The ladder of chemical knowledge

If humanity suffers a cataclysm — nuclear war, runaway global warming or any of a number of other potential catastrophes — a lot of scientific knowledge could be lost, especially the practical 'how to' kind. Today the frontier of such knowledge lies in things such as laser and semiconductor physics, quantum chemistry, bio- and magnetic materials, but if humanity were reduced to a few scattered bands of survivors struggling to find enough food and water, our technological capabilities might fall back several centuries. Pressing challenges might be learning to make soap, cement and glass, or to produce electricity.

There would be no Internet, of course. Nor, very possibly, many preserved books or journals, especially after decades pass, rains fall through collapsed roofs, and nature recolonizes cites. What are the most crucial pieces of knowledge that would help survivors restore the technology of civilization? In his book, *The Knowledge* (Vintage, 2015), Lewis Dartnell has tried to answer this question by reviewing the basic chemical processes humanity has come to master over the past few thousand years. The book is a reminder of how much knowledge is collective, residing in many minds. Working on your own, or with a few friends, it might take years to make something as simple as a butter knife.

As Dartnell notes, the American physicist Richard Feynman once suggested that perhaps the most fundamental of all scientific ideas is the atomic hypothesis — the idea that all matter is made of extremely tiny particles of a relatively small number of kinds. From that insight eventually emerged an understanding of the combinatorial possibilities of chemistry, although it took centuries of exploration and error to learn to isolate elements such as magnesium or aluminium, or to produce compounds like ammonium nitrate.

Lots of chemistry requires intense heat. So a fundamental chemical process any recovering group would need to master is the production of charcoal. Burning wood with restricted oxygen drives off water and other volatile products, and leaves a fuel that is not only lighter, but burns much hotter. Using coal, much the same process yields coke, another hot burning fuel. With sufficient heat, survivors could begin reproducing the chemical knowledge of previous centuries.

It wouldn't be obvious to most of us, but first on the list of useful chemicals may be calcium oxide, or quicklime, produced by burning limestone, which contains calcium carbonate, at temperatures above 900 °C. Quicklime combined with water yields calcium hydroxide, or slaked lime, a strongly alkaline substance crucial in making mortar for building with brick, in water purification or, with the addition of fine clay powder, in the production of cement. Then there's potash (from which the name potassium is derived), obtained by soaking the ashes of burnt hardwoods in a pot of water. Rich in potassium, potash reacted with slaked lime yields potassium hydroxide, or lye, which makes a hard but water soluble soap when combined with fat.

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So our survivors could build durable structures and wash themselves. It might take a long time for someone to discover how glass can be made from the silicon dioxide in ordinary sand, with sodium carbonate added to reduce the melting point, and calcium carbonate so the glass won't dissolve in water. A recovering population would need to learn how to identify iron ores, and smelt them with intense heat — and limestone — to collect molten iron. Doing so would require first learning to build a forced-air furnace, as the Chinese did 700 years ago. The step to hardened steel is more difficult, and would likely require decades of experimentation and the reinvention of the Bessemer converter — used to reduce the amount of carbon in raw pig iron down to the 0.2% range that gives hard steel.

Our survivors would need to preserve wood and make dyes or paints, and hence would need a host of organic chemicals we produce today from fossil fuels and sophisticated industrial chemistry. An alternative: baking wood to make charcoal but capturing the volatile substances given off. Distilled, these yield a spectrum of further substances including methanol, acetone and acetic acid, turpentine, creosote and pitch.

It's rather astonishing to realize how little most of us know about the traditional means for producing the substances we now rely on. As Dartnell points out, the sodium carbonate used in glass making was for centuries produced from the ashes of kelp, seaweed or plants growing in sodium-rich soils. Since the 1860s, it's instead been produced industrially using the Solvay process, which involves a cyclic reaction of limestone, ammonia and brine. For centuries, the nitrates and ammonia required for fertilizers were obtained either from manure, or by mining nitrate compounds. Since the 1920s, they've instead come from industrial synthesis of ammonia from nitrogen gas and hydrogen gas, the Haber–Bosch process. These modern techniques took centuries of science to discover, and would again, unless some scraps of advanced scientific knowledge survive.

Chemistry today remains a science steeped in practical recipes for producing specific molecular products. Synthesis is partially an art form, as chemists start with a target product and work backward, considering how it might be formed from simpler precursors, and how these might in turn be made from even simpler molecules. This is a product of a long history of learning and recording, putting an array of possibilities at any chemist's fingertips.

The information age may take this a step further. Last month, for example, a possibly revolutionary advance in synthesis was announced in a study (M. H. S. Segler, M. Preuss & M. P. Waller, *Nature* **555**, 604–610; 2018) showing that machine learning algorithms can now achieve this backward analysis (for organic chemistry, at least) as effectively as experienced chemists, but far faster. They will likely be superior soon. The combinatorial explosion of chemical knowledge continues, and it would take a catastrophe to set it back. In which case, we may go back to baking crushed limestone and soaking ashes, and climbing the ladder of chemical knowledge all over again. ❐

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