Changes of the type we found in adult animals are actually suggested by perceptual negative aftereffects such as the waterfall, the tilt, the spatial frequency adaptation, and the McCollough effect, in which the aftereffects are complementary to the adaptation conditions. While most of these effects seem to last only for short periods, some seem to last longer. The McCollough effect, for example, has been reported to last for hours, especially if no visual stimuli are presented in the interval between adaptation and testing (*8*). It was proposed that these aftereffects may be due to increased inhibitory synaptic linkage between neurons excited by such stimuli, and that similar mechanisms may be involved in memory (*9*). The present experiments are in line with these psychophysical phenomena insofar as they offer, for the first time, a mechanism by which the nervous system becomes less sensitive to the stimulus to which it was exposed. Our experiments do not clarify, however, whether the relative decrease of units responsive to the trained stimulus is due to an "adaptation" or "habituation" of excitatory connections or whether it is due to increased effectiveness of inhibitory connections within the cortical network (*10*).

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4. It should be noted in this context that, since most cortical neurons respond best or even exclusively to moving stimuli, the description of the fundamental property of a cortical neuron by its "optimal" orientation is therefore incomplete. With this reservation in mind it may nevertheless be used, since a complete description of the fundamental properties of cortical neurons is still a matter of dispute.
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10. Recently, A. Fiorentini and L. Maffei [*Vision Res.* **14**, 217 (1974)] reported that cortical simple cells of adult cats may lose their binocular excitatory input if one eye is immobilized for some time. This demonstrates also that binocularity of cortical cells is plastic in adult animals. A direct comparison of orientation sensitivity and ocularity is not possible, however, since these two properties have a different anatomical basis.

18 November 1974; revised 27 December 1974

Electrostatic and Steric Effects in the Selective Complexation of Cations in Nonactin

Abstract. *The ester carbonyl stretch frequencies of complexes of the macrotetrolide nonactin with* Na^+, K^+, Rb^+, Cs^+, Tl^+, $NH_4{}^+$, NH_3OH^+, *and* $(NH_2)_2CNH_2{}^+$ *have been measured. For the larger alkali cations and the polyatomic cations, the ester carbonyl stretch frequency is linearly proportional to the cation–ester carbonyl electrostatic interaction energy. This constitutes direct evidence that the cation-nonactin interaction is primarily electrostatic, rather than mechanical (steric).*

The biological mechanisms of ion complexation and ionic selectivity have been studied extensively using ionophorous antibiotics (*1*). The macrocyclic antibiotic nonactin is particularly interesting because it selectively complexes with a wide variety of cations (*2*). Crystallographic and nuclear magnetic resonance (NMR) studies show that the cation is located near the middle of the nonactin molecule (*3*) (see inset, Fig. 1a) and suggest that cation binding proceeds primarily through the ester carbonyl oxygen atoms.

While it is generally agreed that electrostatic forces are primarily responsible for the stability of antibiotic-cation complexes (*4*–*6*), several distinct models for the ionic selectivity of nonactin have been advanced. In one (*4*, *5*) the selectivity is ascribed entirely to differences in the electrostatic free energy between the solvated ion in solution and the unsolvated ion bound to the antibiotic, while in another (*6*) it is suggested that "the ability [of carrier ligands] to distinguish among the cations of one group of the periodic system by forming complexes over a large range of stabilities is largely due to intra-ligand steric interactions. . . ."

We report the first laser Raman spectroscopic studies of nonactin and its complexes. By correlating the observed ester carbonyl stretch frequencies with known properties of the cations, we have obtained information on the physical nature of the forces that perturb the carbonyl and tetrahydrofuran oxygen atoms in the nonactin complex.

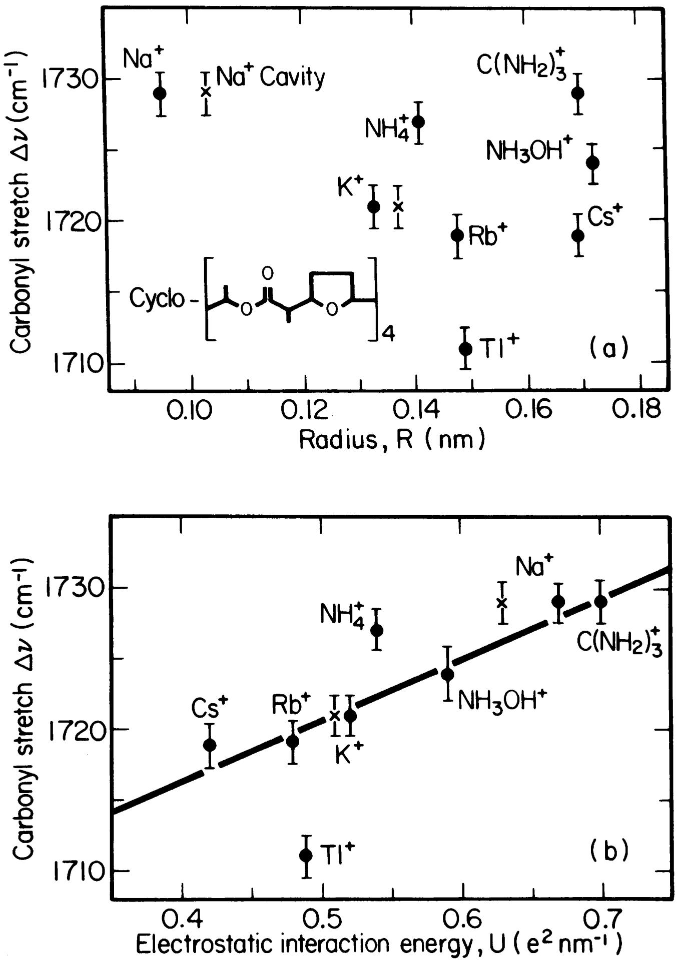

Fig. 1. (a) Ester carbonyl stretch frequency as a function of ionic radius for nonactin-ion complexes. For Na^+ and K^+ the ionic radius and the radius of the cavity in the complex are different; both radii are plotted. (b) Ester carbonyl stretch frequency as a function of electrostatic interaction energy for the nonactin-ion complexes. The electrostatic interaction energy for each complex is calculated by Coulomb's law from the charges and positions assumed (Fig. 2), supplemented by the available x-ray structural data. For the guanidinium and hydroxylamine complexes, where steric interactions between the ion and some of the carbonyl groups are important, the indicated electrostatic energy is for ester carbonyls not subject to steric interactions. Note particularly the positions of the Cs^+, NH_3OH^+, and $C(NH_2)_3{}^+$ ions in (a) and (b).

Raman spectroscopy uses inelastic scattering of monochromatic light to measure molecular vibration frequencies. Spectra were obtained with a Spectra-Physics model 164-03 argon ion laser and Spex Ramalog 4 double-grating monochromator system (*7*); 4-cm^{-1} resolution and incident power of 80 to 200 mw at 457.9, 488.0, or 514.5 nm proved sufficient.

We obtained Raman spectra of nonactin and its complexes with Na^+ (from NaSCN), K^+ (KSCN), Rb^+ ($RbNO_3$), Cs^+ (CsCl), Tl^+ ($TlNO_3$), NH_4^+ (NH_4SCN), NH_3OH^+ (NH_3OHCl), and $(NH_2)_2CNH_2^+$ [$(NH_2)_2CNH_2Cl$]. The solvent, a mixture of methanol and chloroform (molar ratio, 8/1; volume ratio, 4/1), was chosen to optimize the solubility of both nonactin and the free ions; 0.03*M* solutions of complexed nonactin in 0.5*M* salt were obtained. (Uncomplexed nonactin is noticeably less soluble.) The solvent permits useful observations in the important regions 400 to 600, 800 to 1000, and 1600 to 1800 cm^{-1}.

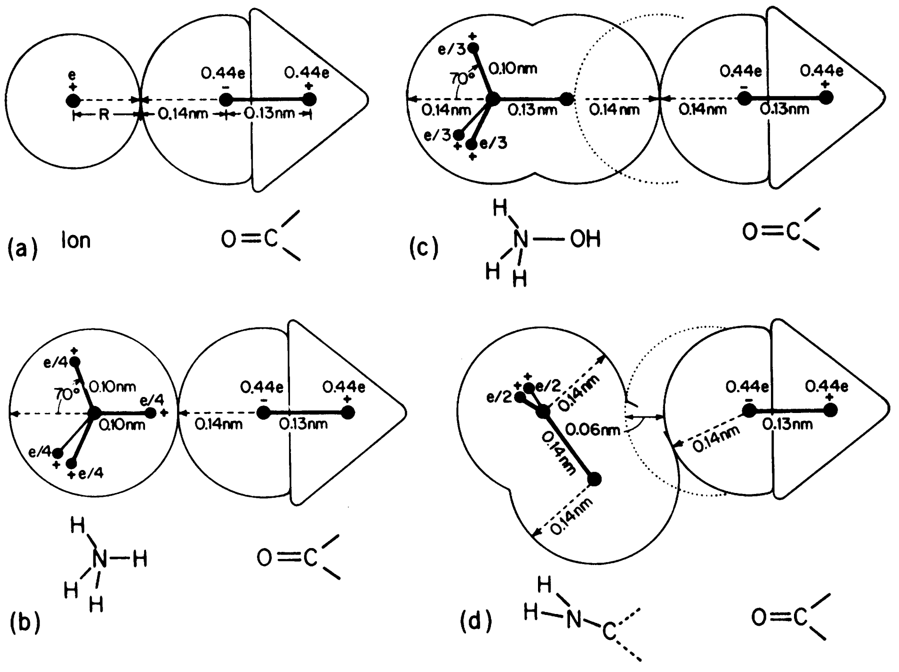

Fig. 2. (a) Model of Krasne and Eisenman (*4*) for the ion-carbonyl electrostatic interaction, showing the edges of the ion (radius, *R*) and the oxygen (radius, 0.14 nm) in contact. It is assumed that nonactin is sufficiently flexible that the other ester carbonyl groups (not shown) can assume equivalent positions with respect to the ion. Individual nuclei (black dots) are taken as the effective positions for the indicated charges in units of the electron charge, *e*. (b) Modification of Krasne-Eisenman model (a) for the NH_4^+ ion. The NH_4^+ crystalline van der Waals radius (0.14 nm) was used. Because NH_4^+ and nonactin both have approximately tetrahedral symmetry, each ester carbonyl in the nonactin faces an equivalent point on the NH_4^+ ion. (c) Model of an ester carbonyl group approaching the hydroxyl end of an NH_3OH^+ ion, showing the substantial steric interaction between carbonyl and hydroxyl groups. The dotted circle indicates the position that the oxygen in the carbonyl would assume if the hydroxyl group were not present. The other three ester carbonyls are assumed to occupy positions facing the three amide hydrogens, as shown in (b). (d) Model of a nonactin ester carbonyl approaching a $C(NH_2)_3^+$ cation near the C-N bond; for clarity, the two out-of-plane NH_2 groups have been omitted. The hydrogens of the NH_2^+ group extend into and out of the plane. One ester carbonyl is able to approach each of these two hydrogens directly, much as in (b). The steric interference between the ester carbonyl and the guanidinium carbon is indicated by the dotted circle, which shows the position which the carbonyl oxygen would occupy if the carbon were absent.

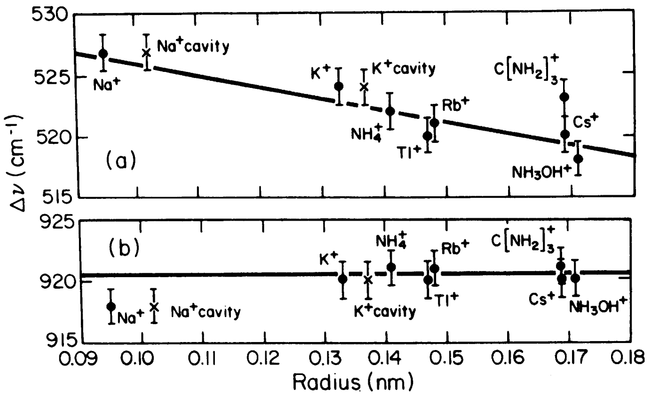

Fig. 3. Dependence on ionic radius of two other spectral lines prominent in nonactin-ion complexes. From model compound studies, the 522-cm^{-1} line (a) is associated with the tetrahydrofuran ring, while the 920-cm^{-1} line (b) is likely associated with the ester groups.

The ester carbonyl stretch vibration at 1700 to 1790 cm^{-1} is highly sensitive to the local environment (*7, 8*). Figure 1 shows Raman frequencies in this region for several nonactin-cation complexes. These peaks are significantly narrower than the corresponding band in uncomplexed nonactin (*9*), which is probably a poorly resolved doublet.

Since there are four ester carbonyl groups in nonactin, there are four ester carbonyl stretch modes. The fully symmetric stretch mode (in which the four ester C=O's stretch in phase) will contain the least contribution from ester carbonyl deformations; it will also give a fully polarized line. The carbonyl stretch band displays appreciable splitting only for the Na^+ complex, for which the fully polarized line appears at 1731 cm^{-1}.

We find that the ester carbonyl frequency depends on the cation. If steric interactions between cation and nonactin predominate, the carbonyl stretch frequency might be expected to depend only on the cation radius, *R*. If cation-carbonyl electrostatic interactions predominate, the perturbation might instead be expected to depend on the electrostatic interaction energy, *U*. For spherical ions, *U* and *R* are simply related; we therefore also studied the nonspherical ions NH_4^+, NH_3OH^+, and $(NH_2)_2C(NH_2)^+$ to help distinguish between these alternatives.

Figure 1a shows the dependence on *R* of the ester carbonyl stretch frequency [for Na^+ and K^+ the nonactin cavity size (*10*), which is larger than *R*, is also shown]. This frequency varies approximately as $1/R$ for the alkali cations, but no systematic correlation with *R* is evident for more complex ions. The radii of the nonspherical ions NH_3OH^+ and $(NH_2)_2CNH_2^+$ are arithmetic means of the four N-O distances indicated in Fig. 2, c and d.

Figure 1b shows the dependence on *U* of the ester carbonyl stretch frequency; *U* was calculated from an electrostatic model (Fig. 2). With three exceptions (Na^+, NH_4^+, and Tl^+ complexes) the data lie on a straight line, suggesting that the interaction between the nonactin carbonyl groups and the cation is predominantly electrostatic. That the frequency of the Na^+ complex is anomalous is not unexpected, because x-ray measurements (*10*) show that the Na^+ ion (R = 0.095 nm) is substantially smaller than the internal cavity of the nonactin (radius 0.102 nm); the ester carbonyl groups are thus sterically constrained by the remainder of the molecule. The anomalously high frequency for NH_4^+ (whose tetrahedral symmetry matches that of nonactin) would correspond to increased electrostatic interaction between cation and carbonyl groups. This anomaly is probably not due to hydrogen bonding, which usually reduces the carbonyl stretch frequency; ^{13}C-NMR data (*11*) provide evidence that carbonyl hydrogen bonds are absent. The anomalously low frequency of the Tl^+ complex corresponds to a reduction of the electrostatic interaction between the cation and carbonyl group. This reduction could arise from a transfer of electron charge to the Tl^+ ion from the carbonyl oxygen, which may also contribute to the total interaction energy. The nonactin extraction coefficients for NH_4^+ and Tl^+ are also anomalous (*4, 5*).

The methods described above can also be applied to other parts of the molecule. For example, the frequency of the intense peak in the complex near 525 cm^{-1} [which is apparently associated with the tetrahydrofuran subunits (*9*)] varies with ionic radius (Fig. 3a), suggesting that the tetrahydrofuran rings interact with the cation, perhaps only indirectly through the nonactin backbone [a conclusion inferred from recent ^{13}C-NMR results (*11*)]. The anomalous position of the bulky $(NH_2)_2CNH_2^+$ ion in Fig. 3a may arise from additional steric interactions.

Many Raman frequencies do not depend appreciably on ionic radius or shape, even though their relative intensities change on complexation; an example is the 920-cm^{-1} line (Fig. 3b).

In some models of ionophore specificity, ionic selectivity arises partially from differences in the mechanical energy required to distort the antibiotic cavity to accommodate ions of different radii. If the observed changes in the ester carbonyl stretch frequency arose from this perturbation, they would be expected to depend on the magnitude of the distortion and thus on the ionic radius. For the larger alkali ions and the ammonium derivatives, the ester carbonyl stretch frequency depends on the ion-carbonyl electrostatic interaction energy U rather than on the ionic radius R. For the Na^+ ion, in which steric constraints are known to be important, the ester carbonyl stretch frequency is anomalous, showing that this frequency can respond to steric effects. This finding emphasizes the importance of electrostatic forces in nonactin cation interactions and thus tends to support electrostatic models (*4, 5*) for the ionic selectivity of nonactin.

Note added in proof: Recent x-ray crystallographic data on the NH_4^+-tetranactin complex (*12*) show that the NH_4^+ cation is hydrogen bonded to the four tetrahydrofuran oxygen atoms. For this structure, U is smaller than shown in Fig. 1b, increasing the observed anomaly. The NH_4^+ hydrogen bonds may also account for the great stability of the NH_4^+-nonactin complex. That the stabilities of the NH_3OH^+ and $C(NH_2)_3^+$ complexes are considerably lower (*13*) suggests that these complexes do not contain such hydrogen bonds.

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31 October 1974

Adaptive Significance of Synchronized Breeding in a Colonial Bird: A New Hypothesis

Abstract. *Bank swallows nest gregariously in colonies usually ranging from 10 to 300 nests. Different pairs within the same colony are highly synchronized with each other, and 67 percent of the nests fledged their young over a period of only 6 days. This high degree of synchronization is demonstrated to be of adaptive significance. Reproductive fitness increases as a function of the precision of synchrony of the colony. It is proposed that social foraging plays an important role in maximizing the feeding efficiency in this species and that asynchronous breeding decreases the effectiveness of this social foraging, particularly in late nesters and among young, newly fledged birds. An individual that fledges either early or at the peak of synchrony will emerge to find a steady stream of other birds traveling to local, ephemeral, concentrations of food. The late emerger finds itself practically alone and thus is deprived of the potential benefits of the pooled information about locations of food resources available to the full colony.*

Synchronization in the timing of breeding is a common feature of the reproductive biology of many colonial nesting birds (*1*). One question arising is whether such synchronization is of ultimate adaptive importance or whether it is a proximal result of either (i) a high degree of gregariousness or (ii) a common responsiveness to the same environmental trigger for breeding.

Surprisingly, very few quantitative studies have dealt with breeding synchrony or have been directed to a search for any effects of synchronization on reproductive fitness. We now present demographic data that provide one of the first clear instances of a positive selective advantage to breeding in synchrony. We then propose a new hypothesis to partially account for the increased reproductive success noted in highly synchronized colonies.

The bank swallow (*Riparia riparia*) is a gregarious bird that breeds in dense colonies ranging from 10 to 300 pairs (*2*). The birds dig their nests 0.5 to 1.3 m deep into vertical banks along rivers, on cliffs, or in sand and gravel pits.

As part of a large-scale study of the adaptiveness of coloniality in this species (*3*), we gathered detailed behavioral and demographic data from over 400 nests in 15 colonies in the vicinity of Tompkins County, New York, during 1970 and 1971. Nest contents were checked at intervals allowing us to determine the time of laying, clutch size, incubation period, and date of hatch, and to monitor the growth and survival of the nestlings during their development until the age of fledging (*4*).

The bank swallows showed an extremely high degree of within-colony synchronization. Including the peak hatch date for each colony, 67 percent of all nests hatched over a period of only 6 days. Nearby colonies, although highly synchronous within