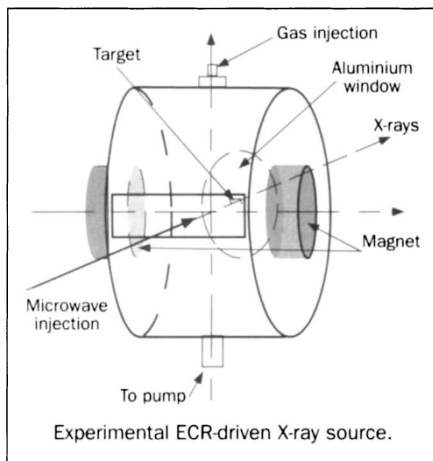


## A compact radiological X-ray source

SIR—The unexpected observation we report here is that a compact electron cyclotron resonance magnetic mirror discharge can possibly produce medical X-rays with energy up to 100 keV. This device is driven by a c.w. 2.45-GHz microwave source of maximum power 700 W. It has no electron-emitting cathode and no high-voltage power supply, as required in existing X-ray tubes.

Energetic electrons in the 100-keV range, in magnetic mirrors heated by electron cyclotron resonance (ECR), were



originally observed in the field of fusion research<sup>1,2</sup>. The mechanism of acceleration of these electrons is not fully understood<sup>3-5</sup>, because adiabatic invariance theoretically predicts the electron energy to be limited to lower values. These earlier devices were much larger than the device described here (the distance between the mirrors reported in ref. 2 was 10 times larger than in the present device). It was argued previously<sup>2</sup> that large devices are required to generate high-energy electrons, or the adiabatic invariance would no longer hold.

In our device (see figure), all the parameters except the radius of curvature of magnetic force lines are the same as in ref. 2. Nevertheless, we find that the mean electron energy can be ten times higher than predicted by the scaling law reported there.

We investigated the X-rays emitted from an ECR-driven magnetic mirror formed by two circular permanent magnets (5,000 G at the surface), located at a distance of less than 10 cm from each other. The microwaves are injected at the mid-plane across the mirror magnetic field, as in ref. 1. The mirror ratio is 2.4, the resonance zones ( $B=875$  G) being located a few centimetres from the mirror axis. A small tantalum target, placed in the mid-plane, a few centimetres from the axis in the resonance zone, emits X-rays when hit by energetic electrons. A thin aluminium window filters the X-rays on the way out of the chamber.

We recorded the X-ray spectrum, as

usual, by a multichannel analyser equipped with a NaI detector. The experiments showed that in argon, the X-ray production is maximum at a pressure of  $3 \times 10^{-5}$  torr. At this pressure the tantalum plate becomes incandescent. The production of X-rays coincides with the heating of the tantalum target. This may indicate that electron acceleration is possible only at low pressure, and is inhibited by the occurrence of collisions.

Attempts to produce X-rays without the metal target indicated that the bremsstrahlung of the argon gas is not the origin of the X-rays observed under these conditions. Rather, the X-ray emission occurred from the chamber metal walls, adjacent to the magnets. This may be the consequence of the non-optimal configuration of the magnetic field, compared with that reported in ref. 2. There exists the possibility for optimization, which will enable the fluxes required for medical radiology to be achieved.

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1. Rasmussen, D. A. *et al.* Rep. ORNL/TM-9372 (ORNL Fusion Energy Division, Oak Ridge, TN, 1985).
2. Quon, B. H. *et al.* *Phys. Fluids* **28**, 1503-1515 (1985).
3. Lieberman, M. A. & Lichtenberg, A. J. *Plasma Phys.* **15**, 125-150 (1973).
4. Ivanov, A. A., Spektor, M. D. & Franck-Kamenetskii, D. A. *Zh. Eksp. Teor. Fiz. Pis. Red.* **11**, 136-137 (1970).
5. Golovanivsky, K. S., Dougar-Jabon, V. D. & Reznikov, D. V. *Phys. Rev. E* **52**, 2969-2973 (1995).

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## Deep-breathing cephalopods?

SIR—Madan and Wells<sup>1</sup> have explored the relationship between gill area and habitat depth. They suggest that the large gill areas found in some pelagic cephalopods enable them to cope with the hypoxic conditions present throughout much of the deep sea. This conclusion is not surprising as enlarged gills as an adaptation to low oxygen have been observed previously for deep-living cephalopods<sup>2</sup>. Furthermore, Madan and Wells make broad comparisons without resolving confounding variables such as body mass, ecology, depth and ambient oxygen, as well as asserting that fish cannot tolerate hypoxic conditions, giving cephalopods a "competitive edge" over fish. But there is a considerable literature demonstrating the existence of fish in very low oxygen and, in many cases, specific adaptations of fish to low oxygen.

Both gill area and gill diffusion capacity, as presented by Madan and Wells<sup>1</sup>, are highly correlated with body weight ( $r^2=0.51$  and  $0.73$ , respectively). The authors fail to mention, though, that gill diffusion capacities sometimes scale at less than direct proportionality<sup>3</sup>. Benthic animals can be expected to have lower metabolic rates<sup>4</sup> and perhaps lower gill diffusion capacities than pelagic species. Removal of the two benthic octopods (also the largest animals in the study) from the analysis solves much of the scaling problem. With the benthic octopods excluded, however, there is no significant difference between the deep- and shallow-living groups in either gill area (Mann-Whitney,  $P=0.24$ ) or gill diffusion capacity (Mann-Whitney,  $P=0.56$ ).

Madan and Wells state that gill areas are reduced in deeper-living fish and that fish cannot tolerate hypoxic conditions. In some cases the gills of deeper-living fishes are indeed reduced relative to shallower species<sup>5</sup>. Reduced gills in deeper-living benthic octopods have also been observed<sup>6</sup>. The phenomenon could be due to reduced activity in the deep sea. Fishes and cephalopods have lower metabolic rates at depth (ref. 4; B. A. S., manuscript submitted). However, both fish and cephalopods living within the oxygen minimum layer in the eastern Pacific (where oxygen falls to  $0.25 \text{ ml l}^{-1}$ , 10% of that cited in ref. 1) have been shown to have enlarged gills<sup>7,8</sup>. Lowered critical oxygen partial pressures, enhanced affinity of respiratory proteins and decreased activity are also demonstrated adaptations of fish to low oxygen<sup>4,8,9</sup>. Fish biomass is typically more than twice that of cephalopods at all depths<sup>10</sup>. The large biomass reported in ref. 1 is based only on total consumption of cephalopods by predators and does not have a volume component<sup>11</sup>. Not only are fishes present within the oxygen minimum layer, but they are also apparently 'out-competing' cephalopods.

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1. Madan, J. J. & Wells, M. J. *Nature* **380**, 590 (1996).
2. Roper, C. F. E. *Systematics and Zoogeography of the Worldwide Bathypelagic Squid Bathyteuthis (Cephalopoda: Oegopsida)* 1-210 (Smithsonian Inst. Press, Washington DC, 1969).
3. Hughes, G. M. & Al-Kadhomy, N. K. *J. Mar. Biol. Assoc. UK* **68**, 489-498 (1988).
4. Childress, J. J. *Trends Ecol. Evol.* **10**, 30-36 (1995).
5. Marshall, N. B. *Exploration in the Life of Fishes* (Harvard Univ. Press, Cambridge, MA, 1971).
6. Voss, G. L. *Mollusca* **12**, 253-276 (1988).
7. Ebeling, A. H. & Weed, W. H. *Dana Rep.* **60**, 1-58 (1963).
8. Yang, T.-H., Lai, N. C., Graham, J. B. & Somero, G. N. *Biol. Bull.* **183**, 490-499 (1992).
9. Torres, J. J., Belman, B. W. & Childress, J. J. *Deep-Sea Res.* **26A**, 185-197 (1979).
10. Maynard, S. D., Riggs, F. V. & Walters, J. F. *Fish. Bull. US* **73**, 726-736 (1975).
11. Clarke, M. R. in *Cephalopod Life Cycles: Comparative Reviews* (ed. Boyle, P. R.) 221-237 (Academic, London, 1987).