

XIX. NEUROPHYSIOLOGY*

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A. A SYMMETRICALLY CYLINDRICAL STRUCTURE OF HYDRATION

Two peculiarities of both collagen and desoxyribonucleic acid (DNA) with respect to water, namely, the facts that the axial repeating distances along the macromolecules equals a whole number (6 and 7, respectively) of second-neighbor distances in water and that both molecules have an angular repeat of 36° , suggested that water might form symmetrically cylindrical structures of hydration.

Investigation shows that such a structure is possible and that it is pentagonal in planes perpendicular to the cylinder axis and hexagonal in planes parallel to the axis. The basic building block of the structure is shown in Fig. XIX-1a; it is a cage with two

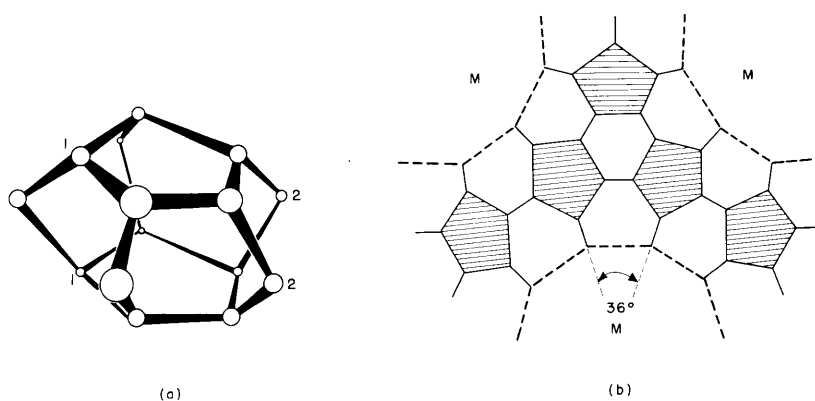


Fig. XIX-1. Symmetrically cylindrical structure of hydration: (a) basic building block, (b) assembly viewed in cross section. The circles, or joining points, represent oxygen atoms; the protons take either of two possible positions along the bonds; M = macromolecule.

pentagonal and five hexagonal faces and with a cavity in the center that may contain a water molecule. The assembly of the cages is such that the molecules marked 2 take the positions of those marked 1 of the adjoining cages. The axial repeat is 4.74 Å; the angular repeat is 36° . In order for the structure to exist in three dimensions, that is, for it to fit at the place where three cages join (see Fig. XIX-1b), a slight distortion is

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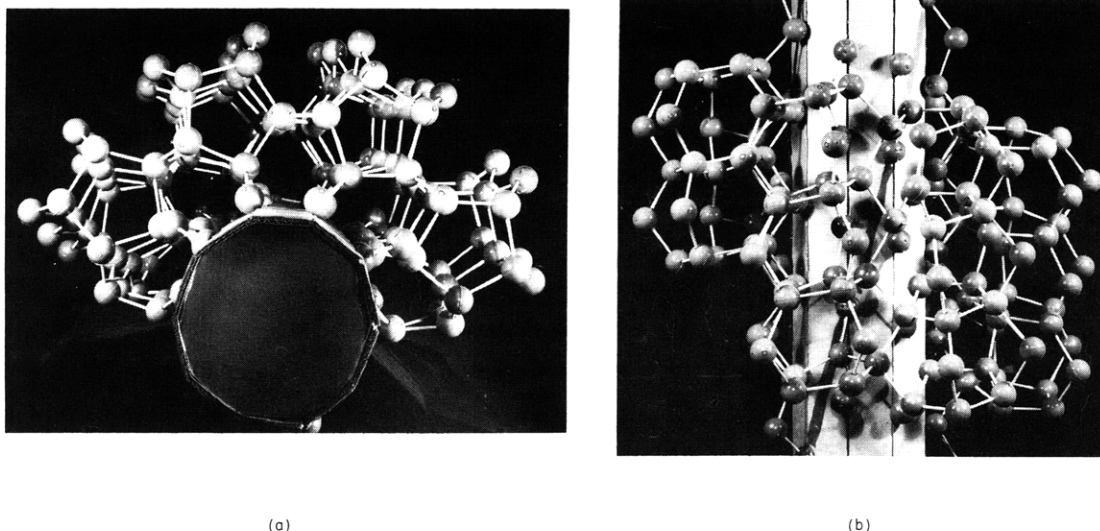


Fig. XI-2. Two views of the structure: (a) along the axis, (b) perpendicular to the axis.

necessary. This distortion is introduced by the macromolecules themselves, which have (accompanying every 36° angle shift along their helices) an axial shift of more than the $(n + 1/2) \times 4.74 \text{ \AA}$ required for the idealized monolayer of water. The actual factors for the shift are, for collagen, 1.8 instead of 1.5, and for DNA, 0.72 instead of 0.5.

Figure XIX-2 shows two views of a crude model made on a collagen threefold helix (simplified as the cylinder in the center). The half balls on the cylinder along the helical line represent oxygen atoms of the glycine groups.

H. J. C. Berendsen, W. S. McCulloch

B. NON-ARISTOTELIAN LOGICS AND REDUNDANT AUTOMATA

The discrete noiseless automaton has long been studied by means of intuitionistic logics that are Aristotelian in character (1). We have shown that the non-Aristotelian logics of Post (2), Lukasiewicz (3), and Lewis (4) can be used to study both the semi-continuous (order-continuous) automaton and the discrete noisy automaton. In particular, we have shown that the functionally incomplete logics of Lukasiewicz and Lewis are appropriate models for the description of the multiplexed automata of von Neumann (5), and that the functionally complete Post logics are models for the description of the "replicated" automata of McCulloch et al. (6). In both cases, redundancy of truth-value is used to combat the equivocation introduced by noise. We have also shown that a certain form of equivocation is introduced into Lukasiewicz and Lewis automata, independently of computational noise. This equivocation results from (a) a noisy input and (b) the interaction of the input topology with the topology of these automata. We have

demonstrated that this equivocation is harmful, on the average, only for the odd-jot functions of two-valued logic. The even-jot functions, on the average, are unaffected. These results are consistent with those obtained by Elias (7), and imply that the necessary condition for utilizing a "coding" scheme is violated (that is, that all mappings, in the absence of computational noise, correspond 1:1 with the nonredundant logical function to be computed). Thus, for these automata, there can exist no positive rate for noiseless computation. This form of equivocation appears to be nonexistent in Post automata, at least for functions corresponding to the "and," "or," and "not" of Boole's Aristotelian logic; therefore, in these cases the necessary condition is satisfied. Finally, we have shown that, by using Lewis logics, continuous automata can be approximated by order-continuous automata.

J. D. Cowan

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C. ERROR IN NEURONAL NETS

We consider single-line neuronal nets in which the neurons have, in their output, a probability of error ϵ that is independent of its antecedents. The output error probability of such nets, η^* , which takes into account the ϵ 's of all neurons, can be reduced by parallel computation and a majority organ or by iteration of layers of majority organs in such a way that η^* approaches the minimum value ϵ .

If logical variables are each carried by a bundle of lines instead of by a single line (which means going from Aristotelian to non-Aristotelian logic) logical computation can be performed without error by an error-free neuron if less than a certain fraction

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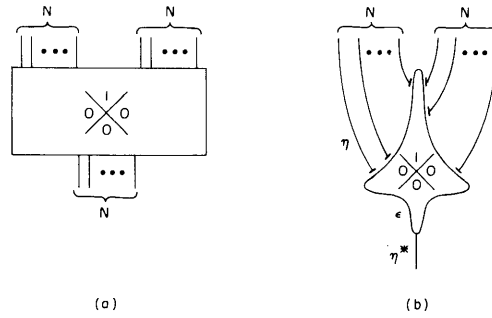


Fig. XIX-3. Logical computer operating on two input bundles to compute the logical "and." (a) Complete computer consisting of N similar neurons. (b) One neuron receiving from $2N$ lines; each line has error probability η , each neuron has error probability ϵ , and each output line has error probability η^* .

of the lines of the bundles are in error.

What can be obtained depends on the logical function to be computed. For example, all functions representable by one jot or one zero in a Venn diagram (hence also many polypchecks) can be computed with a very small probability of malfunction of the output if the input error does not exceed a certain level. This can be done by means of parallel computing by a rather small number of neurons. For example, the logical "and" must be computed from two input bundles. The computer is shown in Fig. XIX-3. The following symbols are used:

N = number of lines per bundle

ϵ = probability of error in neuron

η = probability of error of each input line

η^* = probability of error of each output line

ΔN = maximum number of lines that may be in error in each input bundle without harming the output

θ = threshold of the neurons

The probability of error in each output line if $\epsilon = 0$ is

$$\phi(\eta) < 1 - \left[\sum_{k=0}^{\Delta N} \binom{N}{k} \eta^k (1-\eta)^{N-k} \right]^2$$

The probability of error of each output line has the value

$$\eta^* = \epsilon + (1-2\epsilon) \phi(\eta)$$

The probability of malfunction of the computer, that is, the probability that the fraction of lines in error in the output bundle exceeds Δ is

$$\rho = \sum_{k=\Delta N+1}^N \binom{N}{k} \eta^{*k} (1-\eta^*)^{N-k}$$

The threshold of all neurons must be set in such a way that

$$N + \Delta N < \theta \leq 2(N-\Delta N)$$

Hence, $\Delta < 1/3$.

For given values, $N = 10$ and $\eta = 0.01$, we find that $\Delta N = 3$ and $\phi(\eta) \approx 4 \times 10^{-6}$. If we do not want the error probability η^* to exceed η we must have a value for ϵ that is equal to, or less than, approximately 0.009996. This value for ϵ results in a probability of malfunction of approximately 2×10^{-6} .

M. Blum, W. S. McCulloch, L. A. M. Verbeek

D. ELECTROCHEMILUMINESCENCE

As mentioned in Quarterly Progress Report No. 57, we are interested in the electrochemiluminescence and its applications — in particular, its use for the study of hydrodynamic phenomena. Preliminary experiments have been completely successful. As will be shown here, this method can be used to indicate fluid flow patterns past arbitrarily shaped anodic electrodes, without perturbation of the flow pattern (as is the case with cotton tufts), and also to indicate the time and spatial course of development of the various disturbances. This method should be particularly useful for the study of the transitions from laminar to turbulent flow.

Using a magnetically stirred beaker as a crude water tunnel, we were able to take the pictures shown in Figs. XIX-4a, b, and c which show three flow patterns past a small platinum anode at different angles of attack. Fluid flow is from left to right. Figure XIX-4a (somewhat out of focus) shows nearly laminar flow, 4b shows a turbulent wake resulting from separation of flow near the leading edge, and 4c shows vortex generation at the lower left corner.

These photographs were taken with Ansco Super Hypan film at f3.5 and exposures between 1/16 and 1/64 second. Both the anode and the cathode were platinum. The solution used differed only slightly from that described before: for each 100 cc H_2O , the solution contained

- (a) 1 cc of 2-molar NaOH
- (b) 1 cc of 3 per cent H_2O_2 (as much as 5 cc H_2O_2 can be used, resulting in brighter display)
- (c) 30 mg luminol
- (d) 10 gm of KCl (to increase conductivity)

This mixture will suffice to light 1 square inch of wetted surface of platinum anode for approximately 1/2 hour, after which the H_2O_2 is exhausted, and the solution is highly

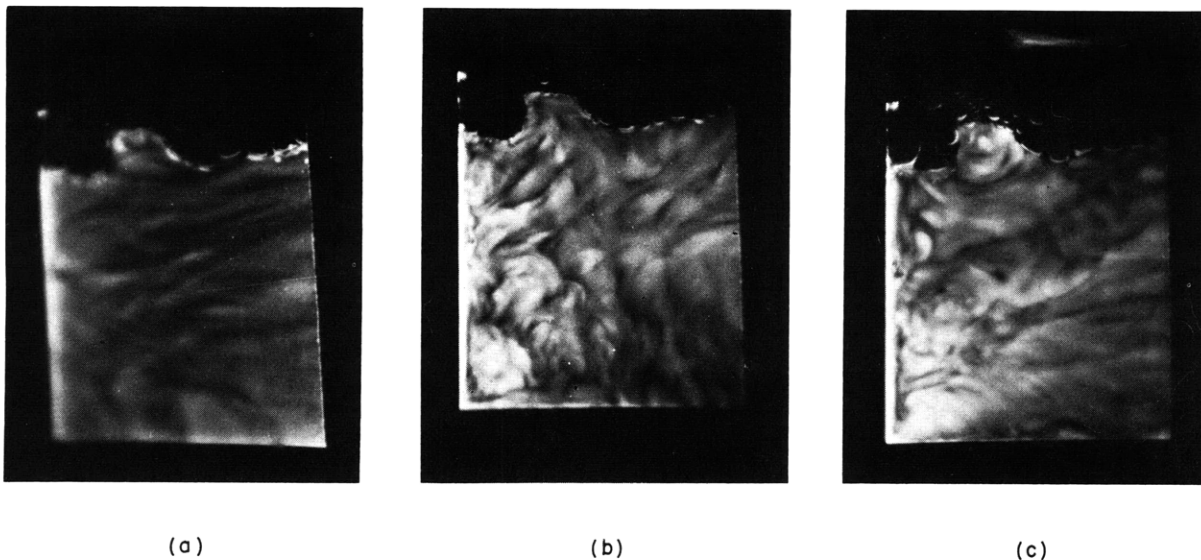


Fig. XIX-4. Patterns of fluid flow past a flat plate, as revealed by electrochemiluminescence.

absorptive of the blue luminescent glow. Operation over the temperature range 20-50°C has been verified. Glycerin may be added to increase viscosity without appreciable effect on the luminescence.

We hope, by using improved photographic techniques, to obtain high-speed motion pictures of various flow situations with improved water-tunnel geometry. Other luminescent systems may also be tested with the hope of extending the range of possible application of these modeling techniques.

R. C. Gesteland, B. Howland, W. H. Pitts

E. STUDENT RESEARCH

Most of the past three months has been taken up with teaching a biology laboratory (Course 7.061), which is now dropped from the curriculum. What the students found is quite new and worth publishing. There were four problems assigned; three required invention or research, the fourth involved the learning of a technique. I shall remark only on the novel results.

The first problem was to record receptors on insect antennae from the outside, that is, without using penetrating electrodes. Most, if not all, of the smell organs of, say, cockroaches, exist on the antennae. Insects in general are capable of detecting incredibly small concentrations of particular substances, not only sexual smells but also those of preferred foods. The specificity is sufficiently great that stereoisomers of the same compound can be told apart – for example, compounds such as female odors

of the silkworm moth.

As W. Pitts and R. Gesteland point out after an exhaustive study of the literature, nobody has the vaguest idea of how such apparatus works, and nobody has built a sensitive, discriminating smell transducer. For many practical reasons (for example, early warning of a chemical warfare attack) it would be a fine thing to have a sensitive smeller. For purposes such as detecting trace chemicals, for example, particular amino acids, one could do worse than use the antennae of, say, the water boatman as a glutathione electrode.

F. Axelrod and R. Burde succeeded in recording from the sensitive hairs on the antenna of a roach, with external electrodes only. This is the first time that such a recording has been done. Dr. Schneider of Germany, who recently has been successful in measuring activity with electrodes thrust up inside the silkworm antennae, attended the exhibit of this method and remarked on the similar patterns of firing. The advantage of our method is that we can identify anatomically the different receptors, which can hardly be done with internal electrodes.

The technique is to use a metal-filled micropipette, plated at the tip with platinum black, and wetted with a solution of lithium chloride in glycerin to which has been added a wetting agent. These electrodes apparently make sufficient resistive contact through the chitin to allow the nervous activity to be measured against an indifferent electrode in the head or thorax of the insect. W. Pitts suggested the composition of the fluid that is used to make contact with the sockets of the sensory hairs. Dr. Paola Marchi will continue this work.

The second problem was a somewhat vague one about human vision, and there were three parts to it. First, the students were asked to verify the Ditchburn-Riggs phenomenon, i. e., that an image held in constant position on the retina (independent of the eye movement) vanishes. Second, they were asked to find how much the human eye sees during a saccadic jerk (the sharp movement of the eyes used in reading). Third, they were asked for some new approaches to the study of after-images. The group, G. Frank, P. McGovern, R. Samaha, and J. Smith acquitted itself admirably – and, indeed, some of the observations have just been confirmed by recent work of G. Sperling at Bell Telephone Laboratories.

The Ditchburn-Riggs effect was shown simply by an entoptic phenomenon – the Purkinje tree. This is the shadow of the retinal vessels on the retina. Since the vessels move with the retina, the Purkinje tree is a truly stabilized image which is also not subject to the dioptric fluctuations of the eye. If a small flashlight bulb is pressed between the bony orbit and the eyeball (with closed lids) and the bulb is wiggled slightly, the tree appears – looking like a set of branching and subbranching cracks issuing from a common center. If the bulb is kept lit and the eye does not move much, the tree vanishes in approximately 4 seconds – the correct time constant. Now if one

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switches his eye sharply in any direction (keeping the light bulb fixed) the shadow changes its position locally everywhere, and the tree reappears for another 4 seconds. Thus, it becomes possible to keep the tree in constant view, but astigmatically, if a pair of bulbs diametrically opposite on the eye ball are alternately flashed approximately 4-6 times per second. The shadows change most for branches that are normal to the axis between the light bulbs and are clearly visible. Branches parallel to that axis cannot be seen. This very cheap demonstration I had developed a few months before and used it to introduce the students to simple methods for doing physiological psychology.

It was in the second problem that the students did first-rate new research. We all know from reading that the page does not blur during the quick jerks of the eye. I had made the observation while smoking in the dark that the dim glowing tip of a cigarette generated a uniform red streak when moved with a rapid jerk in front of my eyes, whereas if I moved my eyes from one fixation point to another past the fixed cigarette, the red streak appeared interrupted or attenuated in the middle. The event on the retina is the same whether I move my eyes with respect to the cigarette or the cigarette with respect to my eye, but the perception is different. Therefore I suggested the presence of a turn-off in the retina. Later I found that Ditchburn had done a better experiment much earlier. He coupled the eyes to an ac amplifier so as to get only the derivative of the movement, and he displayed the output on an oscilloscope having a fast phosphor. It then occurred that everybody could see the eye movements on the scope except the man generating them.

I then posed the question to the students: How much vision is there during an eye movement? The apparatus they chose was quite simple. The General Radio Company had lent us two Strobotacs (argon flash units). The students arranged one unit in such a way that it was triggered only during an eye movement. For a subject seated in a dark room, attempting to read a large headline on a newspaper, the following happened: he could report everything that there was about him except the material he was attempting to read. That headline could be read by anyone else in the room with one flash. The duration of the flash was a few microseconds, so that eye movement produced no blurring. It was then that we observed a startling effect. If a flash occurred while the eye was at rest, there was a marked after-image which helped in reciting the headline aloud. But if the flash came during an eye movement, no such after-image seemed to be there. This was very odd – for it has been held for a very long time that the after-image is an event in the receptors, probably correlated with chemical processes in the rods and cones. I. Kohler's experiments with variability of the after-image, while showing perceptual changes in the after-image under habitational control (which Kohler believes are mediated by efferents to the retina), still do not establish more than a weak modifying influence. Here we have what is virtually an abolition of after-image formation. Very cursory additional experiments suggested immediately

that during a saccadic jerk (reading movement) the fovea is not only shut off perceptually so that all vision during a jerk is peripheral, but also that it does not form an after-image. Because the latter finding was somewhat more startling than the former, we proceeded to develop this theme with another kind of experiment.

Last year at Bell Telephone Laboratories I saw G. Sperling's demonstration of erasure in the retina: a circle surrounding a letter, flashed some 40 msec after a flash of the letter, abolishes perception of the letter. (This sort of experiment is currently popular among several research groups.) He also showed me that the flash of a letter followed by a flash of uniform illumination at approximately 40 msec gives one the perception of the photographic negative of the letter, that is, the image is not seen, only the after-image. Hearing of this, the students set up two argon flash units and a colored picture on translucent paper in such a way that when the picture was turned with its blank back to the observer it could be seen if a flash occurred behind the sheet (transilluminating it); only blank white appeared when a flash occurred in front of the sheet. When the two flashes were given so that the transillumination came before the blank flash (the students thought that the interval was 15-20 msec, but I think they made an error and that it was 30-40 msec) then only the colored after-image could be seen for repetition rates as high as 10-12 per second. Now, if two fixation points were put on the blank back of the picture and the observer was told to look back and forth between the two points, it would occasionally happen that while the paired flashes were generating the negative after-image, suddenly he would see a sharp positive image for 1 cycle, exactly as if the second flash had not occurred. This abolition of the blanking effect of the second flash seemed to occur if the eye began its movement after the transilluminating flash. Such an effect, if verified, would make even more hash of classical ideas about after-images than Kohler's work does. The occurrence of this effect has been tentatively confirmed retrospectively by Sperling, who thinks it is so, but will let us know more certainly after critical experiment.

Therefore, the turning off of foveal vision during eye movement would seem to extend to the formation of after-images.

The third problem attacked by students W. Godchaux, S. Latt, D. Weaver, and M. Wells was whether or no it is possible to establish voluntary control of an autonomic function, such as sweating. To this end, they built a portable hybrid circuit, an electrometer tube and transistor, embedded in a meter in such a way that they could read the galvanic skin response as potential change rather than resistance change. The notion behind their experiment was this: The autonomic nervous system is not ordinarily under voluntary control. However, yoga adepts apparently are able to establish voluntary control over sweating, heart rate, blood pressure, urine excretion, etc. Physical measures prove this claim that control can be learned. The trouble with autonomic functions is that there generally is no direct sensation of what is happening

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to your heart, etc. This in itself is sufficient to prevent conscious control. Therefore the students decided to provide their subjects with meters that measure particular autonomic functions (in the first case, sweating) to see whether a viewing meter would permit one to change the function measured.

I believe the students were more successful in their venture than they think. They showed that it was possible to turn off or attenuate greatly the sweating response to so adverse a stimulus as an electric shock on the arm, even when the shock was unexpected – and that this was learned in approximately 20 minutes. However, they were unhappy about the variability of control in the same subject and between subjects. I had required only that they get an indication, not a proof, of whether or no control could be learned quickly, and I am willing to hold now, on the basis of their work, that this indication is clear. Of course many psychologists will talk about adaptation – but the students early showed that it was possible to condition a large sweating response to a shock, and this responsiveness lasted (when the subject did not view the meter). So if the apparent control is adaptation, the adaptation can be varied at will, and I fail to see any difference between that and direct control.

J. Y. Lettvin