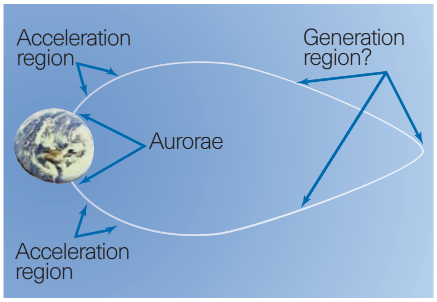

Figure 2 **A magnetic field line connecting auroral regions near the Earth's North and South Poles. A current of electrons and ions, generated by an unknown mechanism far from the Earth, flows along the field lines. These charge carriers are accelerated to high energies before hitting the upper atmosphere, where they cause aurorae.**

the conducting (sunlit) ionosphere, and hence the auroral currents and the discrete aurorae should favour the sunlit region. This shorting out might not happen if these generators in the magnetosphere don't reside at the Equator but rather are closer to the ionosphere[4,5] (with these distances measured along the magnetic field lines, which carry the currents; Fig. 2). Still, it seems unlikely that such generators would only be connected to their nearest ionospheres. Second, for a voltage generator in the magnetosphere driving an auroral circuit, the more resistive (dark) the ionosphere, the less voltage is available to accelerate electrons to make aurorae[6,7]. Third, it is hard to explain the observed slippage of fast magnetospheric flows relative to the ionospheric flow: because electrical coupling is better to a more conducting ionosphere, an aurora-producing electric field that decouples the flows is more likely to form above a conducting ionosphere than a dark ionosphere.

Newell and colleagues point out[1,2] that their results support the ionospheric feedback model[8,9] for auroral arcs. In this model, if the ionosphere has too low a conductivity to carry a large current from a generator, then electrons will be precipitated in the ionosphere, increasing the conductivity and so drawing more precipitation. This feedback results in a robust arc. But the shorting-out problem must still be considered if the generator has access to a sunlit and a dark ionosphere.

Another possibility, for those auroral arcs that move, is that the properties of the Alfvén waves reflecting off the ionosphere control the aurora. In such moving arcs, Alfvén waves — magnetic disturbances in a plasma — are believed to act as transmission-line transients in the magnetosphere–ionosphere circuit. The electric-field structure of a reflecting Alfvén wave depends on the conductivity of the ionosphere[10,11], so the manner in which electrons are accelerated and power is dissipated could be different above dark and above sunlit regions. Here, the shorting-out problem need not arise, as fast transients are still reflected from a conducting terminus.

Another possibility is that, to complete a magnetosphere–ionosphere circuit, the current-carrying electrons in an auroral arc must have enough kinetic energy to be able to penetrate the upper atmosphere to reach the conducting layer[12]. (This is very like the old notion of 'striking the arc'.) In order to reach the conducting layer from above, the electrons must be of higher energy when the atmosphere is dark than when it is sunlit (Fig. 1). Accordingly, auroral arcs, which are caused by energetic electrons, might selectively occur over dark regions, where the charge builds up until the necessary voltage is reached. But again, if the generator has access to a sunlit and a dark ionosphere, the shorting out problem comes into play.

Yet another possibility is that strong horizontal conductivity gradients can form in a dark ionosphere. This type of generator would drive currents when a flow in the magnetosphere passes through a region connected to a conductivity gradient in the ionosphere[13].

The aurora research community has spent most of its effort and space-flight resources investigating the acceleration region of the magnetosphere (Fig. 2). But electron acceleration is only one link in the chain. The least understood, and perhaps most fundamental link is the generator. No big-picture understanding of the aurora will be obtained until space missions are launched to investigate the generator region, to determine how the magnetosphere powers aurorae and how aurorae alter the dynamics of the magnetosphere. As the critical quantities are spatial gradients — in plasma flow velocity, ion pressure and anisotropy, plasma-wave amplitude — multiple-satellite configurations will be needed. No such missions are yet planned, so until they are, aurora researchers must await enlightenment. □

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1. Newell, P. T., Meng, C.-I. & Wing, S. *Nature* **393,** 342–344 (1998).
2. Newell, P. T., Meng, C.-I. & Lyons, K. M. *Nature* **381,** 225–233 (1996).
3. Eather, R. H. *Majestic Lights: The Aurora in Science, History and the Arts* (Am. Geophys. Un., Washington DC, 1980).
4. Harrold, B. G., Goertz, C. K., Smith, R. A. & Hansen, P. J. *J. Geophys. Res.* **95,** 15039–15046 (1990).
5. Birn, J. & Hesse, M. *J. Geophys. Res.* **101,** 15345–15358 (1996).
6. Lyons, L. R. *J. Geophys. Res.* **85,** 17–24 (1980).
7. Goertz, C. K. *Space Sci. Rev.* **42,** 499–513 (1985).
8. Sato, T. & Holzer, T. E. *J. Geophys. Res.* **78,** 7314–7329 (1973).
9. Lysak, R. L. *Space Sci. Rev.* **52,** 33–87 (1990).
10. Mallinckrodt, A. J. & Carlson, C. W. *J. Geophys. Res.* **83,** 1426–1432 (1978).
11. Goertz, C. K. *Planet. Space Sci.* **32,** 1387–1392 (1984).
12. Johnstone, A. D. & Winningham, J. D. *J. Geophys. Res.* **87,** 2321–2329 (1982).
13. Rothwell, P. L., Silevich, M. B., Block, L. P. & Falthammar, C.-G. *J. Geophys. Res.* **96,** 13967–13975 (1991).

Daedalus

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Last week Daedalus was devising crystalline combustion catalysts with highly regular surfaces. Their product molecules were not disengaged randomly as hot gas; instead, they sprang off the ordered surface in a specific direction, carrying with them much of the energy of the reaction. Their ejection imposed a forceful directional recoil on the surface.

Thus chemical energy could be converted to mechanical energy without going through the intermediate stage of heat. Daedalus was planning aircraft, gas turbines, and so on, driven directly by reaction forces from their combustion catalyst surfaces. He now wants to generate electricity this way.

Many reacting catalytic surfaces disengage electrons; at least one (the oxidation of ethylene on a silver catalyst) does so for a form of hydrocarbon combustion. This must be a chemoelectric effect, analogous to the well-known photoelectric effect. The energy of the chemical reaction happens to be equal to the work function needed to eject an electron from the surface — so the energy is resonantly transferred to the departing electron. If the electron, coming from an ordered reaction on a regular surface, is ejected in a specific direction, the result is an electric current.

So DREADCO chemists are performing a range of hydrocarbon oxidations on regular surfaces, seeking the most copious and most ordered chemoelectric emitters. Their goal is a surface on which gas and air impinge, and from which a stream of electrons emerges. Fortunately, electrons lose little energy in interactions with gas molecules; even so, the collecting electrode must be very close to the catalyst surface — perhaps formed on it by microelectronic fabrication methods. The external circuit will return to the catalyst as a counter-electrode. Ideally, the system will burn not ethylene but butane, already used in many small catalytic-combustion devices.

DREADCO's Catabat will be almost the ultimate simple fuel cell. With no moving parts or complicated chemistry, it will take in fuel and air, and burn them to electricity. If efficient enough, it will not even get very hot. The Catabat will replace batteries, small generators, and socket power everywhere. Mobile phones will chatter longer, laptop computers will no longer fade just as the crucial file is being completed, and the global pile of discarded batteries will be replaced by a much smaller one of empty butane canisters.

David Jones