Calcium is the most plentiful mineral element found in your body, with phosphorous coming in second. This probably doesn't come as a surprise, since your bones are strengthened and supported by about two kilograms of calcium and phosphorous. Your body also uses a small amount of calcium, in the form of calcium ions, to perform more active duties. Calcium ions play essential roles in cell signaling, helping to control processes such as muscle contraction, nerve signaling, fertilization and cell division.

Through the action of calcium pumps and several kinds of calcium binding proteins, cells keep their internal calcium levels 1000–10,000 times lower than the calcium levels in the blood. Thus when calcium is released into cells, it can interact with calcium sensing proteins and trigger different biological effects, causing a muscle to contract, releasing insulin from the pancreas, or blocking the entry of additional sperm cells once an egg has been fertilized.

**Sensing Calcium**

As its name suggests, calmodulin is a CALcium MODULated proteIN. It is abundant in the cytoplasm of all higher cells and has been highly conserved through evolution. Calmodulin acts as an intermediary protein that senses calcium levels and relays signals to various calcium–sensitive enzymes, ion channels and other proteins. Calmodulin is a small dumbbell–shaped protein composed of two globular domains connected together by a flexible linker. Each end binds to two calcium ions. PDB entry 3cln, shown here, has all four sites filled with calcium ions and the linker has formed a long alpha helix separating the two calcium–binding domains.

**Calmodulin Look–alikes**

Many different proteins are sensitive to calcium levels inside (and outside) cells. In the late 1960's, before the discovery of calmodulin, troponin C (see, for instance, PDB entry 1tcf) was the first protein shown to be sensitive to calcium. Troponin C senses rising calcium levels and triggers muscle contraction. The structures of troponin C and calmodulin are remarkably similar, the major difference being the length of the linker connecting the two calcium–binding globular domains. The calcium–binding region of the protein, shown in detail in a later section, is almost identical. This motif has since been found in dozens of other calcium–sensitive proteins.
A Functionally Versatile Molecule

Calmodulin's target proteins come in various shapes, sizes and sequences and are involved in a wide array of functions. For example, calcium-bound calmodulin forms a critical subunit for the regulatory enzyme phosphorylase kinase, which in turn is a regulator for glycogen breakdown. Calmodulin also binds and activates other kinases and phosphatases that play significant roles in cell signaling, ion transport and cell death. One common theme in the contact between calmodulin and its different target proteins is the use of non-polar interactions, in particular, through the interactions with the unusually abundant methionines of calmodulin. Calcium binding exposes these non-polar surfaces of calmodulin, which then bind to non-polar regions on the target proteins. The structure shown on the left, from PDB entry 1cfd, shows calmodulin without calcium, and the structure on the right, from PDB entry 1cll, shows calmodulin after calcium binds. The key nonpolar areas are colored with carbon atoms in green and the many methionine sulfur atoms in yellow. Notice how these non-polar amino acids form two neat grooves (shown with red stars) when calcium binds, waiting to grip the target protein. Because these non-polar grooves are generic in shape, calmodulin acts as a versatile regulatory protein and its targets are not required to possess any specific amino acid sequence or structural binding motifs.
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**Flexibility of Calmodulin**

NMR studies clearly show that the connector between the two calcium binding globular domains is flexible even when it is not bound to its target proteins. However, the full range of flexibility can be seen in calmodulin's interactions with its target proteins. Calmodulin typically wraps around its target, with the two globular domains gripping either side of it. The two structures on the left show calmodulin bound to two different target enzymes: calmodulin-dependent protein kinase II-alpha at the top (from PDB entry 1cm1) and myosin light chain kinase on the bottom (from PDB entry 2bbm). In both cases, only a small piece of the target protein chain (shown in red) is included in the crystal structure. Notice how the flexible linker of calmodulin, shown in purple, allows calmodulin to conform to the slightly different shapes of these two targets. A different binding geometry is seen in the edema factor toxin from the anthrax bacteria, shown here on the right from PDB entry 1k93. The toxin is shown in red. Once calmodulin binds to the toxin, a conformational change in the toxin activates its adenyl cyclase activity, which then depletes the host cell's energy stores. Since calmodulin is absent in bacteria, the anthrax bacteria have cleverly evolved to exploit the abundance of calmodulin in their hosts in order to trigger the toxin and take control of their cellular machinery.
Exploring the Structure

Calmodulin contains four nearly identical high-affinity calcium binding sites, as seen in the backbone diagram of PDB entry 1cll shown on the left. The calcium ions are shown in purple. The calcium-binding motif is comprised of a characteristic loop flanked by two alpha helices. As shown on the right, the positively-charged calcium ion is surrounded in the loop by negatively-charged sidechains of three aspartates and one glutamate, as well as one oxygen atom from the backbone of the protein chain.