

Ronald Fox:

ENERGY AND THE EVOLUTION OF LIFE

(Freeman, 1988)

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The USA physicist Ronald Fox argued that the evolution of life is nothing but the evolution of more and more sophisticated forms of transducing and storing energy. According to Fox, life was born (the transition from non-life to life occurred) thanks to structures for transducing energy that were made possible by the use of phosphate compounds; and that life evolved because these structures inevitably evolved ways to regulate and to store energy via phosphate compounds as a consequence of having employed phosphate compounds in the first place. Muscles and nervous systems arose as a consequence of those phosphate-based processes. Muscles and nervous systems allowed the organism to interact with the environment and with other organisms in a much more intense way, thus further accelerating evolution. Fox showed how, from the beginning, it was energy flows (lightning, volcanic heat) that allowed for the manufacture of the unlikely molecules (such as aminoacids and other monomers) that are the foundations of life. Monomers had to combine in order to form the polymers of life (notably, proteins), a process that requires polymers. Fox showed that the flow energy solved this apparent paradox. Energy moved the monomers to a chemical state in which polymerization occurs spontaneously, and then polymers themselves helped manufacture even more polymers. The early Earth geophysical energy flows gave rise to oxidation-reduction energy. Iron is an obvious source of oxidation-reduction energy, particularly during the "iron catastrophe" of 4.5 billion years ago, when the elements of the iron group percolated through the silicate layer of the Earth's crust and became the core of the Earth. Eventually some oxidation-reduction energy got converted into phosphate-bond energy, which flowed through the primitive organic elements and enabled the polymerization of monomers (notably, proteins, which are both catalysts for further polymerization and structural elements of living beings, and polynucleotides, the building blocks of genetic memory). In other words, energy flows excited monomers until they started creating polymers spontaneously. Eventually, the system reached a state in which polymers helped produce (synthesize) more polymers. Thus an important form of energy for the evolution of life on Earth was based on phosphorus, which is a relatively rare element. As Lipmann first observed, the meeting of (pervasive) oxidation-reduction energy and (relatively rare) phosphate-bond energy was a momentous event in the history of life. Organic molecules are based on carbon, and energy transactions are based on phosphorus. The reason is probably to be found in the chemical properties of these elements. Carbon fosters structural stability, phosphorus fosters energy metabolism. Life seems to be, ultimately, a process about storing, transducing and using energy. Fox went on to speculate that the very evolution of life (and the diversity of life we observe today on the Earth) was due to an evolution of the processes of energy metabolism and storage. Biological evolution was also driven by energy metabolism and storage, not just Darwinian natural selection. In other words, Fox argued that, in general, biological events correspond to changes in flows of

energy. One key evolution was the emergence of phosphagens as the main tool for energy storage. This more efficient way of storing and using energy enabled the evolution of muscles and motility in general. Phosphagens themselves evolved, and today all higher forms of life employ creatine phosphate. A key step in the evolution of life was the development of a nervous system. Fox pointed out that the interaction between organism and environment and the interaction between organisms are nonlinear in nature. The nervous system is not only capable of predicting the outcome of linear situations, but also of predicting the much more important outcome of nonlinear situations that are, by their own nature, very hard to predict. The reason is that the nervous system allows the organism to rapidly simulate the outcome of nonlinear events. Rapid simulation is the only way that the organism can predict what will happen, and is therefore essential to survival. A fundamental property of life is the ability to predict the future. Survival depends not so much on being able to calculate what to do, but on being able to predict what is going to happen (in particular, the consequence of an action). A cognitive agent needs to predict situations. Those situations in the real world are described by non-linear systems. The dynamics of nonlinear systems is such that it is virtually impossible to predict their behavior other than by simulating it. Simulation has to be very fast in order to be useful, sometimes faster than real-time. It turns out that the nervous system is precisely such a tool to perform fast simulations of nonlinear systems. Thus the evolutionary advantage of a nervous system is colossal. Once muscles existed, it was important for the organism to predict the effect of a muscle movement on the environment. Fox argued that the evolution of creatine phosphate (the ultimate phosphagens so far) enabled the emergence of this wonderful invention. Yet again, the evolution of life was due to an evolution of energy processes. Darwin's theory of evolution is both too little and too much. Fox showed that the rise and decline of different species is a natural consequence of a non-linear system driven by energy flows. Natural selection is not necessary to explain why there are different forms of life. At the same time natural selection would not be enough to explain how life evolved the way it did. Fox's theory is all based on the simple idea that whatever happened to life was driven by flows of energy, because ultimately life "is" about storing and using energy. Even culture itself (i.e., human civilization) can be viewed as a new flow of energy that is creating a new form of life. Fox did more than advance a hypothesis on the transition from non-life to life: he introduced a new factor in Darwin's theory of evolution. The purely Darwinian picture of natural selection may be too little in order to explain the diversity and dynamics of life on the Earth. But Fox basically points out that there is another very powerful force at work: the flow of energy. Even without natural selection, the flow of energy alone would result in a diversity of forms of life.

This is a fascinating book that lays down a Physics of life capable of explaining everything that happened from the first cell all the way to the human brain.