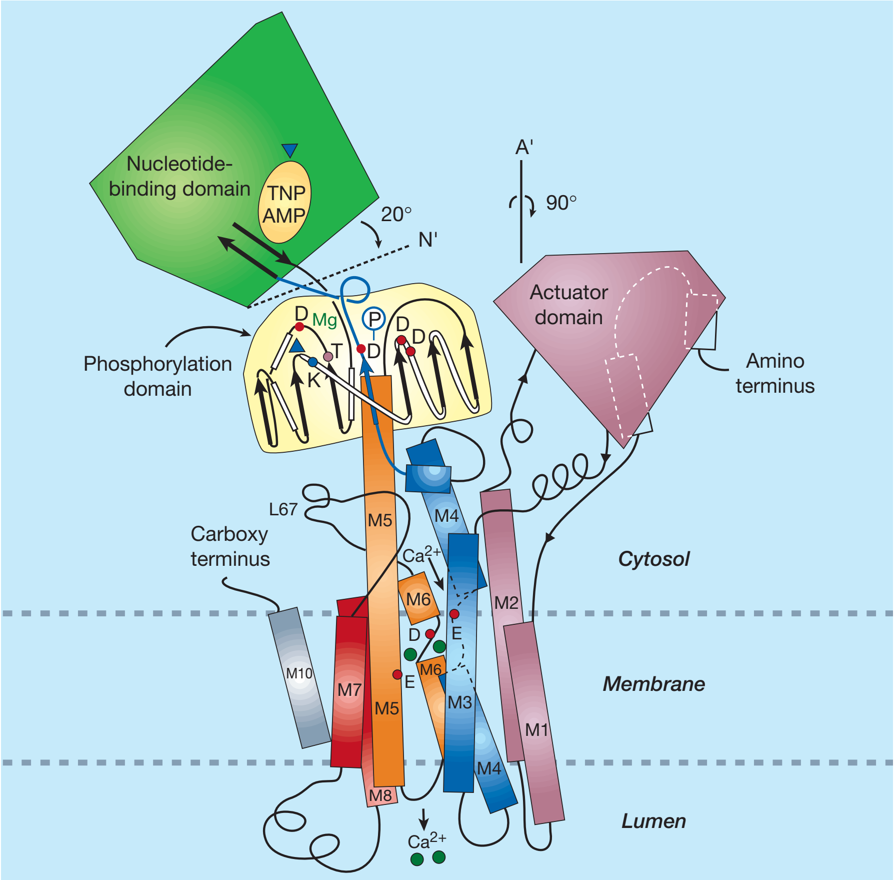

Figure 2 **Overview of the structure of the Ca^{2+}-ATPase, as proposed by Toyoshima *et al.*[4]. Small spheres and single letters mark the positions of residues involved in the Ca^{2+}-binding site or in catalysis (K, lysine (blue); T, threonine (violet); D, aspartate, and E, glutamate (red)). N′ and A′ indicate the rotation of the nucleotide-binding and actuator domains required to match the density of the Ca^{2+}-free conformation[9]. Crosslinked sites are shown as filled triangles and Ca^{2+} ions are shown as green spheres. The membrane region features ten helices, the side-by-side location of the two Ca^{2+}-binding sites formed by transmembrane helices M4, M5, M6 and M8, and the dislocations in M4 and M6 at the common Ca^{2+}-binding motif (E/DGLP). The phosphorylation domain is shown as a seven-stranded parallel β-sheet. The phosphorylated Asp 351 (indicated by a circled 'P') lies at the end of the first strand, which continues into the nucleotide-binding domain.**

energized Ca^{2+} transport. The 'jaws' formed by the P and N domains will close to allow phosphorylation of Asp 351. The gap between the A domain and the P and N domains will close[7]. These changes will be transmitted to the Ca^{2+}-binding and translocation domains, first to occlude Ca^{2+} and then to disrupt the Ca^{2+}-binding sites and to alter their accessibility to cytosolic and lumenal spaces. Toyoshima *et al.* propose that liberation of the A domain allows it to induce closure of the gap between the N and P domains. At the end of the cycle, the release of Ca^{2+} to the lumen is required before E_2MgP can be hydrolysed (Fig. 1). Perhaps this release provokes contrary motions of the A domain, allowing the cleft to open and admit water to the phosphoenzyme.

The complementary transmission of the effects of phosphorylation to the residues that gate the Ca^{2+}-binding sites is a separate conformational problem[7,10]. Phosphorylation may initiate small local changes, which may then be communicated from the P domain to the membrane through the stalk helices and the L67 loop (Fig. 2). There is clearly still more to be learned from this intricate crystal structure of the Ca^{2+} pump. ■

David H. MacLennan is in the Banting and Best Department of Medical Research, University of Toronto, Toronto, Ontario M5G 1L6, Canada.
e-mail: david.maclennan@utoronto.ca
N. Michael Green is at the National Institute of Medical Research, Mill Hill, London NW7 1AA, UK.
e-mail: mgreen@nimr.mrc.ac.uk

1. Ebashi, S. & Lipman, F. *J. Cell Biol.* **14**, 389–400 (1962).
2. Hasselbach, W. & Makinose, M. *Biochem. Z.* **333**, 518–528 (1961).
3. Skou, J. C. *Biochim. Biophys. Acta* **23**, 394–401 (1957).
4. Toyoshima, C. *et al. Nature* **405**, 647–655 (2000).
5. de Meis, L. & Vianna, A. L. *Annu. Rev. Biochem.* **48**, 275–292 (1979).
6. MacLennan, D. H. *et al. Nature* **316**, 696–700 (1985).
7. McIntosh, D. B. *Adv. Mol. Cell. Biol.* **23A**, 33–99 (1998).
8. MacLennan, D. H., Clarke, D. M., Loo, T. W. & Skerjanc, I. S. *Acta Physiol. Scand.* (suppl.) **607**, 141–150 (1992).
9. Zhang, P. *Nature* **392**, 835–839 (1998).
10. Stokes, D. L. & Green, N. M. *Biophys. J.* **78**, 1765–1776 (2000).
11. Clarke, D. M. *et al. Nature* **339**, 476–478 (1989).
12. Andersen, J. P. *Biosci. Rep.* **15**, 243–261 (1995).
13. MacLennan, D. H. *et al. J. Biol. Chem.* **272**, 28815–28818 (1997).
14. Soulie, S. *et al. Biochemistry* **38**, 5813–5821 (1999).
15. Yonekura, K. *et al. Biophys. J.* **72**, 997–1005 (1997).
16. Ogawa, H. *et al. Biophys. J.* **75**, 41–52 (1998).

Daedalus

Pumping a vacuum

Last week Daedalus invented a novel aero-engine. Its air duct was threaded by a.c. electric and magnetic fields at right angles. As the electric field came on, it polarized the air, driving a transient displacement current upon which the magnetic field exerted its motor action. As the electric field turned off again, a reversed displacement current flowed through the air; but since the magnetic field had also reversed, the air felt an impulse in the same direction as before. Thus the motor exerted a unidirectional pump action on its gaseous dielectric.

Daedalus now wonders what would happen if he ran this motor in a vacuum. Vacuum is a perfectly good dielectric: it can sustain a transient displacement current like any other insulator. His electromagnetic pump should exert a force on it. So how can you pump a vacuum?

The modern quantum vacuum, he points out, is a very crowded place. It is dense with transient virtual particles appearing and vanishing again all the time, lasting just long enough for their energy not to infringe the uncertainty principle. Clearly it is these particles that carry a displacement current through a vacuum, and on which the electromagnetic vacuum pump exerts its thrust.

Yet any pump or motor must create a reaction equal to the action of its thrust. If the thrusted particles promptly vanish, their reaction vanishes with them, which seems impossible. But Daedalus notes the theory of particle collisions: a high-energy collision dumps so much energy in a small volume that the virtual particles in the vicinity can seize it to pay off their debt to Heisenberg, and thus become real. His pump must do the same thing. It dumps energy into the vacuum, allowing real particles to appear. And these newly created particles carry away its reaction.

The fields in the electromagnetic vacuum pump have an extremely low energy density; but their volume as a particle source is enormous. In creating its thrust, the pump would pour out vast numbers of particles of amazingly low energy: languid pions, lethargic neutrinos, feeble photons, all travelling in exactly the direction and with exactly the energy needed to balance its thrust. A splendid new field of physics awaits development. So does a wonderful propellant-free space thruster, which could reach the stars on energy alone. **David Jones**

***The Further Inventions of Daedalus* is published by Oxford University Press.**