The biosynthesis of proteins and other biomolecules is carried out with exquisite selectivity and efficiency, and with all building blocks present at the same time. In the laboratory, however, chemical synthesis is much less refined and is typically controlled by performing reactions with pure reactants, one step at a time and with purification steps in-between. Moreover, the formation of covalent bonds occurs through random collisions of reactants, so to proceed efficiently the reactant concentrations must in general be millimolar or higher.

During the past decade an alternative approach has emerged that uses organic molecules linked to short DNA sequences. The technique is known as DNA-templated synthesis and allows reactants to be supplied in nanomolar concentrations at which their chemical reactions can be controlled by the DNA sequences. This approach relies on hybridization events between complementary strands of DNA bringing the molecules into close proximity to each other and therefore increasing their local concentration so that they can react, even when the overall concentration of the molecules is low. (The hybridization events can be between two of the short DNA sequences, or between two short sequences and a DNA template.) The approach is possible because (non-covalent) DNA hybridization is several orders of magnitude faster than covalent chemical reactions. Numerous chemical reactions (including reactions that are otherwise non-compatible) have been controlled in the same reaction vessel with this approach, and it has also been used in the synthesis of DNA-encoded combinatorial libraries of short peptides and other compounds.

However, these approaches require numerous interventions, such as the addition of chemical activators, the cleavage of linkers and protective groups, variations of temperature, or purification steps. Writing in *Nature Nanotechnology*, Yu He and David Liu of Harvard University now report carrying out the multistep synthesis of an oligamide without any kind of intervention by combining DNA-templated synthesis with a DNA walker.

In recent years, several dynamic DNA devices have been invented, including autonomously moving machines called DNA walkers. In 2005, Chengde Mao and co-workers at Purdue University developed a DNA walker that autonomously and unidirectionally moves along an engineered DNA track. The walker mechanism combines thermodynamically driven DNA hybridization interactions with an integrated DNAzyme that has the ability to specifically cleave a diribonucleotide built into the stations of the track. Once positioned on the track, the walker is driven to the first station, which is geometrically within range, to form a more stable DNA duplex. Once there, however, the DNAzyme cleaves the station strand at the diribonucleotide, decreasing the stability of the DNA duplex and driving the walker to the next station.

**Figure 1** | Multistep synthesis of an oligamide in a single solution with a DNA walker. The path has three stations (S1–S3), an initiator (S0), a DNA track and a DNA walker. The stations and the initiator can hybridize to the single-stranded DNA track; each station has an activated N-hydroxysuccinimidyld (NHS)–ester group and two ribonucleotides (shown by a small green dot). The building blocks attached to the stations also contain a rigid spacer that keeps the amine and NHS-ester groups in each species apart (represented here by the large blue, red and green dots; see ref. 6 for further details on the structures). The DNA walker contains an amine group, which reacts with the NHS-ester in the stations, and a DNAzyme (purple line) that can cleave the ribonucleotides in the stations. As the DNA walker moves along the track (each step is ~7 nm) it performs a series of acylation reactions, leading to the synthesis of a triamide.
He and Liu chemically engineered this system so that the walker would also pick up an organic building block at each station through an acylation reaction and thus synthesize an oligoamide that increases in length as the walker proceeds along the track (Fig. 1). The chemical design is very delicate. As the reactions must also proceed autonomously, the building blocks at stations one and two have dual reactivity: an activated ester that reacts with an amine on the walker and thereby cleaves the building block from the station; and an amine that allows reaction with the next building block when that walker has moved to the next station. Furthermore, the chemical reactions must proceed significantly faster than the cleavage of the station strand. He and Liu avoid unwanted side reactions of the highly reactive building blocks by using photolabile protective groups for the building block amines, which are only liberated after the building blocks are conjugated to the station strands and placed on the track. Intramolecular reactions of the liberated amines with the activated esters are avoided by choosing molecules containing a rigid spacer that keeps the two reactive groups apart.

The device can walk over three stations and produces a triamide in an overall yield of ~45%. From a chemist’s perspective this is impressive, but it is of course far from the efficiency and robustness of natural peptide synthesis. Nevertheless, the work of He and Liu2 is unique, and represents the first autonomous and fully artificial mimic of peptide biosynthesis. Furthermore, the work brings advanced chemical function to the field of DNA nanotechnology. Together with other recent advances in the field — in particular, the development of DNA robots that can walk autonomously along a designed track on a DNA origami landscape4, and the development of a DNA-origami assembly line where robots arm bring in cargos to the walker10 — the work could lead to more complex chemical assembly lines.

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MAGNETOELECTRICS

Making metallic memories

A phase transition at the surface of a thin film of iron can be exploited to create a metallic non-volatile memory.

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Electromagnetic devices pervade our daily lives, but devices that exploit the coupling between electric and magnetic phenomena in materials are surprisingly rare. Magnetic data-storage media, for example, generally require magnetic fields to read and write the data stored on them. However, controlling magnetic order with electric fields, and vice versa, may allow useful new classes of devices to be developed. So far research into such magnetoelectric effects has focused exclusively on insulators because they are able to sustain an electric field or a spontaneous polarization. Writing in Nature Nanotechnology, Wulf Wulfhekel of the Karlsruhe Institute of Technology and co-workers1 in Germany, Japan, Romania and the United States demonstrate that magnetoelectric effects can also be produced in metallic systems by using an electric field to cause a phase transition at the surface of a thin iron film.

The possibility of employing electric fields to directly control the magnetic properties of materials has been the subject of research since the early twenty-first century2, but the availability of new multiferroic materials — in which the magnetic and electric ordering are intimately related3 — has led to a resurgence of interest in recent years. However, bulk metals have not been well studied in this regard because their high density of free electrons effectively screens applied electric fields.

By focusing on the surface of thin films, Wulfhekel and co-workers avoid screening effects and observe a magnetoelectric effect in metals. Their approach strongly perturbs the electronic structure of a thin (a few atomic layers) metallic film by a strong (a few millivolts per centimetre) electric field applied through a scanning tunnelling microscope (STM) tip. The field displaces free surface electrons in one direction and atomic cores in the opposite direction, initiating a phase transformation from a non-ferromagnetic to a ferromagnetic ordering. The same STM tip is then used to observe the accompanying changes in structure and magnetic ordering.

These measurements, performed on an iron thin film deposited on a single-crystal copper surface, reveal that the phase transformation is reversible and occurs at least as fast as the time resolution of the STM instrument (60 μs). And because the transformation occurs between two stable phases, the metal in effect acts as a rewritable non-volatile memory. This phase transition in iron is one of the most-studied in any material because of its importance in the design of high-strength, high-toughness steels for structural applications. Its appearance in a nanoscale metallic memory is therefore an interesting new twist on a storied and well-studied property.

Wulfhekel and co-workers demonstrate electric-field-driven low-temperature magnetic switching of islands of iron films (or iron ‘nanodots’) that measure about 10 nm to a side. If each island were to represent one bit of information, the resulting memory device would have a storage density of 1012 bits per square inch, which is better than a modern hard drive by a factor of more than 100. However, this would require reading and writing operations to be performed at room temperature, which has yet to be demonstrated.

The work of Wulfhekel and colleagues clearly shows that it is not necessary to work with insulators to achieve magnetoelectric