as national treasures. The press's first product became its monument.

Teaching the hand press

The letterpress revival has a pedagogical heart: programmes like the book arts centres and university letterpress shops teach printing as Gutenberg's journeymen learned it, hand on the bar, because setting type by hand teaches what no screen can: the physical cost of every character. Students who have justified a line by hand understand typography differently; printers who have made ready a forme understand quality differently. The old machine survives, in the end, as a teaching machine, which is perhaps the most Gutenbergian afterlife imaginable.

The paperback century

The codex's refusal to die was tested most severely by its own industry. In 1935 Allen Lane's Penguin Books put respectable titles into paper covers at the price of a packet of cigarettes, ten titles sold from a church crypt, and proved that a book could be a mass-market object; Pocket Books repeated the trick in America in 1939, and the paperback, carried in pockets through a world war, made the book at last a genuinely universal commodity. The format wars that followed, hardcover against paperback, trade against mass-market, each predicted the codex's death by its own cheapening, and each instead grew the readership. Print-on-demand arrived at the end of the century: digital presses and automated binding made a single copy economic, Ingram's Lightning Source built a business on it from 1997, and the long tail of titles that would once have died for want of an edition size now stays in print forever, manufactured one reader at a time. The bookstore, the library and the review all wobbled under the network; the object did not. The codex endures not because it is old but because, as a machine for reading, it has never been beaten on its own terms: random access, no power, no licence, no tracking, and a spine that tells you where you are.

EPILOGUE

The Machine That Prints the Machines

End where the item began: with a pattern and a surface. Everything the press has done in its history, from the Diamond Sutra to the semiconductor fab, is a variation on that one act. The story this book has told is the expansion of what the pattern can be.

The press's biography is a series of emancipations. First the pattern was the whole page, locked in wood, and it was freed into pieces: movable type, the page as a rearrangeable swarm of atoms. Then the pieces were freed from the foundry, and the pattern became light on film. Then the film was freed, and the pattern became pure data. At every step the industry mourned a craft and multiplied a capability, and at every step the same economic engine ran: make the pattern cheaper, and the world will want more of it. That engine is still running. The pattern today is a circuit, a solar cell, a vaccine's log, a parcel's label, a human tissue scaffold; the surfaces are silicon and skin as readily as paper; and the copies, by any honest count, have never been more numerous.

What should a reader of Industries of India take from the item? Three things. That the press is an industry of matter before it is an industry of meaning, and its history is written in paper mills, alloys and inks. That its social power is real but constructed: the press amplifies, and what it amplifies is chosen by editors, laws and readers, not by the machine. And that the item is not finished. The country that gave the world paper, that printed the Diamond Sutra's civilisation, that today builds one of the fastest-growing print markets on earth, has every reason to watch the press's next century, because the next century will be printed too.

In a workshop in Mainz around 1450, a goldsmith assembled four borrowed things and made a system. The system has now been running for nearly six hundred years, and it has never once stopped; it has only changed its materials. The last word belongs to the object itself. You are reading it.

The item's lesson

There is a method lesson in the press's story, and it is the lesson of this whole series. Start with the item, not the category. The category 'media' dissolves under inspection into paper mills, ink chemistries, press builders, foundries, carriers and shops; the item, the press, holds its shape across five hundred and seventy years and a dozen technological generations, because it answers to a material job: put a pattern on a surface, identically, cheaply, at scale. Follow the item and the industries announce themselves in order: the substrate industry, the image-carrier industry, the machine industry, the chemistry industry, the distribution industry, the dependence structure. The map falls out of the machine. That is the wager behind every book in this series, and the press, the item that taught the world to multiply, is its cleanest proof: everything the press made

possible, from the Reformation to the smartphone, is downstream of a screw, a forme and a smear of grease on stone.

What the machine asks of us

The press ends this book as it began it: a way of saying the same thing to everyone. Every later medium inherits that ambition and accelerates it, and every later medium rediscovers the press's accompanying burdens: who may print, who is believed, what a copy is worth when copies are free, what a public is when everyone can address it. The seventeenth century called the problem licentiousness; the twenty-first calls it content moderation; it is the same argument, conducted at the speed of the machine of the day. If the press has a final lesson, it is that multiplication is never neutral: a technology that makes words cheap makes true words cheap and false words cheaper, and the institutions that sort the two, editors, libraries, schools, courts, are not ornaments on the machine but parts of it, the slow parts, the parts that cannot be printed. The press multiplied the word. What the word is worth remains, as it was in Mainz, a human decision.

APPENDIX

A1 · The Anatomy of a Modern Press

Walk a sheet through a modern sheetfed offset press, the standard machine of the world's book and commercial printing, station by station. Every station is a solution to a problem the hand press had, solved at a hundred sheets a minute.

The feeder

A pile of paper, a tonne of it, sits on a rising platform at the back. Suckers lift the top sheet's rear edge, air blasts separate it from the pile, and forwarding suckers push it onto the feedboard, where conveyor tapes carry it to the front lays: precision stops that square the sheet's leading edge while a side lay squares the flank. Then the grippers of the transfer cylinder take it. The sheet is now in the machine's custody, and it will not be released until it is printed; every subsequent register depends on that first square stop, exactly as the hand press's points and frisket squared the damp sheet in 1450.

The inking train

Above the plate cylinder sits a monument to controlled stickiness: the inking train, a stack of a dozen to twenty rollers, steel and rubber in alternation. The ductor roller takes a film of ink from the duct, and the train does the rest, milling, spreading and thinning the ink across repeated roller contacts until the film reaching the plate is even to a fraction of a micron. Too much ink and the shadows fill in; too little and the solids starve; the pressman walks the keys, the row of screws or motors that open the ink duct more or less at

each point across its width, until the sheet's colour bands match the proof. The train is the descendant of the beater's ink balls, doing at 250 cycles a second what the beater did at four a minute.

Damping, plate, blanket, impression

The lithographic heart: the dampening unit wets the plate with a water-based fountain solution so the non-image refuses ink; the plate cylinder carries the thin aluminium plate, imaged by a computer-to-plate laser, its coating hardened where the image is; the plate transfers its ink film to the rubber blanket cylinder; and the blanket, pressed against the impression cylinder, transfers the image to the sheet. One such unit per colour: a four-colour press is four towers in a row, the sheet passing through all four in a fifth of a second, registration held by the grippers' custody and the units' timing. A perfecting press adds a turning device to print the back in the same pass.

The delivery

At the far end, gripper chains carry the sheet over the delivery pile, air slows it, and it settles onto the stack, jogged square, still drying. A modern press watches itself: cameras inspect every sheet for defects and colour drift, consoles log the run, and the next job's plates are already in the queue. The whole machine, feeder to delivery, is the hand press's loop, square the sheet, ink the image, press, release, executed with two centuries of mechanical refinement, and its crew is still called by the old title: pressmen.

APPENDIX

A2 · The Materials of Print

A reference tour of the substances the press consumes: the papers, inks, plates and skins whose properties set the limits of everything printed. The industry's performance is, in the end, the performance of its materials.

Paper grades

Paper is engineered to its process. Newsprint is groundwood-rich, cheap, absorbent, and yellows in years, a deliberate ephemerality; book papers are freesheet, low-lignin, built for centuries; coated papers carry a clay-mineral surface that holds halftone dots on top of the sheet for photographic sharpness, in gloss, silk and matt; the cartonboards layer mechanical pulp between clean liners for stiffness at low cost. Basis weight, caliper, brightness, opacity, formation, pick strength, moisture: the printer orders paper by a dozen numbers, and every press run begins with the question of what the sheet will tolerate. The great historical transitions of paper, rag to wood, acid to alkaline, virgin to recycled, each forced the press to retune: alkaline papermaking

in the 1980s and 1990s finally ended the slow self-destruction of wood-pulp books, the brittle pages that had threatened a century of libraries.

Ink systems

Each process owns an ink physics. Sheetfed offset inks are pastes that set by absorption and harden by oxidation; heatset web inks dry in ovens; coldset newspaper inks never truly dry, they set into the sheet; flexo and gravure inks are thin liquids carried by solvents or water; UV inks are monomers that polymerise in a flash of ultraviolet light, drying instantly on any surface; liquid toners and powder toners fuse; inkjet inks must jet, a fluid engineered for the nozzle before it is engineered for the page. The common thread is the one Gutenberg found: the ink must be exactly as fluid as the transfer requires and no more, and then become permanent on the sheet.

Plates and blankets

The offset plate is a masterpiece of surface engineering: aluminium grained to hold water, anodised to harden, coated with a photosensitive layer that hardens or softens under a laser's 830-nanometre dots, then developed. Processless plates now drop the chemistry entirely, ablating clean on-press. The blanket is rubber on fabric, compressible to absorb the nip's pressure, surfaced to release the ink film whole. Between them, plate and blanket determine print quality as much as the press; they are consumables, replaced on schedule, and their makers are among the hidden industries of Part VIII.

The chemistry of permanence

The oldest material question of print is how long the product lasts. The Gutenberg Bible survives because its paper was rag and its ink was carbon in varnish, both chemically near-inert; the wood-pulp century endangered libraries because acid hydrolysis eats cellulose; modern alkaline papers and pigment inks restore the promise. Every choice in the materials chain is, knowingly or not, a bet on the intended lifetime of the printed thing: a newspaper is designed to die in a day, a banknote to survive five years of wallets, a Bible to outlive its printers. The press makes ephemera and monuments on the same machines, and the difference is material.

APPENDIX

A3 · A Chronology of the Press

The item's timeline, from the first paper to the present. Dates are as the sources give them; where a date is approximate or contested, it is marked.

c. 105 CE	Cai Lun reports papermaking to the Han emperor; archaeological scraps of true paper are older still.
c. 700s	Woodblock printing matures in China; dharani charms printed in Korea and Japan.
c. 770	Empress Shōtoku's million printed charms, the Hyakumantō Darani, distributed in Japan.
751	Battle of Talas; papermaking moves west along the trade roads to Samarkand.
868	The Diamond Sutra printed in China: the world's earliest dated printed book.
c. 1040s	Bi Sheng makes fired-clay movable type, recorded by Shen Kuo in the Dream Pool Essays (c. 1088).
1298-1313	Wang Zhen's wooden movable type and rotary type cases described in his agricultural treatise.
1377	The Jikji printed at Heungdeoksa temple, Cheongju: the oldest surviving metal-type book.
c. 1276	Paper mill at Fabriano, Italy; gelatin sizing and watermarks develop.
1434-1444	Gutenberg in Strasbourg; court records show secret work with presses and metal.
1448-1450	Gutenberg returns to Mainz; loans from Gelthus, then Fust's 800 guilders; work on the Bible begins.
c. 1454-55	The 42-line Bible printed in Mainz; the 31-line indulgences among the first dated printed products.
1455	Fust sues Gutenberg; the Helmasperger Instrument records the venture's accounts.
1457	Fust and Schöffer's Mainz Psalter: first printed colophon, first colour printing from type.
1462	Sack of Mainz; the printers disperse and carry the craft across Europe.
1465-1476	Printing reaches Italy (Subiaco, 1465), Paris (1470), and England (Caxton, Westminster, 1476).
1494-1501	Aldus Manutius founds the Aldine Press in Venice; the octavo classics and italic type follow.
1501-1550	Some 30,600 incunable editions will have been printed by 1500; the book trade becomes international.
1517-1522	Luther's theses go to press; the September Testament of 1522 sells out in weeks.
1543	Copernicus's De revolutionibus and Vesalius's Fabrica: science enters its printed era.
1556	The first printing press in India established at Goa by the Jesuits.
1559	The first papal Index of Prohibited Books.
1605	Johann Carolus's Relation appears in Strasbourg: the first newspaper.
1644	Milton's Areopagitica against licensing.
1665	The Journal des savants and Philosophical Transactions: the learned journal begins.

1710	The Statute of Anne: the first modern copyright law.
1735	Zenger acquitted in New York: truth becomes a defence against seditious libel in practice.
1796-1798	Senefelder invents lithography in Munich (1796); Robert patents the continuous paper machine (1798).
c. 1800	Stanhope's iron press; stereotyping industrialised.
1814	Koenig's steam cylinder press prints The Times, 29 November, at 1,100 sheets an hour.
1817	Koenig & Bauer founded at Oberzell: the world's oldest press-builder.
1827-1843	Napier's perfecting presses; Keller's groundwood pulp patent (1843); Hoe's rotary "lightning press" (1843).
1846	Hoe patents the type-revolving machine; rotary newspaper printing begins.
1851-1866	Reuters founded; the Atlantic cable opens; news becomes planetary.
1886	The Linotype first used commercially by the New York Tribune, 3 July.
1887-1897	Lanston's Monotype patented; British Monotype founded 1897.
1904	Rubel's accidental offset: the rubber blanket enters the press.
1931-32	Times New Roman drawn for The Times and released by Monotype.
1938	Carlson and Kornei make the first xerographic copy, Astoria, 22 October.
1959	The Xerox 914: the plain-paper office copier.
1969-71	Starkweather's laser printer at Xerox PARC.
1970s-80s	Phototypesetting and offset absorb the book and newspaper trades; hot metal ends.
1984-85	PostScript, the Macintosh and the LaserWriter: desktop publishing.
1986	Wapping: the British newspaper industry breaks with the composing room.
1993	Indigo's E-Print 1000: the first digital colour press.
2000s	Print-on-demand normalises the edition of one; newspapers begin their decline.
2010s	The ebook plateaus; the printed book holds; packaging becomes print's centre of gravity.
2020s	High-speed inkjet and functional printing extend the press into electronics, energy and medicine.

APPENDIX

A4 · Glossary of the Craft

The press kept its own language for six centuries; these are the terms this book uses, in the senses the trade gives them.

Blanket	The rubber-surfaced cloth on an offset press's middle cylinder, which receives the image from the plate and transfers it to the sheet.
Case	The shallow tray, divided into boxes, from which a hand compositor picks type; upper case held capitals, lower case small letters.
Colophon	The statement at the end of an early printed book naming printer, place and date; first printed by Fust and Schöffer, 1457.
Compositor	The craftsman who sets type; by extension, the keyboard operator of the hot-metal age.
Composing stick	The small hand tray in which a compositor assembles a line of type.
Forme	The locked-up assembly of type (and blocks) from which a page or sheet is printed.
Frisket	The hinged frame that masks the sheet's margins during hand-press printing.
Galley	The tray that holds composed type before it is made into pages; a galley proof is a trial print from it.
Halftone	The screen process that converts continuous tone into printable dots of varying size.
Hand mould	The adjustable two-part mould, Gutenberg's key device, for casting interchangeable type sorts from a matrix.
Imposition	The arrangement of pages in a forme so that a folded sheet reads in sequence.
Incunabula	European printing from before 1501; from the Latin for swaddling clothes, the infancy of the art.
Intaglio	Printing from ink held in incised lines, as in engraving and banknote printing; the opposite of relief.
Laid and chain lines	The wire shadows in hand-made paper, the mould screen's fingerprint, used to date and place sheets.
Letterpress	Relief printing from a raised inked surface; the press's original process.
Lithography	

	Planographic printing from a flat surface divided chemically into image and non-image; Senefelder, 1796.
Make-ready	The preparation of a press and forme for a quality impression; by extension, all pre-run setup.
Matrix	The copper block bearing the struck impression of a punch, from which type is cast; in the Linotype, the brass female letter carried by the machine.
Offset	Printing in which the image passes from plate to rubber blanket to paper; the dominant modern process.
Point	The unit of type size; the Didot point and the Anglo-American point (about 0.351 mm) both descend from Fournier's system.
Punch	The hardened steel rod engraved with a letter in relief, struck into copper to make a matrix.
Registration	The alignment of successive impressions or colours on the sheet.
Sort	A single piece of type; to be "out of sorts" is the compositor's complaint fossilised in the language.
Stereotype	A solid metal plate cast from a mould taken of a set page; the key to reprints and rotary printing.
Tympan	The framed membrane of the hand press on which the sheet is laid for the impression.
Type metal	The lead-tin-antimony alloy of cast type: fluid, sharp-casting, hard, remeltable.
Watermark	The design pressed into hand-made paper by a wire sewn to the mould; a date-and-place marker for historians.
Web	Paper fed as a continuous roll rather than in sheets; hence web-fed and web offset.