torsional oscillation of the star can, in principle, produce the required amplitude of phase modulation, but it would be nearly impossible to reproduce the apsidal motion and the Einstein delay. Moreover, this object would still be very special, since no other radio pulsar is known to exhibit a similar behaviour.

In short, it requires quite a cosmic conspiracy for any physical mechanism (other than the motion in a binary system) to produce a pulsar signal with a phase modulation that accurately mimics an eccentric binary orbit with two relativistic corrections.

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1. Lyne A. *Nature* **342**, 128–129 (1989).
2. Ables, J. G. *et al. Nature* **342**, 158–161 (1989).
3. Wijers, R. A. M. J. *Astr. Astrophys.* **209**, L1–L4 (1989).
4. Zapolsky, H. S. & Salpeter, E. E. *Astrophys. J.* **158**, 809–813 (1969).
5. Nelson, R. W., Finn, L. S. & Wasserman, I. *Astrophys J.* **348**, 226–231 (1990).

Early tetrapod hearing

SIR—I should like to respond to the comments in Scientific Correspondence[1,2] on my recent Letter on the stapes of the early tetrapod *Acanthostega*[3]. This bone is pierced by a stapedial foramen, clearly marking it as a stapes rather than a fish hyomandibula[4]: a more certain basis for distinction than inferred function[1].

Second, neither the hyomandibula of osteolepiforms (the group of lobe-finned fishes presumed ancestral to tetrapods) nor the stapes of *Acanthostega* have direct connections with the jaws. The suggestion[2] that this decoupling in *Acanthostega* is a major difference from the osteolepiform condition is therefore untrue.

Third, we need not accept that osteolepiforms had a tympanic membrane[2], with the implication that an open spiracle is incompatible with an air-filled spiracular pouch. Spiracles can be closed, and a pouch with a functional spiracle might also act as a middle ear cavity. The existence of a basilar papilla in the extant coelacanth *Latimeria*[2] suggests that an auditory function for the inner ear is a primitive feature of lobe-finned fishes, in association with an air-filled spiracular pouch with or without a membranous closure.

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1. Gottfried, M.D. & Foreman, B. *Nature* **344**, 116 (1990).
2. Fritzsch, B. *Nature* **344**, 116 (1990).
3. Clack, J.A. *Nature* **342**, 425–427 (1989).
4. Smithson, T.R. & Thomson, K.S. *Zool. J. Linn. Soc.* **74**, 93–103 (1982).

When is random random?

SIR—The intelligentsia is not on speaking terms with itself. Ochs[1] correctly cautions against sloppy use of the term 'random', but seems unaware of the work of mathematicians on this problem over many years. If each event in a set is selected with equal probability, say the toss of a fair coin, the selection is indeed random. But the probability of a 7 in a fair throw of two dice is not the same as that of a 2, yet the process is clearly to be considered random. Thus there is more randomness in a sequence of heads or tails from the toss of a fair coin than in a sequence of throws of two dice. Clearly a more sophisticated definition of randomness is required than one finds in a dictionary.

Suppose we wish to send to our little green friends on a planet near Arcturus the value of π. We could start sending the digital sequence in the decimal representation of π, but that would take an infinite time and an infinite amount of information, for there is no pattern among these digits. But π is a transcendental number, and we could send one of the algorithms from which it is calculated, not necessarily the shortest, letting our little green friends do the rest. Thus it is clear that π and all other transcendental numbers have a finite amount of information, namely, that in the algorithm by which they are calculated.

In the case of a sequence of heads and tails generated by the tossing of fair coin, there is no algorithm which can shorten the sequence. We must simply send the sequence itself. Such random sequences are known as Bernoulli chains or strings. On the other hand, the probability distribution in the tossing of two fair dice may be used to shorten the sequence of numbers generated. This is because some information is lost when the numbers on the faces of the two dice are added and only the sum is recorded. (We cannot know from the sum, especially in the case of 7, the exact faces which were uppermost.)

Thus we can measure the amount of randomness in a sequence by the length of the algorithm, in bits by which we can describe it to our little green friends. This fact emerged from the initially independent work of Solomonoff[2], Kolmogorov[3], Chaitin[4] and Martin-Löf[5] on the foundations of probability theory. Sequences which cannot be described by an algorithm shorter than the sequence itself have the greatest measure of randomness. Because any computable number can be described by an algorithm which is finite in length, no computable number is random[6]. It is impossible to prove that any given sequence was generated by a random process.

The current state of the theory is due to Chaitin[6]. I suggest that this literature be consulted by those who are interested in the proper use of the term 'random'. Ochs[1] repeats a common mistake in that he attempts to squeeze meaning out of words such as 'chaotic, unpredictable, uncertain, arbitrary, undetermined'. 'Arbitrary' and 'undetermined' do not mean 'random'. Words are merely names of mathematical functions and take their meaning from the mathematics, not the other way around.

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1. Ochs, T.L. *Nature* **343**, 303 (1990).
2. Solomonoff, R.J. *Inform. Control* **7**, 1–22, 224–254 (1964).
3. Kolmogorov, A.N. in *Problems of Information Transmission* (Vol. 1) (IEEE 1965).
4. Chaitin, G. J. *J. ACM* **13**, 547–569 (1966).
5. Martin-Löf, P. *Inform. Control* **9**, 602–619 (1966).
6. Chaitin, G. J. in *Information, Randomness and Incompleteness*, (World Scientific, Singapore, 1987).

Cold shock and DNA binding

SIR—Goldstein *et al.*[1] have recently described a gene from *Escherichia coli* that is induced in response to low temperature, giving rise to a cold-shock protein (csp) CS7.4. No similarity between CS7.4 and any other protein was noted by these authors. But when this sequence is compared with GenBank v62 using the program SEQFT [2], a striking similarity with a conserved region of human DNA-binding proteins is revealed. The human proteins DbpA, DbpB (ref. 3) and YB-1 (ref. 4) share a region of conserved sequence which closely matches the entire deduced sequence of CS7.4.

The function of CS7.4 is unknown, with suggestions varying from antifreeze protein to a role in initiating translation. It has also been suggested that the protein is autoregulatory, interacting with its own gene promoter[1]. DbpA and DbpB are DNA-binding proteins of unknown specificity[3] but YB-1 has

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                .  *. * *****. .*.***. .*   ***** .**...    * .*. .*. * * .  * **. *.***
csp   MSGKMTGIVKWFNADKGFGFITPDDGSKDVFVHFSAIQNDG---Y-KSLDEGQKVSFTIESGAKGPAAGNVTSL     1-70
dbpa  LATKVLGTVKWFNVRNGYGFINRNDTKEDVFVHQTAIKKNNPRKYLRSVGDGETVEFDVVEGEKGAEAANVTGP   157-230
dbpb  IATKVLGTVKWFNVRNGYGFINRNDTKEDVFVHQTAIKKNNPRKYLRSVGDGETVEFDVVEGEKGAEAANVTGP    95-168
ybl   IATKVLGTVKWFNVRNGYGFINRNDTKEDVFVHQTAIKKNNPRKYLRSVGDGETVEFDVVEGEKGEEAANVTGP    55-127
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Alignment of deduced amino-acid sequences of CS7.4 (csp)[1], DbpA and B[3] and YB-1[4]. Sequence positions are indicated. Residues which are identical between the prokaryotic and eukaryotic proteins are marked with an asterisk; conservative changes are marked with a dot.

been shown to bind to the CCAAT-containing Y box of HLA class II genes[4]. Conceivably, the conserved sequence in all these proteins represents a novel DNA recognition motif, one which is found in both prokaryotes and eukaryotes.

1. Goldstein, J., Pollitt, N.S. & Inouye, M. *Proc. natn. Acad. Sci. U.S.A.* **87**, 283–287 (1990).
2. Kanehisa, M. *IDEAS Users Manual* (FCRF, Frederick, Maryland, 1986).
3. Sakura, H. *et al. Gene* **73**, 499–507 (1988).
4. Didier, D.K. *et al. Proc. natn. Acad. Sci. U.S.A.* **85**, 7322–7326 (1988).
5. Garnier, J., Osguthorpe, D.J. & Robson, B. *J. molec. Biol.* **120**, 97–120 (1978).

Secondary structure predictions[5] for these sequences are somewhat inconclusive but it is interesting that there are six invariant glycine residues, suggesting that critical turns or bends are important features of the tertiary structure.

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Radiation and exposure rate

SIR—Substantial evidence has recently emerged that the coefficients relating the risk of lung cancer to exposure to radiation from radon in mines differ with the rate of exposure, and that the relative risk increases with decreasing exposure rate. This may be due to a genuine exposure rate effect or, possibly, to an effect of total dose.

The first evidence came from studies[1,2] of the workforces at two uranium mines in Canada, operated by Eldorado Resources Ltd[1,2]. Surveys at each mine allowed the lung cancer risk to be related to individuals' exposure, in working level months (WLM). At Beverlodge (Saskatchewan) and Port Radium (Northwest Territories), the increase in relative risk with exposure was found to be 3.28 per cent per WLM (95 per cent confidence interval 2.08, 4.48) and 0.27 per cent (95 per cent confidence interval 0.11, 043), respectively.

The difference between the absolute risks is equally striking, being 20.8 per 10^6 person-years per WLM at Beaverlodge (95 per cent confidence interval 11.8, 29.8) and 3.10 at Port Radium (95 per cent confidence interval 1.89, 4.32). The chief difference between the two mines seems to be the average exposure rate, estimated at 5 WLM a year at Beaverlodge and 109 at Port Radium. Further evidence that risk is related to exposure rate has come from three sources.

First, Hornung and Meinhardt[3] have shown an inverse exposure-rate effect among uranium miners on the Colorado Plateau. They conclude that, among miners with equivalent cumulative exposure, the risk of lung cancer is greater at lower levels of exposure for longer periods of time. Moreover, this effect varies with cumulative exposure. For miners of similar age and smoking status, and with similar cumulative exposure, Hornung and Meinhardt find that a 90 per cent reduction in exposure rate is associated with a 58 per cent increase in risk for miners with cumulative exposure in the range 0–834 WLM, but that a similar reduction of exposure rate is associated with only a 10 per cent increase in risk if the cumulative exposure is in the range 834–10,000 WLM.

Second, the BEIR IV committee[4] has estimated risks for four cohorts of miners (see table, which includes data from Port Radium not available to the committee). The estimates shown are specific for ages 55–64 and a period 5–14 years after exposure, thus avoiding the complications of differences of age structure between the cohorts and different follow-up intervals. Again, it seems that lower exposure rates are associated with the higher risks. Third, a similar effect among Czech miners has been briefly reported[5].

By themselves, these studies do not exclude the possibility that the observed association reflects confounding between exposure rate and total exposure: workers with lower exposure rates tend to have lower cumulative exposure. But if this were the case, one would expect that the slope of the dose–response relationship at high exposure rates (Colorado, Port Radium) would be greater at lower than at higher total dose. Such an effect is indeed apparent in the Colorado data, for which reason the BEIR IV committee used only cumulative lagged exposures of less than 2,000 WLM in its analysis. Below this level, the data from Colorado and Port Radium are inconclusive.

Whatever the explanation, the practical consequences for evaluation of the risks of exposure to indoor radon are the same. Because the exposure rate is low (about 0.1 WLM per year in Britain, for example), estimates of risk are more appropriately based on studies such as those at Beaverlodge and Malmberget rather than on all the available data. Relative risks thus estimated will be greater than the BEIR IV estimate of 2.5 per cent per WLM by between 50 and 100 per cent (the BEIR IV excess relative risk at Beaverlodge and Malmberget over the overall BEIR IV estimate; see table).

If there should be a further increase of relative risk with decreasing dose rate below about 5 WLM a year, even these increased estimates may be too low. The only study so far to have reported[6] direct estimates of the effect at indoor levels of exposure to radon suggests an increase in relative risk of about 3.4 per cent per WLM, but this estimate is imprecise (95 per cent confidence interval 0.0, 8.0). Estimation of the effect by extrapolation is complicated by the interaction of radon exposure and smoking, which may not be multiplicative[7], but for non-smokers an upper limit can be derived from the observation that their lifetime risk of lung cancer of about 0.6 per cent is, with few exceptions, remarkably constant in all populations for whom data are available, despite a variation of at least twofold in the average national exposure to radon indoors.

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RELATIVE RISKS AND AVERAGE EXPOSURE RATES IN FIVE COHORTS OF MINERS EXPOSED TO RADON

Cohort	Average exposure rate (WLM per year)	Relative risk (per cent per WLM)	
		Original*	BEIR IV†
Beaverlodge	5	3.3	5.1
Malmberget	5	3.6	3.6
Ontario	10 (approx.)	1.3	1.8
Colorado	124	‡	0.9§
Port Radium	109	0.27	–

* Estimate given by original authors.
† BEIR IV estimate, based on internal comparison, for age 55–64, 5–14 years after exposure.
‡ Original paper gives estimates only after allowing for exposure rate effect and are thus not directly comparable.
§ Based on cumulative lagged exposures of less than 2,000 WLM only.

1. Howe, G.R., Nair, R.C., Newcombe, H.B., Miller, A.B. & Abbatt, J.D. *J. natn. Cancer Inst.* **77**, 357–362 (1986).
2. Howe, G.R. *et al. J. natn. Cancer Inst.* **79**, 1255–1230 (1987).
3. Hornung, R.W. & Meinhardt, T.J. *Health Phys.* **52**, 417–430 (1987).
4. *Committee on the Biological Effects of Ionizing Radiations (BEIR IV)* (National Academy Press, Washington, DC, 1988).
5. Sevc, J., Kunz, E. & Tomasek, L. *Health Phys.* **54**, 27–46 (1988).
6. *New Jersey State Department of Health* Technical Report-Phase I (1989).
7. Lubin, J.H. *Yale J. biol. Med.* **61**, 195–214 (1988).