the subjects were tested for 4 days after removal; the others continued wearing the spectacles, in connection with a study of adaptation to spatial distortion. Prismatic dispersion is indicated in terms of a standard measure, namely, the relative angular displacement of the Fraunhofer C and F lines, which bracket the region of the spectrum to which the eyes are most sensitive. In terms of this measure, the spectacles worn by the subjects had a dispersion of 10.2 minutes of arc. The data points show the mean compensation power of the subjects' eyes, that is, the amount of prismatic dispersion in the variable prism which was just balanced by the adaptation response. The solid lines describe the data in terms of a steady state before spectacle-wearing and an exponential growth process during wearing.

Two levels each of target-stripe absolute luminance (L_1) and luminance relative to background (L_1/L_2) were tested, giving the four developmental curves shown in Fig. 1. Changing the relative luminance from 1.25 to 14.0 produced no important change in the eyes' compensation power. Changing the absolute luminance produced a change in compensation power which is statistically significant ($p \leq .01$); a hundred-fold increase in absolute target luminance reduced the compensation power by approximately one-half.

The same order of inverse relationship between compensation power and absolute target luminance was more general, in a special test series on the tenth day, throughout a luminance range from 10^{-3} to 40 mlam. At the lower end of this range, the compensation power actually exceeded the dispersion power of the spectacles. Below this region of ordinary color sensitivity, no color fringes were seen. Therefore although polychromatic light is not necessary to evoke the adaptation response, stimulation of the receptors participating in wavelength discrimination is necessary.

The effects of relative and absolute target luminance on the adaptation response itself cannot be directly inferred from their effects on its power to compensate for prismatic dispersion. Indeed, an analysis of the joint effects of prismatic dispersion and target luminance on the retinal image indicates that the adaptation response must vary with relative target luminance, and to a lesser degree—if at all—with absolute target luminance. Our reasoning is as follows.

The angular dispersion of the prism, which we measured to determine compensation power, produces a relative displacement of the long- and short-wavelength components of the target image. Thus the long-wavelength image of the target is partially superimposed on the short-wavelength image of the background, and vice versa. The color fringes which a prism initially produces are due, then, to the difference between the luminance of the target and that of the background. This luminance difference will be increased both by increasing absolute target luminance alone (by increasing target and background luminance in proportion), and by increasing relative target luminance alone (by decreasing background luminance). In accordance with this, the prism-produced color fringes are more vivid in high illumination than in low, and along high-contrast borders than along low-contrast borders.

This means that for a fixed amount of angular dispersion, a constant level of compensation would require that adaptation response strength increase with increases of either absolute or relative target luminance. Since we found that the amount of compensated dispersion did not change significantly with increases of relative target luminance, it follows that the strength of the adaptation response must have increased in proportion to relative target luminance. On the other hand, since the amount of compensated dispersion decreased with increases of absolute target luminance, we infer that the adaptation response does not change in proportion to absolute target luminance.

We may hypothesize, therefore, that the adaptation response underlying compensation for prismatic dispersion consists of an alteration of some normal psychophysical function of relative target luminance, such as contour formation or color contrast.

The possibility of similar adaptation to the chromatic aberration produced by spherical spectacle lenses, or to the intrinsic chromatic aberration of the eye (*4*), is not established. The dispersion produced by these differs in certain important respects from that of the prism spectacles. As a fundamental test, however, it may be suggested that wherever adaptation such as that we have studied takes place, it should manifest itself in ineradicable color fringes along high contrast borders in monochromatic illumination.

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References and Notes

1. J. J. Gibson, *J. Exptl. Psychol.* **16**, 1 (1932).
2. I. Kohler, *Oesterreichische Akademie der Wissenschaften, Philosophische-historische Klasse* **227**, 1 (1951).
3. R. Held and A. V. Hein, *Perceptual and Motor Skills* **8**, 87 (1958).
4. S. H. Bartley, in *Handbook of Experimental Psychology*, S. S. Stevens, Ed. (Wiley, New York, 1951), p. 921.
5. Supported by grants M-6427(A) and M-6430(A) from the National Institutes of Mental Health. We thank Dr. J. J. Gibson for use of the facilities of the Cornell University Psychology Department, and Dr. Edwin Hart who performed ophthalmological examinations on our subjects before and after the experiment.

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Behavioral Response Rates in Pigeons: Effect of α-Methyl-m-tyrosine

Abstract. *An intramuscular injection of α-methyl-*m*-tyrosine (100 mg/kg), which differentially depletes serotonin and norepinephrine in both brain and heart, was given to two groups of pigeons trained to peck at a key for food. The first group received an injection 12 hours before the daily session and showed no behavioral effect. Response rates of birds in the second group, which were injected 30 minutes after the start of the daily session, decreased and returned to normal within 9 hours after injection. Preliminary data on brain serotonin of pigeons indicate that the disruption of the behavior follows the same time course as the change in serotonin.*

Since 1954, data have been accumulated which suggest that 5-hydroxytryptamine (serotonin) has an important function in the central nervous system and that variations in the physiological levels of this amine affect behavior. One way to investigate the effect of serotonin upon the central nervous system is to correlate the abnormal levels of this amine with changes in behavior. In-

jections of D,L-5-hydroxytryptophan hydrate, the precursor of serotonin, are followed by increased levels of serotonin in the brain and peripheral sites. In our recent work we have injected intramuscularly 50 mg/kg of D,L-5-hydroxytryptophan hydrate into pigeons trained to peck at a key for food. Under these conditions, the length of time that the behavior is disrupted or atypical is correlated with the length of time required for 5-hydroxytryptamine in the telencephalon and diencephalon to peak and then return to normal. There is no such correlation between the behavioral change and other brain areas or peripheral tissues, such as heart, lung, or liver (*1*). The question naturally arises: what behavioral changes would follow a decrease in brain serotonin? Recent studies with α-methyl-*m*-tyrosine show that after administration of large amounts of this amino acid, serotonin and norepinephrine are differentially depleted in brain as well as in peripheral tissues, such as heart (*2–5*). Costa *et al.* (*4*) reported that rabbits receiving an intravenous injection of 100 mg/kg of α-methyl-*m*-tyrosine showed no overt effects of sedation, although the serotonin was decreased by 35 percent and norepinephrine by 87 percent. Since direct observations of the behavioral response of an animal are at best approximations, a more quantitative behavioral measurement was made after administration of α-methyl-*m*-tyrosine. In the present study, using the behavioral measures of operant conditioning, we attempted to determine whether, after intramuscular injection of 100 mg/kg of α-methyl-*m*-tyrosine into pigeons, a change in behavior could be measured.

Ten pigeons (White Carneaux cocks) approximately 6 months old were trained to peck at a translucent plastic disk on a multiple schedule of reinforcement: FR_{50} FI_{10} (FR, fixed ratio; FI, fixed interval). The details of the behavioral techniques as well as the historical development of both the neurochemical and behavioral areas have already been published (*1, 6, 7*).

Once a stable base line of behavior was established (after about 4 weeks' training), two 0.5 ml intramuscular saline injections were given 48 hours apart. Seven birds received saline injections at the end of the third interval of the daily session. The birds were quickly removed from the experimental boxes, injected, and returned to the boxes to complete the session. On the second day after the last saline treatment, one

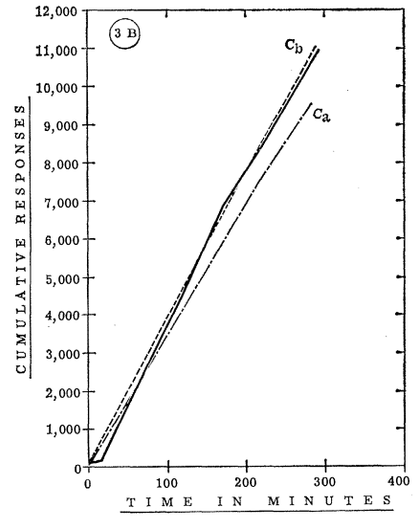

Fig. 1. Cumulative response curves of pigeon receiving intramuscular injections of saline (C_a, C_b) and α-methyl-*m*-tyrosine (100 mg/kg) 12 hours before daily session.

intramuscular injection of α-methyl-*m*-tyrosine (100 mg/kg) was given (*8*). Three birds received saline injections 12 hours before the daily session. One intramuscular injection of 100 mg/kg α-methyl-*m*-tyrosine was given to these three birds on the second day after the last saline dose, but 12 hours before the daily session. After this period, serotonin in the brain had returned to normal levels whereas norepinephrine was still low (*9*).

Typical cumulative response curves after saline and α-methyl-*m*-tyrosine treatments are presented in Figs. 1 and 2. The overall response rate of pigeon 3B (see Fig. 1) after the saline injections (broken line C_a, C_b) is virtually

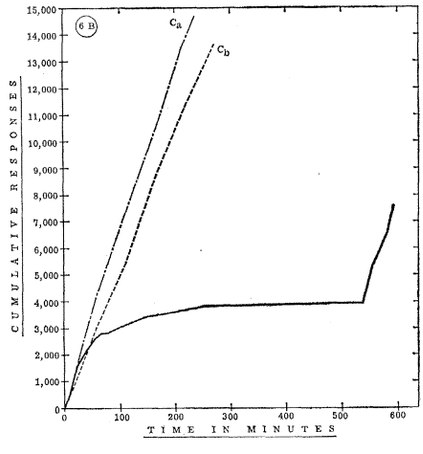

Fig. 2. Cumulative response curves of pigeon receiving intramuscular injections of saline (C_a, C_b) and α-methyl-*m*-tyrosine (100 mg/kg) 30 minutes after start of daily session.

the same as after α-methyl-*m*-tyrosine (solid line). Pigeon 6B (Fig. 2) received saline injections and the α-methyl-*m*-tyrosine injection after the third interval of its daily session (30 minutes after start of session). After this latter injection the cumulative response curve for this bird shows a gradual decrease for 4 hours in response rate followed by nearly complete cessation of responding for about the next 4½ hours. Between 8 and 9 hours after injection there is a sudden return of the response rate to normal. The duration of the behavioral effect differed for each bird, but all birds in this group showed a decrease in response rate after α-methyl-*m*-tyrosine followed by a gradual return to normal within 9 hours.

Preliminary data on total brain serotonin and norepinephrine after injections of the same dose of α-methyl-*m*-tyrosine in untrained pigeons indicate that serotonin returns to normal about 9 hours after injection, whereas norepinephrine remains depressed for at least 4 to 7 days (*9*). The atypical behavior displayed by the pigeons was not related to the lowered levels of norepinephrine since the behavior returned to normal at approximately the same time as the serotonin levels returned. Whether dopamine levels also returned to normal at this time in the pigeon, or whether α-methyl-*m*-tyramine peaks at this period remains to be determined. In other species, it appears that the time course of the change in dopamine is different from that in serotonin and norepinephrine (*4*).

Previously we have shown that increased total (free plus bound) brain serotonin is followed by a period of depressed responding in the pigeon working on a schedule of reinforcement, multiple fixed ratio (FR_{50}) fixed interval (FI_{10}) (*1*), whereas in the present study the data indicate that a decrease in total brain serotonin is also followed by a period of depressed responding on the same behavioral schedule. One explanation for the two opposite biochemical situations which result in virtually the same behavioral changes is found in the concept that a neurohumoral agent or neurochemical modulator must be free (to diffuse to the proper receptor protein site) rather than bound (in synaptic vesicles) in order to produce its physiologic effect. Although the time course of the behavioral effects due to an injection of D,L-5-hydroxytryptophan hydrate and α-methyl-*m*-tyrosine are distinctly different, it appears that in both

these cases more free serotonin can be formed or released than in the normal state (*6*). Therefore, a physiological situation can exist where greater amounts of the free form are available at synapses to produce its effect (*10*).

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References and Notes

1. M. H. Aprison, M. A. Wolf, G. J. Poulos, T. L. Folkerth, *J. Neurochem.* **9**, 575 (1962).
2. S. M. Hess, R. H. Connamacher, M. Ozaki, S. Udenfriend, *J. Pharmacol. Exptl. Therap.* **134**, 129 (1961).
3. T. L. Sourkes, G. F. Murphy, B. Chavez, M. Zielinska, *J. Neurochem.* **8**, 109 (1961).
4. E. Costa, G. L. Gessa, C. Hirsch, R. Kuntzman, B. B. Brodie, *Ann. N.Y. Acad. Sci.* **96**, 118 (1962).
5. S. Udenfriend and P. Zaltzman-Nirenberg, *J. Pharmacol. Exptl. Therap.* **138**, 194 (1962).
6. M. H. Aprison and C. B. Ferster, *ibid.* **131**, 100 (1961).
7. M. H. Aprison and C. B. Ferster, *Rec. Advan. Biol. Psychiat.* **3**, 151 (1961).
8. α-Methyl-*m*-tyrosine monohydrate was purchased from Cyclo Chemical Corp., Los Angeles, Calif.
9. M. H. Aprison and J. N. Hingtgen, *Federation Proc.* **22**, 273 (1963).
10. Supported by research grant MH-03225-04 from the National Institute of Mental Health. We thank Mary Ann Wolf and George J. Poulos for their help in collecting the data reported in this paper.

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Hydrogen Ion Incorporation in Crystals

Abstract. *The protons in crystal structures can be related to the oxygen lattice through several spatial arrangements. In orthosilicates (for example, hydrogarnets), so-called tetrahedral hydroxyls have been demonstrated by indirect methods. Similar methods, when applied to kehoeite and viséite, lead to the conclusion that $(H_3O_2)^-$ units can occur in the framework of analcime, a structure in which all apexes of oxygen tetrahedra are shared.*

"Water of crystallization" and the water liberated during the thermal decomposition of "acid salts" have been recognized for many years as ways in which hydrogen ions are incorporated in crystalline compounds. The possible incorporation in crystals of $(H_3O)^+$ has gained theoretical recognition. However, comparatively little is known about $(H_4O_4)^{4-}$ (so-called tetrahedral hydroxyls) or $(H_3O_2)^-$, a newly discovered structural component.

On chemical analysis, one of the oxides reported for many substances is water; it is conventionally reported as water liberated above 105°C (H_2O+) or below 105°C (H_2O-). This method of reporting analytical results is merely a convention, because more than a few hydrates lose part (or all) of their water of crystallization at temperatures below 100°C. No clue to the method of incorporation of the water within the crystal is ordinarily obtained in the absence of differential thermal analysis or thermogravimetric analysis.

Some increments of water, those involving hydroxyl ions, may be tenaciously retained; they may not be liberated below a temperature of 1000°C, or even higher.

Many of the tetrahedral oxygen configurations of several minerals, chiefly orthosilicates, but also orthophosphates, and a series of sulfate-silicate-carbonates (*1*) lack the small, highly charged, centrally located cation. The evidence, to be sure, is indirect, but the isostructural nature of $Ca_3Al_2(SiO_4)_3$ and $Ca_3Al_2(H_4O_4)_3$ can leave little doubt about the association, in this hydrogarnet series, of four hydrogen ions with four oxygens which would otherwise comprise a tetrahedral anion—for example $(SiO_4)^{4-}$. The evidence is not so much a question of an excess of water as it is the absence of silica, although the conformity between silica "deficiency" and "excess" water is astonishingly precise in several cases.

In addition to the series of hydrogarnets (*2*), excess water (accompanied by a deficiency in P or Si or S) has been proposed to explain the compositions of antigorite, coffinite, crandallite, montmorillonite, griphite, and apatite. Most of these examples are *ortho* compounds, but two phyllosilicates, antigorite and montmorillonite, are included. The structures of these two minerals contain sheets of SiO_4 tetrahedra which are joined at three apexes to produce $n(Si_2O_5)^{2-}$. Here again, the substitution of four protons for one silicon atom appears to be the rule (*3*).

Something different evidently occurs in tectosilicates, a well known example of which is analcime. The structure of analcime (*4*) is a three-dimensional framework of oxygen atoms in tetrahedral configuration; all four apexes are shared with other tetrahedra containing Si or Al ions to give the formula $Na(AlSi_2O_6)\cdot H_2O$. This framework, regardless of whether or not there is ordering among the Al and Si atoms, can be described as being constructed of $2n(SiO_2)^0$ and $n(AlO_2)^-$ units—remembering that their structural configuration is essentially tetrahedral in both cases.

Besides aluminum and silicon, an appreciable amount of phosphorus can occur as portions of this framework (*5*). However, the amounts of P, Al, and Si are quite inadequate to provide the framework of viséite. The deficiency of P, Al, and Si is compensated by protons; the proton to oxygen ratio is 3:2, that is, $n(H_2O_2)^-$ (*5*).

Recently, a more straightforward example of this $(H_3O_2)^-$ "anion" (*6*) has come to light as a result of crystallochemical investigation of kehoeite (*7*), a mineral described in 1893 but not previously classified. Briefly, the structural framework consists of essentially identical quantities of $(H_3O_2)^-$, $(AlO_2)^-$, and $(PO_2)^+$ units, rather than $(AlO_2)^-$ and $2(SiO_2)^0$, as in analcime. And while kehoeite and viséite both appear to be essentially isostructural with analcime, kehoeite contains no SiO_2, and its large cation is principally zinc, rather than calcium (viséite), sodium (analcime), or cesium (pollucite).

As is true for the so-called tetrahedral hydroxyls, the structural positions of the protons for $(H_3O_2)^-$ have not been determined by direct methods, such as neutron diffraction or nuclear magnetic resonance. Nevertheless, direct calculation of the number of oxygen atoms in the unit cell (*8*), in combination with chemical analysis and structural information obtained by x-ray diffraction, demonstrates analogies which cannot be explained except on the basis of protons substituting for P, Al, or Si ions (*9*).

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References and Notes

1. D. McConnell and J. Murdoch, *Mineral. Mag.* **33**, 59 (1962).
2. T. Thorvaldson, N. S. Grace, V. A. Vigfussen, *Can. J. Res.* **1**, 201 (1929); D. McConnel, *Am. Mineralogist* **27**, 452 (1942); E. P. Flint, H. F. McMurdie, L. S. Wells, *J. Res. Natl. Bur. Std.* **26**, 13 (1941).
3. D. McConnell, *Am. Mineralogist* **39**, 830 (1954); ———, *Clay Minerals Bull.* **1**, 178 (1951).
4. S. v. Náray-Szabó, *Z. Krist.* **99**, 277 (1938); *ibid.*, p. 291; W. H. Taylor, ibid. **74**, 1 (1930); *ibid.* **99**, 283 (1938).
5. D. McConnell, *Am. Mineralogist* **37**, 609 (1952).
6. Although $(H_3O_2)^-$ is loosely referred to as an "anion" or "unit," it has no independent existence as such. It is merely a link in a continuous framework $n(XO_2)^{x-}$. In the case of kehoeite the minimal unit becomes $[(Al_{16}(H_3)_{16}P_{16})O_{96}]^{16-}$, which is the framework of one unit cell with an edge of 13.7 Å. The 16 negative charges of this framework are neutralized by eight zinc and calcium ions (5.5 Zn + 2.5 Ca).
7. D. McConnell, *Am. Mineralogist*, in press.
8. ———, *ibid.* **39**, 929 (1954).
9. Supported by research grant D-1411 from the National Institute of Dental Research.

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