

large samples, where the finer points of statistical inference are relatively unimportant, but biologists often have to argue from quite small samples. It is no accident that the greatest impetus for the refinement of the logic of statistical inference has come from the biological sciences, and especially from human genetics, where the paucity of the data is matched only by the importance of the inferences. Nuclear accidents fall into the same category.

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## Stunning whales

SIR—M.A. Taylor's comments on prey echolocation and sonic squid-stunning by whales (*Nature* **323**, 298, 1986) contain an incorrect discussion of the relation between the maximum detection distance by the whale ( $D$ ) and the maximum distance at which potential prey can detect the whale's echolocating emissions ( $d$ ). If for simplicity we neglect absorption, refraction, scattering by extraneous bodies, inhomogeneities, anisotropies, near-field and frequency-dependent effects, then the outward power-flux at distance  $r$  is  $W/4\pi r^2$ , and the returning power-flux experienced by the whale is  $W\sigma/16\pi^2 r^4$ , where  $W$  is the emitted power and  $\sigma$  is the backscattering cross-section of the prey. If the minimum flux detectable by the whale is  $S$  and by the prey is  $s$ , we may find  $D$  and  $d$  from the equations  $S = W\sigma/16.235^2 D^4$  and  $s = W/4\pi d^2$ . The ratio  $d/D$  is  $(WS/\sigma s^2)^{1/4}$ . This expression can be made more illuminating by normalizing to prey-length,  $L$ , letting  $\sigma = \alpha L^2$  and  $D = \beta L$ , yielding  $d/D = 2\beta(S/\alpha s)^{1/4}$ . For any useful sonar system, the maximum prey detection range will be several prey-lengths ( $\beta > 1$ ), and typically  $\alpha < 1$ .

Thus, for roughly equal hearing sensitivity,  $d/D$  will be greater than unity, and the prey will be able to take evasive action before detection by the whale. The ratio  $d/D$  is not 2, as indicated by Taylor's Fig. 1. This does not affect his fascinating discussion, but the relation given here permits additional variations of strategy in Taylor's "evolutionary arms race".

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## Body temperature and the specific heat of water

SIR—John Paul attempts to explain why the normal body temperature of homoiotherms is approximately 36 °C by its proximity to the temperature of minimum

specific heat of water<sup>1</sup>. He states: "An organism functioning at this temperature will find it necessary to generate or dissipate the minimum amount of heat energy in order to maintain its temperature constant". But the rate of heat loss (and therefore rate of heat generation with which it is balanced) is equal to the temperature differential between body and environment times the heat transfer coefficient ("conductance"). This is independent of heat capacity, or heat content (specific heat times mass times temperature change). In fact, temperature would be maintained more easily if the specific heat and heat content were greater — that is, for a given amount of heat loss, the temperature decrease would be less.

Perhaps a better reason for maintaining body temperature considerably higher than the average ambient temperature is that this ensures that excess heat produced by the high metabolism of terrestrial mammals and birds can be dissipated by conductive, convective and radiative means which require no evaporative water loss<sup>2</sup>.

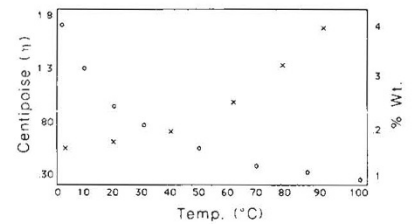
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SIR—We were intrigued by the proposal<sup>1</sup> that the nearly constant body temperature (around 36 °C) of many homoiothermic animals can be explained by the fact that the specific heat of water passes through a minimum around this temperature. The explanation offered was that "an organism functioning at this temperature will find it necessary to generate or dissipate the minimum amount of heat energy in order to maintain its temperature constant. From the point of view of the organism's energy economy this temperature is clearly the most efficient at which to function".

This explanation is appealing but it cannot be correct. The amount of heat required to maintain a given temperature is, of course, exactly equal to the amount of heat lost to the environment; this depends on many factors, such as the temperature difference, surface area and thermal conductivity of a body, but it is independent of its specific heat. Moreover, the smaller the specific heat, the larger will be the fluctuations in the temperature of the body, so that the problem of maintaining a constant body temperature becomes all the more difficult. Finally, the specific heat minimum at about 36 °C applies to pure water. Aqueous solutions generally shown no minimum in the specific heat, which usually decreases monotonically as the temperature drops and is appreciably lower than that of pure water in the re-



Crosses, solubility; circles, viscosity.

levant temperature region. The specific heat of normal blood plasma is about 6 per cent lower, that of haematopoietic cells about 11 per cent lower<sup>2</sup>.

What then is the explanation? We do not know, but most likely, a temperature of around 36 °C, if it is the product of natural selection at all, is selected because it corresponds to an optimal mix of properties. We consider here only two, viscosity and 'hydrophobic' effects.

The rates of many biological processes are limited by diffusion. As temperature rises, long-range structures in water are disrupted, the viscosity decreases, and the rates of diffusion-limited processes become faster. This factor by itself would appear to favour higher body temperatures. But disruption of the long-range structures in water will also lead to changes in hydrophobic effects, which are important in many vital processes, such as substrate binding, protein folding and bilayer membrane formation.

The accompanying figure shows the viscosity of water and, as a measure of hydrophobic forces, the solubility of benzene in water<sup>3</sup>, both as a function of temperature. By inspection, a temperature of around 36 °C seems to be a reasonable compromise; high enough to give a low viscosity, low enough that hydrophobic molecules do not dissolve too easily.

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## Reproductive failure in common seals

THE table shown below was omitted from the letter by P.J.H. Reijnders on page 456.

**Table 1** Number of participating, ovulating and pregnant seals in both experimental groups, during the season 1983-84

Group	1	2
No. of females	12	12
No. ovulating	12	12
No. pregnant	4	10