

How to define entropy

SIR—A suitable definition of entropy was not possible at the time of publication of the 'E' section of the first edition of the *Oxford English Dictionary*, because quantum theory had not yet been discovered. It is sad that the new edition of the *OED*¹ reviewed in *Nature* by Stephen Jay Gould², does not fill the gap in the definition, except perhaps as a branch of information theory. It seems that no dictionary has advanced beyond the age of steam.

The problem in constructing a contemporary definition is usually circumvented by defining entropy in terms of its traditional properties. A good definition³ of this type is: "(Phys.) Measure of the unavailability of a system's thermal energy for conversion into external work; measure of the degradation or disorganization of the universe". A specialist, however, would ask for a definition applicable to an isolated system with a more or less well-defined energy and number of particles.

Because entropy is not really a classical quantity, we must build quantum mechanics into the definition. Landau and Lifshitz⁴ put it well: "Only the concept of the number of discrete quantum states, which necessarily involves a non-zero quantum constant, enables us ... to give an unambiguous definition of the entropy".

It suffices to define entropy as: the logarithm of the number of quantum states accessible to a system. This sentence is best known by word of mouth, perhaps starting with the lectures of Tolman and Oppenheimer, but it has appeared in the occasional textbook⁵. The quantity thus defined has all the necessary properties. It can be a terrifying experience to count the

states of a large system in some yet-to-be-specified energy range, but we rarely have to calculate from the definition. We work from the temperature and the chemical potential, which are the derivatives of entropy with respect to energy and number of particles, to the Gibbs or Boltzmann distributions, from which the entropy is then readily calculated.

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1. *The Oxford English Dictionary* 2nd edn Prepared by Simpson, J.A. & Weiner, E.S.C. (Clarendon, Oxford, 1989).
2. Gould, S.J. *Nature* **338**, 385–386 (1989).
3. Sykes, J.B. (ed.) *Concise Oxford Dictionary of Current English* 7th edn (Clarendon, Oxford, 1982).
4. Landau, L. & Lifshitz, E. *Statistical Physics* 2nd edn (Pergamon, Oxford, 1969).
5. Kittel, C. & Kroemer, H. *Thermal Physics* 2nd edn (Freeman, San Francisco, 1980).

Not abandoned

SIR—I was surprised to learn in the slightly misleading News and Views article by Marek Abramowicz and George Ellis (*Nature* **337**, 411; 1989) that a feature of the Venice conference on cosmology and philosophy had been my abandonment of the final anthropic principle. In fact, my talk was concerned primarily with other subjects. But the documented discussion following other speakers reveals that the scientific basis of this proposal was presented and defended. It is particularly interesting in view of recent ideas about information-processing and complexity. For a truer picture, I refer the interested reader to the conference proceedings, which will be published by Cambridge University Press under the editorship of U. Curi.

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Peer review?

SIR—We recently learned of the claim that successful experiments have been carried out in a laboratory demonstrating that nuclear fusion is possible.

I would hope that *Nature* will feel able to carry out an investigation of this claim, and on the basis of past experience I suggest that the investigating team be made up of (1) a journalist with a scientific background, preferably in a subject far removed from nuclear physics, (2) a professional conjuror, (3) an expert in scientific fraud.

Such a team, with their undoubted expertise, will surely be well-qualified to determine the validity of the claim.

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Moral responsibility

SIR—We agree with Jamie Love (*Nature* **335**, 758; 1988) on the moral responsibility of scientists involved in military research: such a position has been taken by many leading scientists in the past (Einstein for example), but the problem remains because of a minority of scientists and engineers who are still working on projects with possible military application. It is our duty to encourage them to change their minds.

The whole international community should help those who want to change from military to civil research, if they get into trouble for this reason: the greater the risk from this choice, the greater the merit of a scientist who acts in this way and the greater the help he should receive from the community.

This is why many scientists, including Nobel prizewinners, are now supporting

Mordechai Vanunu, the Israeli nuclear engineer who was kidnapped in Italy by the Israeli secret service and sentenced in Israel to 18 years in jail because he left his job at the nuclear plant of Dimona, which produces weapons-grade plutonium, and revealed the existence of at least 50 Israeli nuclear warheads.

We suggest that all peace-loving scientists should support Vanunu by sending letters to the Israeli court or to embassies, by collecting signatures or by acting in any other way they think could be useful.

The release of Vanunu would be welcomed by all those now considering the possibility of ceasing to be "techno-accomplices to murder".

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Selfish academics?

SIR—The recent correspondence in *Nature* regarding the necessity or not of reprints and reprint requests has perhaps best illustrated academic selfishness rather than any other point. There are scientists who feel that it is more efficient for themselves to send multiple reprint requests rather than to visit the library and make a single photocopy for their own use, thereby throwing the burden of time and cost onto the author rather than the requester. Similarly, those antagonistic to reprint requests (for reasons other than impecuniness) are selfishly denying the genuine requests among those that they have received.

However, the principle may be obscured by the influence of human nature. In my experience, scientists who need or want to answer reprint requests will continue to do so, although often for reasons that are closer to personal advertising than scientific altruism. Conversely, scientists who request reprints are diluted beyond those with genuine purpose by others with either inherent laziness or insecurity. Scientists in most Western countries should be able to fulfill their needs through modern library facilities (including electronic searching and inter-library loans), although reprint requests from scientists in relevant institutions not so fortunate as to have these facilities should still be met where possible with politeness and encouragement (that is, a reprint or photocopy of the article in question).

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