In the former $n/(n + 1)$ may be replaced without error by unity in the approximation we are interested in. Substituting the values so obtained for the sums in (8) gives

$$\frac{3 \epsilon - 1}{4 \pi \epsilon + 2} = \frac{N \mu^2}{3kT}.$$  

We see then that here, just as in the case of diatomic molecules, the permanent moment of the molecules and the part of the dielectric constant due to it are related by Debye's equation derived on the classical theory provided the temperature is sufficiently high.

As regards the behavior of the bands emitted by dipole-molecules of the kind considered in an electric field, there should be a linear Stark effect for all lines arising from transitions between states for which $n$ is different from zero, as may be seen directly from (7) and (3). The deflection of the molecules in an electric Stern-Gerlach experiment of the kind described in the previous paper\(^1\) can be easily predicted, too, by introducing the value of $P$ determined by equations (4), (3) and (5) into the formula for the deflection.


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**TROPISMS OF MAMMALS*  

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Conceptions of the mechanism of adjustor function in the central nervous system have chiefly been based upon results of "learning" tests, as in a maze, and upon the method of conditioned reflexes. These modes of experimentation are cumbersome, and do not give direct approach to the understanding of variability in conduct and the basis of moment-to-moment adjustment in behavior. On the other hand, interpretation in terms of reflexes has obvious limitations.

We desired to see if certain conceptions of the analysis of conduct, as derived from study of lower animals, might not after all be applicable in this connection, and to obtain if possible another route of approach; one which would permit the expression of behavior in quantitative terms and make possible the dynamical formulation of conduct in situations
determined by the conflict of alternative types of response. If an organism
be exposed to two sources of stimulation the resultant movements may
be controlled by the summation or balance of the respective excitations;
or, with other suitable experimental arrangements, the organism's move-
ment may be decided by one of the two excitations to the complete exclu-
sion of the effect of the other. Such a "decision" may be taken to repre-
sent an elementary act of central nervous adjustment, and, given rational
units in which to express the effects of the two sources of excitation when
acting singly, its nature may be investigated by measuring its quantitative
modification under controlled conditions. Thus with the negatively photo-
tropic larva of the beetle Tenebrio the arrangement can be made such that
the intensity of light may be measured which is just sufficient to suppress
the animal's positive stereotropism.

The development of such a method for investigation of central nervous
functions in higher animals, mammals for example, requires the identifi-
cation in them of mathematically predictable modes of behavior. Al-
though it has been loosely suggested that "ideas" and "memory images"
may serve as sources of tropistic guidance, it is fair to assert that little
more than figurative progress has been made toward the study of tropistic
conduct in mammals. Our own experiments suggest that absence of
information on this topic is due, partly, to the fact that the necessary and
very simple experiments seem not to have been made hitherto.

It proves possible to recognize in the behavior of young mammals very
definite modes of tropistic behavior. We have employed nestling rats
and mice. Careful attention must be given to the age and to the genetic
uniformity of the experimental material. In fact, we believe that within
certain limits the resulting methods may be used for the exact comparison
of genetically diverse stocks.

It turns out that in several respects it becomes feasible, on the basis of
these experiments, to refine and to extend the general account of photo-
tropism and of geotropism as modes of behavior. We confess a certain
satisfaction in being able to reverse to this extent the traditional argument
that behavior-analysis is to be attained first with "lower" animals.

The vector character of stereotropism in young rats and mice is readily
demonstrated. When creeping in contact with the outer surface of a
box or a solid block the rat turns the corner and continues to follow the
vertical surface. If two blocks make contact, one with either side of the
rat, there is no swerving to either side on emergence from the zone of
contacts. The result is, therefore, identical with that in similar exper-
iments upon arthropods.

Phototropism and geotropism may be examined in a manner permitting
exact statement of relations between the intensity of the acting force and
the amount of the response; this is not possible with stereotropism. Young
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Rats and mice, before the eyelids have parted, move away from a source of horizontal light; after the eyes are opened, the situation is quite different, due to image formation. The negative orientation is precise. That it is a truly tropistic orientation is proved in two ways. If one eye be removed, illumination from above results in the continuous execution of circus movements toward the blind side. The postures of the limbs, showing heightened extensor tone on the non-blind side, recalls in all essentials the limb positions of an insect such as Ranatra. On the other hand, if exposed to two diametrically opposed sources of light the rat moves in a path at an angle to the line joining the two sources. This angle may be calculated from the measured intensities of the two lights, by mean of the basic assumption of the phototropism doctrine. This assumption is that the animal ceases to orient when the illumination on its two sides is equal; under the conditions given, orientation is possible for a negatively heliotropic animal when its photoreceptive surfaces are non-parallel. The basic assumption leads to the equation

\[ \tan \theta = \frac{(I_1 + I_2)}{(I_1 - I_2)} \cot \frac{H}{2}, \]

where \( I_1 \) and \( I_2 \) are the respective photic intensities, \( \theta \) is the observed angle of inclination to the line connecting the two lights, and \( H \) is the effective angle between the photosensitive surfaces. In the rat, increased total illumination \((I_1 + I_2)\) causes increased photokinetic "random" movement of the head; hence it is found that \( H \) decreases very nearly in proportion to \( \log (I_1 \times I_2) \). The formula given can be tested, with very satisfactory agreement, for cases in other animals where \( H \) does not vary with the intensity of illumination.

\[ \text{FIGURE 1} \]

The amount of upward orientation of young rats, measured by the angle \( \theta \) of the path with the horizontal, when creeping upon a wire grid inclined at angle \( \alpha \) with the ground. The average orientation is directly proportional to the logarithm of the effective gravitational attraction. (One point departs from the course of the rest by as much as twice its P.E.)
The geotropism of the young rat is equally precise. Allowed to creep upon a fine-meshed wire grid, orientation is always upward. The amount of orientation depends upon the angle of inclination of the creeping-surface. The path of progression is a straight line, more and more nearly at 90° orientation as the inclination of the creeping-plane is increased. The minimum inclination giving orientation is 10°+; at 70°+ inclination the angle of orientation on the creeping-plane is 90°. Between these limits the angle of orientation (θ) is directly proportional to the log (sin α), where α is the angle of inclination (Fig. 1). This proof of orientation as determined by the active component of gravity is checked by the fact that the coefficient of variation of the measurements at a given inclination decreases directly as log (sin α). Thus not only the amount, but also the precision of orientation, is determined by the effective gravitational attraction.

The interpretation of this result is, simply, that a differential pull of the animal's weight upon the (leg?) muscles is responded to if it exceeds a certain threshold. This amounts to assuming that the difference between the pull of the animal's weight upon the legs of the opposite sides during creeping calls forth respectively pulling and pushing movements of the "upper" and the "lower" limbs, so that the rat turns until the distribution of the pull of the weight upon the opposite limbs is such that the difference between the two effects is a constant fraction of the total. This is a fair assumption because the amount of orientation is proportional to log (sin α); it leads to the expectation that the ratio \( \frac{\cos \theta}{\sin \alpha} \), where θ is the angle of upward orientation, should be very nearly constant. Figure 2 shows that this expectation is thoroughly satisfied.

The further proof of this interpretation is given by the fact that the amplitude of orientation (θ) is increased by attaching weights to the animal's tail, and in proportion to the logarithm of the added mass.

Detailed consideration of these points is given in another place. We are now concerned merely to record the nature of the findings as regards these tropisms of young rats. They are as definite and predictable as in the most favorable instances among invertebrates, and they may be brought into opposition with one another in a similar way. Thus it is a fairly simple
matter to determine the photic intensity required to drive a rat away from stereotropically maintained contact with a glass plate, or to measure precisely the resolution of conflicts between stereotropism and geotropism, or between phototropism and geotropism. We consider it possible, therefore, that these modes of response may be employed for fairly direct and precise analysis of certain elementary functions of the central nervous system even of mammals.

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