recovery medium containing strophanthidin continued to gain some sodium and lose some potassium. All the results reported are statistically significant at the stated levels.

It is interesting that strophanthidin prevented the gain of potassium as well as the extrusion of sodium. The inward movement of potassium ions to replace the extruded sodium ions must be in some way linked with the mechanism for transporting sodium ions outwardly. Keynes *et al.*⁶ have shown that, in vertebrate skeletal muscle, the inward potassium movement during recovery may be in the direction of or against the electrochemical gradient for potassium ions, depending on the conditions. The nature of the inward potassium movement during recovery of barnacle giant muscle fibres from the sodium-rich state is now being investigated in this laboratory.

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GENERAL

Biological Entropy Pump

THE recent exchange between Woolhouse¹ and Popper² presents the enigma of the low entropy content of living systems. The means whereby their rapid decay into the inert state of "equilibrium" is avoided are serious problems to the theoretical biologist. It is, of course, to Schrödinger³ that we owe the classic analysis of biological entropy. It was the source of negentropy which Schrödinger was unable to discover, as the recent discussion indicates. That from one generation to the next, a complex coding and decoding can occur without net loss of negentropy is problem enough, but in the large sequence of generations through geological time, we see that, if anything, the informational system becomes fuller and the organization of many species more improbable. It is my purpose here to show what I believe to be the answer to this seeming paradox and to describe the "entropy pump" whereby the species of living matter not only prevent a drop into a position of greater positive entropy at each generation, but may in fact acquire more negentropy as their reproduction continues. This will involve only principles widely known and easily defended.

From the second law of thermodynamics, we learn that at temperatures above absolute, chemical change always proceeds, in a statistical system, from states of lower to higher entropy. Put in a biological reference we might express it thus: if a female codfish lays a million eggs, these eggs (considered on mass) will show the expected degradation and the egg genomes will have an average entropy content higher than the original egg genome of the parent. Very few generations of such deterioration can be envisaged as compatible even with the continuance of life. Yet we know that such a succession of generations of nearly infinite extent precedes our hypothetical drama. The acc in the hole, so to speak, is that in such a system as the million eggs from one parent, the entropy content

Fig. 1. The "entropy pump" as illustrated by the hypothetical distribution of entropy content of the genomes of 1,000,000 eggs produced by one codfish. The entropy content of the maternal genome is indicated by E_m . The mean entropy content of the genomes of the eggs is denoted by dotted line E_{f1} . A marks area where egg genomes have entropy lower than or equal to that of the parent.

of the individual genomes may be expected with certainty to distribute in a simple fashion about a mean value which by the dictates of the second law must be of a higher value for entropy than that of the original egg genome. In such a set we might suppose that, in perfect consistency with the second law, one tenth of 1 per cent or some such low proportion of the eggs actually has a genome with an entropy content equal to or less than that of the parental egg (Fig. 1). These remarkable ones are most likely to grow up and repeat the reproductive process. It will be seen that this is but a re-statement of the mechanism of natural selection, fully consistent with the meaning of the term as used by Darwin and as still used by our contemporaries.

This simplification does clarify one point which has perhaps not been sufficiently stressed in statements of evolutionary mechanisms. For this I suggest the term "chemical selection" to denote the very intense selection which goes on in such a clutch of eggs long before the "survival of the fittest" exerts its statistical leverage. Many of the eggs would not hatch because, as they are at the high end of the entropy distribution, they have such serious defects as the lack of some essential enzyme which crosses them out of the survival race at the starting gate. When we consider that mammalian sperm frequently show 10 per cent morphological abnormalities, the reality of this chemical selection may be appreciated. Selection at this molecular level has been discussed previously by Lima-de-Faria⁴, although in a context apart from the present one. It has also been appreciated by Whyte⁵ as "internal selection".

One might be tempted to the view that such an "entropy pump" would be a characteristic of living processes and might indeed furnish a definition to distinguish the living from the non-living world. Since the advent of subcellular biology and of the molecular approach to life processes, it would be gratifying to differentiate the world of living things from that of the non-living with such a succinct criterion. The note of Spiegelman *et al.*⁶ extends the process of chemical selection down to the adaptation of enzymes, thus raising the question of the propriety of defining life only with reference to cellular processes. There seems to be little objection to the hypothesis that life preceded the evolution of cellular structure and that subcellular mechanisms may show replicative or reproductive processes. The differentiation of the living from the non-living may perhaps be made on the basis of such an "entropy pump".

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