sions within a nation was too small to permit adequate statistical test), the aggregated 1764 political subdivisions did yield a regression slope between log-size and log-density of −0.66, a result which very clearly conforms to the theoretical expectation developed here. It would thus seem that the general assumption, that social structures evolve in such a way as to minimize the societal time which must be expended for their operation, is sufficient to account for the observed empirical relation between size and density.

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2. W. Duncan, *Physical Similarity and Dimensional Analysis* (Arnold, London, 1953).
3. The value of $g$ for all $n$-sided regular polygons, including the circle as a limiting case, can be determined as follows: Let the centroid of the $n$-gon be the origin of the polar axis bisecting one of its central angles, forming the angle $\phi$ ($= \pi/n$) with an adjacent radius $R$ of its circumcircle. The axis, radius, and $n$-gon edge will form a triangle with area equal to $\frac{1}{2}R^2\cos\phi\sin\phi$. The average distance to the center of the $n$-gon will then be given by

$$E(r) = \frac{2}{R^2\cos\phi\sin\phi} \int_0^{\phi} \int_0^{\psi} r^2 \, dr \, d\Theta$$

where $E(r)$ is the expected value of the distance between the origin and a random point ($r$, $\Theta$) within the triangle, and $\psi = R\cos\phi/\cos\Theta$, the upper limit of $r$ given $\Theta$. Evaluating the integral gives

$$E(r) = \frac{R}{3}\left(1 + \frac{\mathrm{In}(\sec\phi + \tan\phi)}{\sec\phi\tan\phi}\right)$$

which, divided by the square root of the area of the $n$-gon, gives the value of $g$. In practice, the only $n$-gons which attract the attention of regional scientists are the triangle, square, hexagon, and circle; the first three permit tight packing in lattice structures and the fourth is useful in ideal constructions around a central point. The value of $g$ is 0.4037 for the triangle, 0.3826 for the square, 0.3772 for the hexagon, and 0.3761 for the circle.
4. E. Stephan, *Am. Sociol. Rev.* **37**, 365 (1972).
5. I thank Albert J. Froderberg of Western Washington State College for his help and advice on this report.

13 January 1977

# Head Capsule Transmission of Long-Wavelength Light in the Curculionidae

Abstract. *The head capsule of many weevils contains a region that transmits only far-red and near-infrared light. In the alfalfa weevil,* Hypera postica, *this extraocular cutoff filter evidently works in conjunction with the compound eyes, enabling the insect to use visual cues in locating or recognizing its host plant.*

Most members of the insect family Curculionidae, commonly known as weevils, possess a unique morphological characteristic which seems to be part of a newly discovered receptor system sensitive to long-wavelength light. In these insects all or part of the head capsule acts as an optical filter, which transmits only far-red and near-infrared radiation (650 to 900 nm) to the underlying tissues. Receptors sensitive to this portion of the electromagnetic spectrum are virtually unknown among arthropods (*1*).

Fig. 1. Transmission of light through the head capsule of an alfalfa weevil as recorded on infrared-sensitive film.

The head capsule does not appear capable of transmitting any light when an intact weevil is examined by reflected light, and it is probably for this reason that the structure has, until now, been undetected. The cephalic skeleton is heavily sclerotized, usually dark in color, and covered by a stubble of acuminate scales. But if the head is removed and illuminated from behind with a tiny spot of white light, its translucent region will assume a deep red hue (Fig. 1).

The head capsule filter was first discovered in the alfalfa weevil, *Hypera postica* (Gyllenhal), where it forms a large crescent encompassing the vertex and genae of the head. It extends forward to the level of the ocular sutures at the top of both compound eyes, and narrows to a point on each side of the head near the subgenae. The rest of the head, including the frons and the snout, is nearly opaque. All other members of the genus *Hypera* have similar structures, and a survey of 39 other species representing 28 subfamilies revealed 25 species with substantial red transmission and an additional 12 species with only moderate absorption. In a few cases, notably *Anthonomus grandis* Boheman (cotton-boll weevil), the entire head, including the beak, the frons, and the subgenae, is translucent to red light. A few other insects may perceive light which passes through the head (*2*), but in every case the cephalic exoskeleton is lightly pigmented and transmits a wide range of visible light.

In the alfalfa weevil, the distinctive pigmentation (*3*) absorbs about 90 percent of incident light at 590 nm, but only about 10 percent at 640 nm. Most other species examined show a similar cutoff range; however, the Curculioninae and the Anthominae transmit a little more yellow (90 percent absorption at 530 nm and 10 percent at 600 nm), and the white pine weevil (*Pissodes strobi* Peck) is translucent over a wide range of visible light (*4*).

In some of these species there is a remarkable correlation between wavelengths transmitted through the head capsule and the phototactic action spectrum. Under controlled conditions, the starved alfalfa weevils and cotton-boll weevils are attracted to green light (500 to 550 nm) and to wavelengths in the far-red and near-infrared region. However, when the vertex of each weevil's head capsule is covered with an opaque lacquer, the response to red light is almost completely eliminated (*5*). In fact, most weevils which have a red head capsule filter are attracted to some extent by wavelengths in the range 700 to 900 nm. Those which lack the filter, such as the black vine weevil, *Brachyrhinus sulcatus* (Fab.), do not respond to wavelengths greater than 630 nm. Apparently light passing through the red filter influences positive phototaxis by changing the sensitivity of the compound eyes or by stimulating an extraocular receptor.

Since the cephalic filter is so wide-

Table 1. Response of alfalfa weevils in the behavioral bioassay. The decrease in the visual response to alfalfa in the treated groups was evaluated by the $\chi^2$ test with 1 degree of freedom.

| Treatment | Number attracted | | $\chi^2$ |
|---|---|---|---|
| | Alfalfa | Control | |
| None | 438 | 162 | |
| Clear shellac | 215 | 71 | 0.49* |
| Lampblack and shellac | 161 | 108 | 14.90† |

*Not significant. †Significant at the 99 percent level.

spread among the Curculionidae, it seems unlikely that it would serve the same function in all species. Its presence or absence does not appear to be correlated with any obvious biological or ecological attribute, and since "no particularly logical arrangement of the Curculionid subfamilies has been proposed" (*6*), it cannot be identified with any taxonomic categories. In general, however, its adaptive value is probably related to visual (photokinetic) orientation, to regulation of daily activity patterns, to entrainment of circadian rhythms, to measurement of light intensity, or to analysis of light quality.

The exact function of the cephalic filter has been explored most extensively in the alfalfa weevil. Since this insect's action spectrum had already been found to coincide with the reflectance spectrum of alfalfa, *Medicago sativa* (*7*), the possibility of a link between the red head capsule filter and host plant recognition was examined in more detail.

A behavioral bioassay originally developed to evaluate the relative importance of visual and olfactory cues in remote sensing of host plants (*8*) was modified to determine whether or not adult weevils need the red filter to locate living alfalfa. Groups of starved weevils, placed in the bioassay chamber, were offered an option of moving toward either a greenhouse flat of live alfalfa or a similar flat of dead alfalfa sprayed with a green paint which lacked the strong infrared reflectance of living alfalfa. A control group of untreated weevils were able to discriminate between the two choices: 73 percent moved toward the living alfalfa (Table 1). However, weevils in a second group, whose red filters were occluded (*9*) by an opaque mixture of lampblack and white (clear) shellac, were more random in their choice of direction and showed a statistically significant decrease in the visual response to alfalfa (Table 1).

This change in the response cannot be an artifact of the shellac mixture because a third group of weevils, which received a coat of white (clear) shellac over the same part of their heads, were able to locate the living alfalfa as well as the unpainted weevils (Table 1). A final group of beetles, whose compound eyes were covered by the opaque lacquer, became much more sedentary and seemed reluctant to move. When placed in the bioassay chamber they generally remained stationary and showed no definitive response to either the alfalfa or the control flat.

The normal pattern of host plant recognition, therefore, seems to require functional compound eyes as well as transmission of light through the red head capsule filter. These sensory inputs are presumably integrated by the brain or nervous system as the alfalfa weevil evaluates the suitability of potential food sources.

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3. This is not a structural color because it is not affected by changes in the refractive index of the surrounding medium.
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5. The action spectrum shows only a single peak in the yellow-green and very little response in the infrared [J. R. Meyer, *Ann. Entomol. Soc. Am.* **69**, 21 (1976)].
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9. A brush small enough to apply the opaque mixture was made from three nylon bristles (1 cm long) glued to the end of an applicator stick.
10. I thank E. M. Raffensperger and K. Adler for assistance in various phases of this research.
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17 September 1976; revised 9 November 1976

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# Anomalous Temperature Dependence for a Partial Vapor Pressure

Abstract. *In a limited temperature range the partial pressure of gallium subsulfide ($Ga_2S$) above gallium sesquisulfide ($Ga_2S_3$) increases when the temperature is decreased. The anomaly in the partial pressure is caused by changes with temperature in the equilibrium compositions of two solid phases that coexist at 1228° ± 3°K. At this temperature the solids differ in sulfur content by 0.4 atomic percent sulfur.*

In the course of a mass spectrometric study of the vaporization of gallium sesquisulfide ($Ga_2S_3$), we were surprised to find that near 1220°K decreases in temperature caused increases in the partial pressure of one of the two principal vapor molecules, gallium subsulfide ($Ga_2S$), (Fig. 1). In other temperature ranges, decreases in temperature caused normal exponential decreases in the partial pressures. The anomaly near 1220°K was reproducible and large; the partial pressure increased about 50 percent when the temperature was lowered 25°K instead of decreasing 50 percent as was expected from the variations of partial pressure with temperature in other temperature ranges.

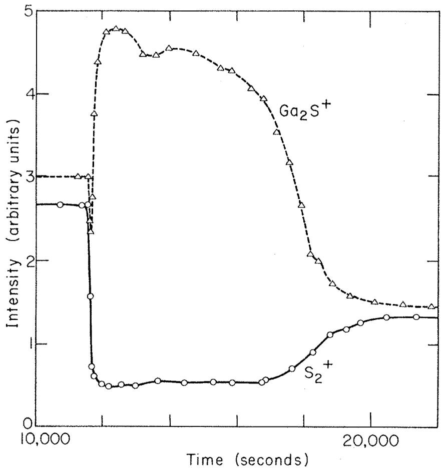

Fig. 1. Variation of the partial pressures of $Ga_2S$ (proportional to $Ga_2S^+$, dashed line) and $S_2$ (proportional to $S_2^+$, solid line) with time. At about 11,700 seconds the temperature was lowered from 1230° to 1203°K.

After about an hour under our experimental conditions, the anomalously high partial pressure decreased over a similar time span to values that were consistent with interpolations of pressures from higher and lower temperature ranges. The anomaly could not be dismissed as arising from purely kinetic factors; it must have a thermodynamic basis because partial pressures can only change, even during reactions, in directions that increase the total thermodynamic stability of the system.

The key to explaining the partial pressure anomaly lies in recognizing that two-component solids such as $Ga_2S_3$ have variable compositions (*1*). The vaporization of $Ga_2S_3$ occurs by dissociation,

$$Ga_{(2+2\epsilon)}S_{(3-\epsilon)}\ (s) = (1+\epsilon)\ Ga_2S\ (g) + (1-\epsilon)\ S_2\ (g) \quad (1)$$

where $\epsilon$ takes small positive or negative values that depend upon conditions of preparation and subsequent treatment of the sample. When heated to some fixed temperature in a crucible from which the vapor can escape through a small orifice into a vacuum, the solid loses either $Ga_2S$ or $S_2$ preferentially. The preferential loss shifts the composition of the remaining solid in a direction that reduces the partial pressure of the more volatile vapor molecule and increases the partial pressure of