Chemistry and the Written Word:
Chemical Foundations in the Global Spread of Knowledge

Meeka Gandhi

Throughout human history, progress has been measured by the spread of knowledge. Through the development of the written word, knowledge has been harnessed, embodied within books, manuscripts, and other media. Knowledge has been published and translated, making it more easily transferred across geocultural boundaries. The production and sustainability of the written word depends on the advancement of ink technology. Ink comes in many varieties, each with its unique properties. The role of ink in the spread of knowledge is facilitated by chemistry and chemical technology.

The origins of ink lie in Egypt and China. Egyptians were producing dyes for colored clay tablet engravings as early as 2500 B.C. They used charcoal powder and gums with water to create a viscous suspension, the beginnings of ink. During the same time, the Chinese were producing inks for drawing; they were made of soot, gelatin derived from animal skin, and lamp oil [1]. Both civilizations used some form of carbon suspended in an oil or oil-like substance. This suspension allows for the adherence of ink to particular solid surfaces as it dries [2]. This notable achievement of applied chemistry facilitated the harnessing of knowledge through words and pictures permanently captured on a solid substrate.

An obstacle in both Egyptian and Chinese ink innovation was that the charcoal powder and soot—the pigments—are not soluble in the oils or gums—the vehicles. Thus, the ink only lies on the surface of the paper; it is not absorbed, preventing permanence in writing and drawing. The Roman Empire addressed this problem with the development of encaustic inks. These inks, used in combination with heat to enhance absorption, were made of lampblack, copper sulfate, and water, a suspension that made the ink more difficult to erase [1].

Chemistry can explain the interactions of different compounds that allowed for better absorption. Innovations in ink continued to occur; one of the most notable was the development of gall inks in Arabia around 1100 A.D. By the 15^{th} century, gall inks, that used gall nuts and copper sulfate for color, became the most widely used ink, particularly in Europe. The copper sulfate helped to turn the ink black. These inks often had gums to improve fluid quality as well as to prevent oxidation of pigment. The composition of gall inks shows how the chemistry of this particular ink allowed it to become the most prevalent. Because of their unique and effective chemical properties, gall inks were used to produce and translate religious texts [1]. By translating texts, documents, and manuscripts into different languages, knowledge was able to flow across geographical, cultural and political borders.

In the late Middle Ages, knowledge was slowly circulating, a tentative but steady flow that depended on translations from monasteries in the 15^{th} century. However, the innovation that truly revolutionized the dissemination of knowledge was the invention of movable type, initially a system of printing using engraved clay, first invented in China in the early 11^{th} century [3]. The Chinese invention had little effect in Europe until Johannes Gutenberg introduced a better system in the mid-15^{th} century and later the printing press [4]. These inventions made it possible for the written word to be mass-produced. Knowledge, in the form of the written word, was now more accessible, thus having a greater impact across borders. Ink had to be adapted to this new system of writing. The composition of ink was altered to accommodate the needs of printing. Inks were made of iron sulphate, lampblack (less carbon than was previously used), linseed oil, and other natural resins and varnishes [2]. Linseed oil and other resins allowed the ink to stay wet when adhering to the face of the blocks and typeface used in movable type or the printing press, while it dried on paper. Iron sulfate enhances color through reactions of added tannin with atmospheric oxygen [5]. This new ink had both advantages and disadvantages; over time, its chemistry was changed to make it more effective.

Throughout the evolution of ink, a few components have been consistently necessary: the pigment, the vehicle, and the drier. The pigments are typically found in substances such as powdered charcoal or lampblack, as well as naturally colored minerals for non-black colors. The color of the pigment is not only affected by the base minerals used but also by the size and shape of pigment molecules. A smaller pigment molecule increases color strength, transparency, viscosity, and dispersability. Pigment molecules are coated in resin to maximize these effects[12]. The solubility of a pigment molecule is also important. For ink to be absorbed onto a writing surface, the pigment must be soluble in the vehicle.

The vehicle is usually some kind of oil or resin that also contributes to the ink's ability to stay wet or dry quickly [1]. A drier is an additional component that changes how an ink dries based on where it is deposited. Ink can dry by absorption, oxidation, or evaporation. If the paper is soft and porous, absorption occurs. In other cases, coated paper for example, ink dries by oxidation. Evaporation usually occurs by one of the other two ways [6]. Driers can enhance the ability of each or all of these three methods of drying to occur.

Ink has continued to diversify through the use of different oils, driers, pigments, and vehicles. Compounds have been mixed, switched, and reacted to create inks that most appropriately serve the intended application. One example is newspaper ink. Newspaper ink is specifically engineered to adapt to situations encountered by newspapers frequently. The ink is made of nonpolar mineral oils [7]. This allows newspapers to be exposed to water without the words smearing. Because nonpolar ink is not soluble in polar water[8], newspapers can be transported and distributed regardless of weather.

The effectiveness of ink involves the paper on which ink is deposited. Ink can be engineered in certain ways to best fit the paper. For example, ink often contains particular resins that influence the way it adheres to paper. In many instances, some of the ink is absorbed into the paper while some adheres to the paper's surface. This property makes a document rub-resistant but also keeps too much ink from seeping into the paper creating blemishes. Paper is made to accommodate this property. Different types of paper yield different degrees of rub-resistance. Smoother, glossier paper is more resistant while rough paper is more vulnerable to ink rub-off[11].

A contemporary innovation in ink concerns ink in printers. The chemical engineering of printer ink is complex because not only does the ink need to be appropriate for the paper but it also needs to be appropriate for the method of depositing, namely, the type of printer. The density, surface tension, and viscosity of the ink need to be considered when creating printer ink. Without suitable chemical properties, the ink would blemish or spot the paper instead of providing sharp, clear text [9]. The main chemical components of printer ink are: the pigment, a film-forming resin mostly made of oils modified with fatty acids, and an organic solvent. This composition, which includes a few other ingredients, is fundamental because it gives the ink in printers the ability to withstand external factors such as unfavorable weather. It also prevents degradation of the printed layer of ink as well as fading [10]. Resins and other additives in the ink prevent it from smearing once put onto paper. All of these qualities, produced by the chemical makeup of printer ink, allow printed paper to be safely transported[11]. With expanding use of printers, the cost of printer ink must be considered as a factor that affects the spread of knowledge. Black ink ranges from $0.021 to $0.123 per page of text. Color inks are more expensive, ranging from $0.069 to $0.267 per page[13]. These prices reflect the cost of ink manufacture, taking into account the specific requirements of functional ink.

Ink has undergone numerous changes, adapting to different writing surfaces and to different methods of writing. The chemistry of inks determines its adaptability and versatility. The widespread use of ink has allowed the mass circulation of books, newspapers, manuscripts, magazines, advertisements, etc. Using ink, knowledge has been captured and has spread through the power of the written word.

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