

chloric acids. The residue from this treatment was taken up in 1.5N HCl and treated in the same manner as the water samples for the isolation of the lead-210. There was no lead-210 activity on the filters, within experimental error. The activity in the biological tows, comprised of zooplankton, was easily measurable, but was insignificant when considered on a per-liter-of-sea-water basis.

The results of our work are given in Table 1. The over-all experimental errors in the tabulated values are less than 10 percent.

The activity in the oceanic mixed layer proved to be less than it was in deeper waters—a result contrary to expectations. This strongly suggests a removal of lead-210 from the surface waters to deeper water by biochemical or inorganic processes. This can be seen more clearly by setting up the steady-state equations for a simple two-layer model of the oceans (6):

$$dN_m/dt = 0 = P - BN_m - K_{m-d}N_m + K_{d-m}N_d - \lambda N_m$$

where N_m and N_d are the amounts of lead-210 in the surface and deep waters, K_{m-d} and K_{d-m} are the rate constants for the mixing of mixed to deep waters and deep to mixed waters, B is the rate constant for the biological or inorganic removal of lead, λ is the decay constant of lead-210, and P is the total input of lead-210 into the mixed layer both from atmospheric radon-decay and from radium-decay in the sea water. Rearranging, we find

$$P = (B + \lambda) N_m + (K_{m-d} N_m - K_{d-m} N_d)$$

Taking the volumes of the mixed and deep layers as 10 and 500 lit./cm² (that is, an average oceanic depth of 5000 m) respectively, and the concentration of lead-210 in the mixed and deep layers as 0.1 and 0.3 disintegration per minute per liter, we find

$$0.53 \frac{\text{disintegrations/min}}{\text{cm}^2} \text{ year} = (B + 0.03) 1 + (K_{m-d} \times 1 - K_{d-m} \times 150) \text{ or } 0.50 = B + (K_{m-d} \times 1 - 150 K_{d-m})$$

Although order of magnitude values of K_{m-d} and K_{d-m} exist (6), we first consider the extreme case where no mixing occurs between the mixed and deep layers, that is, $K_{m-d} = K_{d-m} = 0$. Here, B is 0.5, or the biological removal time of lead-210 is 2 years. The second term in the last equation must be

negative for the cases where the K 's have positive values, inasmuch as any physical mixing can result only in a net transfer of lead-210 from the deep to the mixed layer. This would make values of the biological removal period even smaller. However, the period may be longer, if the oceanic rains are, on the average, poorer in lead-210 than we have indicated. Nonetheless, the order of magnitude is of primary significance.

The residence time of lead in the deep oceans before precipitation to the sediments is of the order of 10,000 years (7). The markedly shorter residence time in surface waters emphasizes the distinction between the mechanisms of transport of lead from the mixed to the deep waters and from the deep waters to the sea floor. The well-known enrichment of heavy metals in the marine biosphere, coupled with the biological activity in the mixed layer, suggests biological transport in the first case, while inorganic processes are undoubtedly responsible for the accumulation of lead in sediments. The observations on the distribution of barium in the oceans (8) have already indicated the importance of biological activity in the conveyance of heavy metals from the mixed to deeper waters.

The very long residence time of lead in the deep oceans indicates that only an insignificant fraction of the oceanic lead-210 will be deposited in the sediments. This seems to be borne out by our observations also. The concentrations of lead-210 in deep-sea waters are found to be essentially in secular equilibrium with the radium-226 values reported for such waters (9).

The behavior of lead-210 in terrestrial surface waters was sought in order to evaluate its use as a tracer of the movements of these waters. It is quite clear from Table 1 that there is a rapid depletion of lead-210 in the Colorado River during its journey from the area of its feed waters to the man-made reservoir Lake Mead. These results clearly direct one to the conclusion that the composition of river waters reflects not only the geology of the drainage basins and the accompanying weathering processes therein but also, and possibly of equal significance, the chemical reactions, either inorganic or biochemical, that occur within these waters (10).

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Discharge Patterns of Neurons in Cochlear Nucleus

Abstract. Patterns of discharge in slowly adapting, spontaneously discharging neurons of the cochlear nucleus were studied. A technique for analyzing the distribution of intervals between discharges of neurons is described. The response to a steady tone generally was an irregularly spaced train of impulses. In the majority of cells examined, the intervals between discharges were distributed exponentially. The mean interval and standard deviation of the distributions decreased as the level of afferent excitation was increased, but the modal value of the distribution was unchanged.

Many neurons of the mammalian central nervous system have highly irregular patterns of discharge. Measurement of the average frequency of discharge of these neurons does not sufficiently characterize their behavior. A useful method of analyzing the behavior of these neurons is to determine the frequency of occurrence of the various intervals at which they discharge. These intervals can be plotted in the form of a histogram. Histograms of this type have been constructed by various authors for muscle spindle receptors (1), retinal ganglion cells (2), and neurons of the auditory cortex (3). Analysis of these histograms may provide information about fundamental properties of the neuron (1, 2, 4). The present report is concerned with describing some examples of histograms of discharge intervals in units in a sensory nucleus in the cat.

Tungsten microelectrodes with tip diameters of 1 μ were used for the extra cellular recording of discharges of single neurons. Light pentobarbital anesthesia or awake chronic preparations with implanted microelectrode

advancers were used. Only spontaneously discharging neurons that adapted slowly to steady stimulation, and whose discharge characteristics were stable,

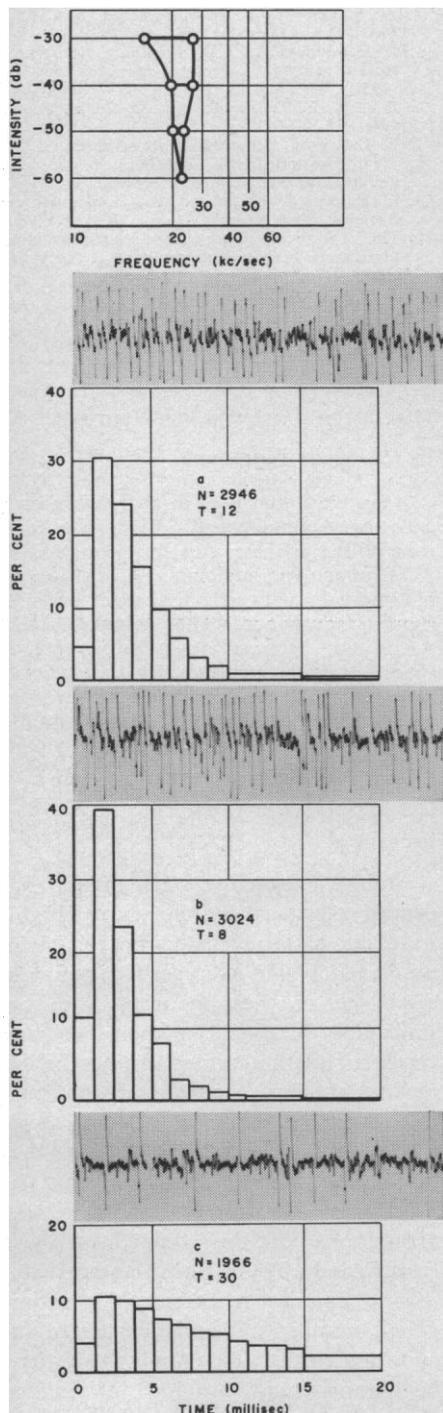


Fig. 1. Cochlear nucleus unit, unanesthetized cat. Histograms of discharge intervals: *a*, stimulation of ipsilateral ear with a tone of 21.5 kcy/sec at -20 db; *b*, stimulation with a tone of 21.5 kcy/sec at -40 db; *c*, no stimulus, spontaneous activity. The exponential tails of these histograms have been omitted to conserve space. Insets: Threshold of response versus frequency. Oscillographic strips: Recordings of the electrical activity of the neuron for a 1/10-sec period. (*N*, total number of discharges; *T*, approximate length of record in seconds)

were studied. Discharges were recorded on magnetic tape. Time intervals between discharges were electronically sorted by a machine constructed from standard digital elements. The machine contained a 100-kcy/sec oscillator that was used to measure the discharge intervals by counting the number of oscillator cycles that occur between successive discharges of the neuron. A logic network was used to determine when a count fell between the limits of a particular predetermined class interval. A bank of registers totaled the counts for each class interval (5).

Histograms of discharge intervals were obtained for 31 cells in the cochlear nucleus, making use of a class interval of 5 msec. Thirty of these cells had an exponential distribution of interspike intervals that could be approximated by the equation:

$$P(t) = re^{-rt}$$

where $P(t)$ is the probability density for intervals of duration t , and r is the mean frequency of discharge. To obtain a finer structure for the histograms, discharge interval distributions were also obtained with a class interval width of 1.25 msec. A histogram for a typical unit is shown in Fig. 1. This unit responded to high-frequency tones and had a click latency of 2 msec at a sound intensity level 40 db above threshold. Without stimulus the cell had a mean discharge rate of 73 pulses per second. The standard deviation of the interval distribution was 13.6 msec. With a sustained tone having a level of -40 db (20 db above threshold), the average discharge rate of a cell was 303 pulses per second, and the interval distribution was narrower, with a standard deviation of 2.2 msec. With an increase in the strength of the stimulus to -20 db, the rate of discharge of this unit decreased, giving a new average discharge rate of 256 pulses per second, and the width of the resulting histogram increased, giving a standard deviation of 2.8 msec.

The distribution of intervals fell in an exponential manner from the modal value to the longer intervals. A striking characteristic of these units was that the modal value of their interval distributions was constant for all levels of excitation of the unit, although the mean interval and standard deviation of the distributions changed.

In contrast to these units, one neuron

was observed with an approximately bell-shaped distribution of discharge intervals. Histograms for this unit are shown in Fig. 2, measured with a class interval duration of 5 msec. In the spontaneous state the mean discharge rate for this cell was 28 pulses per second, and the standard deviation was 11.9 msec. During stimulation the modal value of discharge shifted to a shorter interval. The mean discharge rate for this state was 178 pulses per second, and the standard deviation was 2.3 msec. This type of behavior is more typically seen in units in the central somatosensory pathways (4).

The exponential character of the distribution of intervals of discharge observed in units in the cochlear nucleus suggests that a Poisson type of random process is involved in the generation

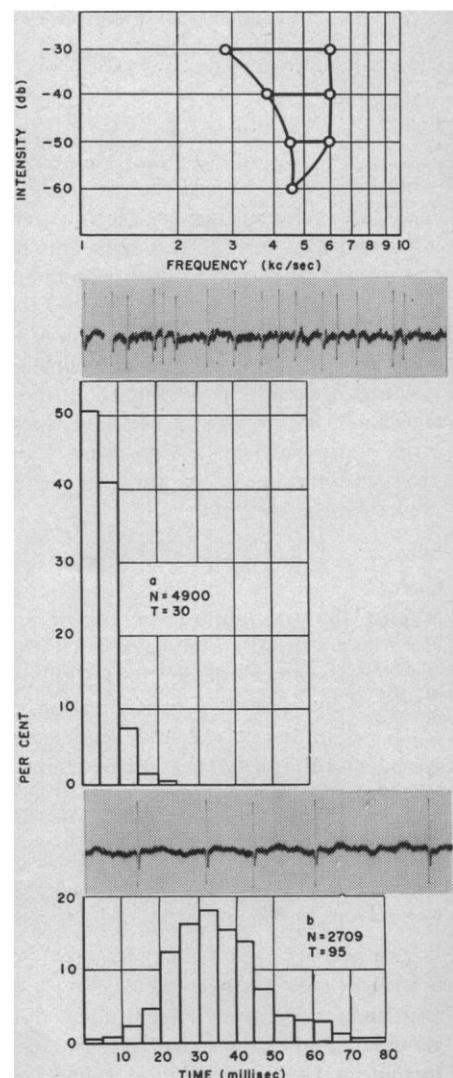


Fig. 2. Cochlear nucleus unit, anesthetized cat. Histograms of discharge intervals: *a*, stimulation of the ipsilateral ear with a tone of 4.5 kcy/sec at a level of -40 db (20 db above threshold); *b*, spontaneous activity.

of trains of impulses in these units. At shorter intervals the recovery processes of the neuron limit the generation of impulses, preventing the distribution from being truly exponential.

The highly irregular character of the discharge patterns observed in response to stimulation with pure tones, and the general similarity of the interval distributions for most units, appears to preclude any simple interpretation of the coding of tone frequencies by the pattern of impulses carried by individual neurons.

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Search for Evidence of Axial Current Flow in Peripheral Nerves of Salamander

Abstract. The demonstrated association of the d-c bioelectric field with central nervous system elements implies the longitudinal flow of charge carriers within that system. Transverse d-c voltages, attributed to the Hall effect, have been obtained from the extremities of intact salamanders under circumstances suggesting such electric current. These voltages disappeared after nerve section, and their magnitude was related to the depth of anesthesia.

The d-c or steady-state, bioelectric field has been studied extensively (1), and has been found to correlate with growth (2), tissue repair (3), tumor formation (4), cephalocaudal relationships (5), sleep state in man (6), and human behavior (7).

Recently, precision determinations have shown that this bioelectric field is a complex one, with multiple sources

and sinks bearing a close spatial relationship to the anatomical arrangement of the central nervous system (8). This observation led to the theory that the d-c field is generated within and distributed by elements of this system and that it might further represent a primitive data transmission mechanism of neural or neural-related tissue. This theory is at variance with the views which hold that the d-c field is generated by the sum total of electrical activity of all of the cells of the organism and that it possesses no specific organization other than cephalocaudal polarity (9). Implicit in the thesis is the necessity for longitudinal movement of electrical current carriers within the neural structures, and demonstration of such a phenomenon would be necessary for further substantiation. The Hall effect (generation of a potential gradient at 90° to the direction of current flow in the presence of a steady-state magnetic field, oriented at 90° to the direction of current flow and also at 90° to the potential gradient) was selected as evidence to be looked for in support of the hypothesis of axial current flow.

Adult salamanders (*Triturus viridescens*) were used since the d-c field has been completely mapped in this animal. Intact extremities were utilized rather than nerve fibers dissected free to prevent interference from currents of injury. The nerves, however, can be completely severed by fairly simple surgical approaches at a distance far enough away from the recording electrodes to avoid pickup of injury currents. Electrodes were silver-silver chloride, saline-filled, with thin, terminal, cotton wicks. The magnetic flux was obtained from a 7000-gauss permanent magnet with a 3/8-in. air gap, mounted on a movable nonmagnetic support. The electrode contacts were placed just proximal to the elbow joint in such fashion that a line joining both contacts would be 90° to the long axis of the limb and oriented in a cephalocaudal direction.

The magnet was so arranged that, when it was swung into position, the flux field completely encompassed the areas of electrode contact, with the field direction oriented 90° to the line joining the electrodes. Movement of the magnet was without mechanical vibration, and care was taken to insure that no portion of the magnet or its support came into direct contact with the animal. Potentials were amplified by a chopper type direct-coupled preamplifier and a d-c power amplifier. All determinations were carried out in a double-

walled Faraday cage, and the experimental setup was as shown diagrammatically in Fig. 1.

The electrodes alone making contact through a drop of saline demonstrated a steady potential of 25 μ v. No change in this potential was obtained with the application of the magnetic field other than the voltage transients associated with movement of the field in and out of position (Fig. 2A). These transients averaged about 4 sec in duration. In the animal experiments, once the magnet was swung into position it was left stationary for from 20 to 60 sec, a time more than sufficient to permit decay of the transients.

In all 24 salamanders tested, transverse d-c voltages of from 10 to 150 μ v were obtained during the period of steady-state magnetic field application. Removal of the magnetic field brought about a return to the original base line

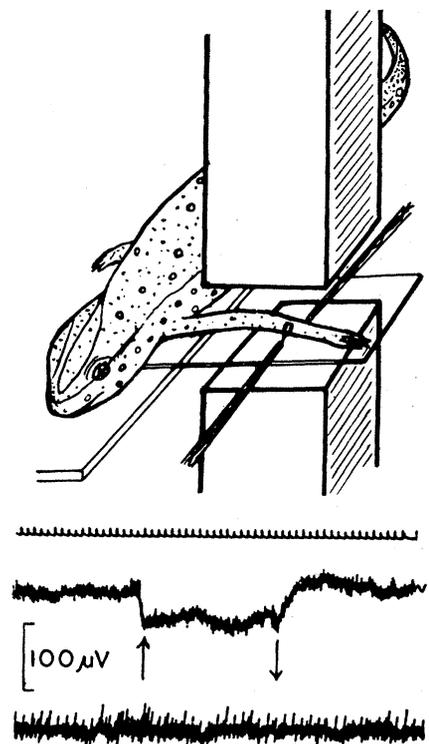


Fig. 1. (Top) Schematic view of the experimental apparatus with the magnet poles swung into place. All portions of the apparatus are made of nonmagnetic materials. The long axis of the limb, the direction of the magnetic flux field, and the inter-electrode line are all at 90° to each other. (Bottom) Top trace is a time marker with 1-sec intervals. The second trace is a typical Hall voltage, the transients of opposite sign indicating magnet movement. The arrow pointing up indicates movement of the magnet into position; pointing down indicates movement out of position. The lower trace is the electrocardiogram measured from precordium to the right extremity—the rate here is about 50 per minute with irregularities.