Mind, Matter, and Diversity of Stable Isotopes

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Abstract—Most chemical elements have two or more stable isotopes. One can ask if isotopic diversity of key biological elements (H, O, C, N) plays some nontrivial role in bioevolution up to the level of consciousness. In this paper we discuss the possible role of the diversity of stable isotopes in brain functioning. We suggest that the information processing associated with consciousness can be assisted by the inclusion of isotopic effects into the neural information processing at the microscopic level.

Keywords: isotopes — morphogenesis — Cantor — Platonic world — information theory — consciousness — pattern formation — neural networks — memory patterns — volume transmission.

Introduction

In the development of earlier discussion of isotopic effects in consciousness (Berezin, 1992), we explore the possible connection of isotopic information dynamics with more universal level of information. We propose that the isotopic "degree of freedom" (isotopic randomness) serves as an informational connector to the fundamental resource of pattern formation which is ultimately available in the form of "absolute" mathematical relationships sometimes referred to as the ideal Platonic World of forms and numbers. A precursor to the latter connection is implicative in the mathematical theory of infinite sets (the so called hierarchy of aleph-sets) proposed by Georg Cantor over a century ago (Dauben, 1979).

The availability of chemical elements on Earth has spawned a nearly unlimited variety of structures and organisms by variations of the chemical composition of these structures. It appears that by finding some biological role for essentially all chemical elements (including "microelements") Nature optimizes the resources of chemical diversification available to it. A similar possibility can likely arise for the isotopic diversity of elements. It seems improbable that

Nature could "overlook" an additional level of informational diversification available through isotopic degree of freedom and randomness.

Currently, research literature contains only sporadic observations related to biological role of isotopic effects. Fitter et al. (1998) have suggested that carbon isotope transfer from one mycorrhizal community to another may be beneficial to fungal species in a nonpassive way. Fitter determined that isotopes ^{13}C and ^{14}C were selectively transported between fungal communities on different plants. This finding implicates isotopes in a special role in influencing both symbiosis between plant and the fungal species, and entire communities of varied species linked only by the mycorrhizal network. Isotopes ^{13}C and ^{14}C are isolated when fungal digestive enzymes fuel metabolic processes by the breakdown of organic matter. Yakir, DeNiro, and Rundel (1989) state that even though environmental effects can produce significant changes in plant organelles such as vascular cells, there is a buffering effect against such changes in isotopic composition for energy-producing structures. Taking into account thermodynamic and randomization processes that occur in photosynthetic leaves, the upkeep of isotopically pure pools in energy-synthesizing plant organelles may indicate that isotopes are functionally necessary to life systems in their informational role.

Experiments by DeNiro and Epstein (1978, 1981) and Shimba, Unno, and Okada (1990) demonstrate statistically significant variations in stable isotopes of carbon and nitrogen in some organisms and cellular structures, as well as species variations of isotopic preferences in tissues. For example, diets enriched with ^{15}N isotope fed to mice may result in nonproportional isotopic composition of specific cells and organs (DeNiro & Epstein, 1981). A possible interpretation of this effect is that organisms may show propensity for nonrandom preference of some specific isotopes in particular cells (Sternberg, DeNiro, & Savidge, 1986; Yakir, DeNiro, & Rundel, 1989). Such a preference, in turn, may be related to some physiological advantages attained through the selective use of physical differences between isotopes, such as mass difference, vibrational frequencies, nuclear energy levels, magnetic and spin differences, and symmetry modification (e.g., in globular proteins and more solid structures).

Furthermore, isotopic variations can have a pattern-forming role at the level of spatial morphogenesis (organ formation). This is an especially tough problem for developmental genetics. For example, earlier Rakic proposed an idea of a "protomap" for neurogenesis (Rakic, 1988). The protomap hypothesis claims that the spatial orientation of guiding axons is intrinsic to cells with specified potential for differentiation for the neocortex; the latter being controlled by genetic mechanisms, and, possibly, by the ionic gradients.

However, the protomap hypothesis does not address problems of spatial orientation of single cells and their pattern formation in the absence of any adhesion molecules or other cues as to their numerical identity. As an alternative, it may be suggested that there is spontaneous and time-fixed reformation in original patterns of cells in the absence of both extrinsic and intrinsic (genetic) po-

larity cues, ion gradients, and gravitational manipulation (Pui, unpubl. data). Also, the evolution of the larger neocortex that anatomically separates humans from other primates and mammals, the predetermined numerical and spatial radial columns, and the number of divisions per cell in each of these columns (Caviness, Takahashi, & Nowakowski, 1995) requires specialized information that cannot be explained by genetically expressed cues. The latter calls for the existence of some submolecular instruction code and isotopic diversity presents a likely candidate for this role.

The relevance of these developmental aspects to isotopic information poses several questions, e.g., (1) At what stage is the positional information generated in the life cycle of organisms? (2) How is the accuracy of the positional information determined? (3) How far can the information be transmitted?

Sternberg, DeNiro, and Savidge (1986) and Galimov (1982) presented much-ignored findings about the isotopic composition of biochemical and genetic pathways. For example, during photosynthesis, the carbon obtained from CO_2 consists of ^{12}C and ^{13}C, but depending on the species of the plant, only one of these isotopes is preferentially fractionated. In the production of energy in the form of adenosine triphosphate (ATP), the carbon isotopes are selectively placed so that they will be propagated throughout the series of reactions in that same position. This conservation of isotopic structure persists in spite of the fact that the catalysis of enzymes changes the carbon skeletal structure of the intermediate molecules. Perhaps a key point here is that the thermodynamic effects do not overshadow or cancel out the selectivity among isotopes that can be distinguished by their subatomic properties.

Elementary combinatorial analysis leads to an enormously large number of possible isotopic permutations within chemically fixed structures. For example, a segment of DNA molecule with 1 million carbon atoms has about 10,000 randomly distributed ^{13}C atoms. The number of isotopically distinguished distributions (the number of possible placements of 10,000 atoms among 1,000,000 sites) is about $10^{24,000}$ (far greater than the number of atoms in the Universe which is "only" about 10^{90}). If we include the spatial arrangements that can be produced by point substitutions in other stable isotopes, such as ^{16}O by ^{17}O and ^{18}O, or ^{14}N by ^{15}N, etc., the possibilities of information transfer and information diversification carried parallel to "macros" information (such as genetic transcription of codons, or chromosomal crossover) increases even further (exponentially).

Turning to consciousness-related mental information, Kohonen (1989) addressed the problem of memory size and estimated that we require storage facilities for some 10^8 distinct memory patterns. The human brain maximally possesses approximately 10^{12} neurons. The current prevailing model of brain functioning is the elaboration of the original Cajal hypothesis (Engert and Bonhoeffer, 1997). For the coordination of movements, actions, speech, decisions, emotions, and inner thoughts (all of which we can also remember) with our memories, we would require about 10^{20} neurons. According to the Cajal hypothesis, the neurotransmitter molecules such as serotonin and dopamine,

as well as proteins, form long-term changes in neuron terminals. These changes are thought to underlie long-term memory. However, there is an accumulating body of evidence that suggests that the information is also conveyed diffusely in cerebral fluid (termed "volume transmission"), rather than by electrical transmission alone (Agnati et al., 1995).

We suggest that the deficiency in information processing and storage capacity as stated above may be compensated by the isotopicity in the following way. Without the constraint of wiring, the signals transferred by the volume transmission can diffuse over a large brain surface area, interacting with deep brain structures, with several stops along the way for information replication and exchanges. To give a general overview, isotopes can be involved in a receptor-specific action of a variety of neurotransmitters involved in volume transmission. Galimov (1982) showed that molecules formed in succession in enzymatically catalyzed pathways have conserved ^{13}C in precisely the same position from the beginning to the end of the pathway. He also pointed out that the positions of ^{13}C atoms are nonrandomized but are predetermined by an unknown mechanism.

While identical isotopes are indistinguishable quantum particles (like electrons), different isotopes are distinguishable in the sense of classical physics. For example, classical distinguishability of ^{12}C and ^{13}C isotopes in DNA chain can drastically affect the level of quantum coherency of holographic-type memory storage. Another effect may arise from nuclear spin-spin interactions between ^{13}C isotopes (^{12}C has zero nuclear spin). The fact that different isotopes obey different quantum statistics (e.g., ^{12}C are bosons and ^{13}C are fermions) may also reflect processes of information transfer at the subatomic level.

From this perspective, nuclear spins and quantum coherency do not seem to mean much, until we notice that various kinds of organisms have been shown to differentiate between isotopes and to form isotopic pools. Furthermore, it has been shown that metabolic processes and structures are altered, stressed, or become more efficient depending on the type of stable isotopes used. Since isotopes differ by their mass and nuclear spins, and given that organisms demonstrate distinguishability between stable isotopes, we can hypothesize that isotopes add to the beneficial aspects of consciousness by (1) coping with the surplus of information in the environment and maintaining information coherency within our brains and/or (2) enabling anticipation by coordination of information.

The possibility of anticipating events brings us to the subject of consciousness and attention with respect to the isotopic diversity. The ongoing debate about the nature of time perception in humans involves consciousness regardless of the position one wishes to take (whether our sense of time is merely a byproduct of our sensory systems or not). To propose a substrate, tangible substance for the characteristics of consciousness, we must include the attempts of our consciousness to extrapolate into infinity and its universal durability. Not only are isotopes the "basic stuff" of the universe, they also have multi-

level participation in every organic system. Isotopes are necessarily a part of molecules, organs, organisms, and entire communities of living systems, and we can speculate that they play a decisive role in connecting all these biological structures and functions to the fundamental metaphysical substrate of the universe (the ideal Platonic world), which serves as a resource for all pattern-forming activities.

The concept of the Platonic world, where integers are immortal, infinite, and immutable, defies the "physical" order, which may be created or destroyed in any particular moment. On the contrary, the immutability of numbers provides us with as close a view of the infinity as we, humans, can have. The "weight," or "pressure," of invariable integers may manifest itself in time-related matters, such as perceptions and thoughts. Combining "local" and "cosmic" aspects of isotopic information previously discussed, isotopes are numerically placed in chemical substances, forming islands of isotopes, and also remain basic components of the complex universe.

For infinite integers to be a candidate for an organically based ageless consciousness of individuals, they require some kind of presence in the physical world. Because isotopic configurations in biological systems can be mapped into sequences of integer numbers (e.g., through their instantaneous coordinates), isotopic quantum dynamics, such as tunneling effects (Berezin, 1992) could act as a bridge toward the process of this embodiment. Such an embodiment (metaphysical patterns of numbers become a physical reality) can be interpreted as a transcendence of the infinite "innocence" (lack of "real" experience) that numbers have as entities of the timeless Platonic world.

Neurons have constantly varying input, associations and outputs in normal conditions. We can consider this as a finite analogue of the lowest infinite set, aleph-zero (countable set). But neurons are only one part of consciousness, which relies on the varying input and output for a continued existence. While we are able to determine some of the principles of consciousness, we face monumental difficulties in determining or examining the whole. Just as there are subconscious levels of which we are seemingly not aware, likewise, for the first countable set of integers, we have only a vista of its whole range, and examination of this set does not allow for a simultaneous examination of the individual particulars of each integer. For example, 2 is an integer which belongs to the lowest infinite set (aleph-zero), but the (irrational) square root of 2 is a real number at a higher level of infinity (real numbers constitute next aleph, aleph-one set).

Thus, the concept of "square root" does not belong to the set of integers, no matter how far into the infinity we can view integer (countable) set. Consciousness exists both within the first set of infinity, the set of neuronal activity, and in a higher set of infinity.

Although isotopes are finite, they may possess an inherent capacity to form connections to and participate in higher levels of information, at both a more expansive and more subtle levels, than the finiteness of neurons. Whereas neu-

rons require action (and an absolute "yes" or "no" response) by neurotransmitters and electrochemical signaling, isotopes possess properties which may allow for large scale action without the macros level at which neurons can act.

Isotopes, through their profound role in the structure of the physical universe, may have a stronger connection to the integer information basis of the universe (immutability of the infinite integers and other entities of the "Platonic World") than do macros like neurons. As many philosophers have argued, consciousness involves a dichotomy of temporal-spatial process ("here and now"), as well as eternal timeless aspects (our general statements, logical and mathematical statements and concepts, etc. are all atemporal entities).

To conclude, isotopes are physically present as a part of both our brains and of the external world. The subtle dynamics of isotopes can have profound effects in neural structures due to exponentially high informational potential hidden in isotopic diversity.

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