May 2005: Self-splicing RNA

**Self-splicing RNA**
Nature is full of surprises, and you can be sure that once you think you understand something, Nature will come up with an exception. Twenty years ago, this was the case with enzymes. After decades of work, biochemists thought that proteins were the only molecules that catalyzed chemical reactions in the cell, so it came as a surprise when Thomas Cech and his coworkers discovered a natural RNA splicing reaction that occurs even when all of the proteins are removed. Since then, researchers have discovered many additional examples of *ribozymes*—RNA molecules that perform chemical tasks.

**Excising Introns**
In plants and animals, most RNA molecules are made as long precursors that need to be trimmed and reassembled to create the final active molecule. These precursor RNA molecules are composed of *exons*, which are the important parts, separated by *introns*, which must be removed. In most cases, the RNA is cut and spliced together by a spliceosome, a molecular machine composed of protein and RNA. In a few cases, however, the RNA can perform the splicing reaction on its own. The first example, discovered by Thomas Cech, was a ribosomal RNA found in a protozoan. Since then, hundreds of examples have been identified in genome sequences of many organisms. The example shown here, from PDB entry 1u6b, is part of a bacterial transfer RNA that must be spliced before it can adopt its functional form. In the illustration, the large structure in green is the intron, which uses a GTP and two magnesium ions to remove itself. The two exons that will be spliced together are colored red and blue—note that only a small piece of each exon is included in the structure.

**Ribozymes Everywhere**
Once researchers started looking, ribozymes turned up everywhere. In some cases, they are built into RNA molecules and act upon themselves, as in the self-splicing introns. In other cases, ribozymes act on other RNA molecules, breaking and rejoining the phosphate bonds that hold the chains together. In some ribozymes, such as the spliceosome and ribonuclease P (which processes transfer RNA and other RNA molecules), the RNA works along with proteins to perform the reaction. Most ribozymes perform cutting and pasting reactions on RNA, however, the ribosome (which is thought to be a ribozyme) shows that RNA can also perform other reactions, such as the formation of peptide bonds in proteins.
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The Simplest Ribozyme
The hammerhead ribozyme (so named because diagrams of its nucleotide sequence look like a hammer) is the smallest natural ribozyme discovered so far. The example shown here is from PDB entry 1mme. It performs a very simple reaction: the hydroxyl group colored red attacks the neighboring phosphate shown in orange and pink, breaking the RNA chain. The unusual surrounding loop structure holds this linkage in just the right position to promote the break. These types of "nucleolytic" ribozymes are used to solve a special problem encountered by organisms that have circular DNA. When RNA polymerase makes RNA from a DNA circle, it keeps going around and around, making copy after copy strung together in a long continuous strand. Ribozyme self-cleavage sites built into the RNA then break the long strand into smaller functional pieces.
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Exploring the Structure
The self-splicing RNA in PDB entry 1u6b has been caught in the middle of its splicing reaction. In this picture, the two exons are shown in red and blue, and part of the intron is shown in green. The rest of the intron (shown on the first page of this Molecule of the Month) is omitted. The reaction starts with one continuous piece of RNA. Imagine that the O3' end of the red exon is attached to the phosphate group circled at the top. Then, if you follow the chain, you go from red exon, through the green intron, and out the blue exon. The structure shows the molecule after the first cleavage has been made. The GTP has broken the chain between the intron and the exon in red, leaving the GTP attached to one end of the intron. At this point, the O3' atom of the red exon is perfectly placed to attack the phosphate at the end of the blue exon (lower circle). When that bond is made, the green intron will be released, and the red and blue exons will be spliced together. Notice that the short portion of the intron shown here, termed the "guide sequence," aligns the two exons perfectly next to one another.