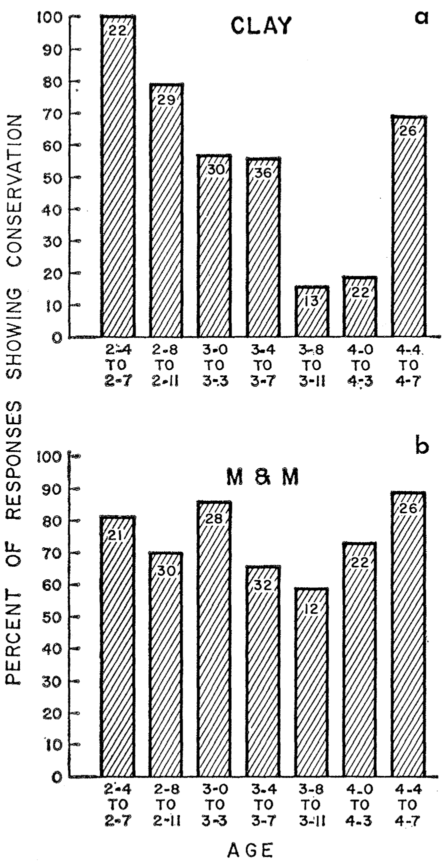

Fig. 2. The proportion by age of responses choosing the row with more members in the situation shown in Fig. 1b. Numbers inside bars indicate total number of subjects of that age.

for eating of M & M's, $P < .01$ by chi-square).

Occasionally children responded one way on verbal judgments of which clay row had "more," yet in the case of M & M's they took the other row to eat. This might show some uncertainty in the child's capacity to judge quantity. To strengthen our basic finding that children at 2-6 and 4-6 show more conservation than children of 4-2, we separated those children who showed consistent responses on both M & M's and clay pellets from children with inconsistent responses. Among the children who gave consistent verbal and nonverbal responses, there were more consistent nonconservation responses at age 4-2 than at 2-6 ($P < .02$ by chi-square) or at 4-6 ($P < .03$ by chi-square). Furthermore, if a child gave inconsistent responses, it is more likely that the single conserving response was to the M & M's than to the clay pellets ($P < .01$ by chi-square in favor of M & M conservation) (*4*).

Our results indicate that the inability to conserve quantity is a temporary phase in the developing child. The child does not gradually acquire quantity conservation during his 4th year; rather, he reacquires it. The fact that the very young child successfully solves the conservation problem shows that he does have the capacities which depend on the logical structure of the cognitive operations. Eventually, he develops an *explicit* understanding of these operations: at age 5 he solves the same problem by counting the pellets in each row. We think that the temporary inability to solve the conservation problem reflects a period of overdependence on perceptual strategies. These strategies develop on the basis of experience with correlations of apparent shapes and actual quantity. Surely, it is a general rule that longer arrays usually have "more" components, and a reasonable perceptual expectancy would reflect this. Just after the young child incorporates this expectancy into his perceptual scheme, he is misled by the apparent length of a row into thinking that it has more components. The fact that children at all ages tend to take the M & M row with "more" indicates that this perceptual strategy can be overcome, given sufficient motivation to do so. Eventually, the child develops a more sophisticated integration of the logical operation with his perceptual strategies which allow him to count the individual members of an array. He then has the capacity to ignore his perceptual expectancies in those critical instances in which they are not confirmed. The intermediate age "nonconserving" child cannot disengage his perceptual strategies in this way. Thus, nonconservation behavior is a temporary exception to human cognition, not a basic characteristic of man's native endowment.

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1. J. Piaget, *The Child's Conception of Number* (Humanities, New York, 1952); *The Origins of Intelligence in Children* (International Univs. Press, New York, 1952).
2. Subjects were children attending local play groups and private nursery schools in the Greater Boston area as well as some participating in the Harvard Infant Study. Older and younger children were drawn from the same schools and groups whenever possible and were often siblings.
3. Occasionally a child would refuse to respond, or would choose the clay pellets or M & M candies one at a time instead of the whole row. These responses were ignored.
4. We also ascertained that the conservation responses in the young children are not due to a tendency to take and to name short rows. Sixteen children, age 2-4 to 2-9, were presented with an array in which the row with six clay pellets or M & M's is in fact longer (Fig. 1c). In this condition there were 22 conservation responses (picking or naming the long row) and ten nonconservation responses. Out of eight children who responded consistently on M & M's and clay judgments, seven showed consistent conservation responses. This indicates that the young children are attending to the actual quantity in a row. Preliminary analysis indicates that for children below 3 years of age, experimental order of M & M's and clay did not affect the tendency to exhibit conserving responses.
5. Research supported by NIH grant 5-TO1-HD00111-02 to Professor Halle at M.I.T. and by NASA grant NaG 496 and by U.S. Department of Defense, Advanced Research Projects Studies and the Harvard Society of Fellows. We thank J. Epstein, who ran all the experiments in this study. We also thank Professor H.-L. Teuber, H. Koopmans, and Dr. M. Garrett for comments on this manuscript; Dr. T. G. R. Bower for the use of his research space, and D. J. Kagan for providing access to his well-studied group of children. We are also grateful to all those schools that kindly allowed us to test their children.

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Optical Differentiation of Amoebic Ectoplasm and Endoplasmic Flow

Baker and Johnston (*1*) offer photographic evidence that they have detected "optical activity" in living amoebas. The term "optical activity," which has traditionally meant optical rotation, is redefined by the authors to include "any polarized light phenomenon." However, their "dynamic polarized light detection system" is, in fact, incapable of differentiating among several phenomena detectable with polarized light (phase shifts due to birefringence, optical rotation, linear or circular dichroism, refraction absorption, surface depolarization, and light scattering). The photograph shown in Fig. 2 could have resulted from a mixture of any of these "optical activities."

In optical analysis one should identify the type of light-matter interaction observed in specimens and then proceed to quantify this interaction. Usually identification and quantification are accomplished simultaneously by null compensation for phase shifts or rotation of the plane of polarization (*2*). Another electronic detection technique using phase modulation referred to by the authors (*3*) does, in fact, use the null method through automatic compensation of rotation, phase shifts due to birefringence, and dichroism. The null compensation method, in any event, separates the phenomena detectable only in polarized light from absorption refraction and light scattering, properties that are not only detectable in polarized light but are frequently so strong that they mask birefringence and other polarized light effects.

The method of Baker and Johnston not only lacks selectivity but is apparently incapable of quantifying any single optical phenomenon. Nevertheless, the authors claim their ". . . system capable of detecting low-level optical activity in living specimens which has heretofore escaped detection. . . ." To be convincing, such a claim should be accompanied by data indicating the peak-to-peak or root mean square noise level for the phenomenon being registered. At present the indications are that Baker and Johnston have only transferred an ordinary light microscopic image to a storage cathode-ray tube. Any serious attempt to interpret such an image in molecular terms should be classified as "inference microscopy."

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3. R. D. Allen, J. W. Brault, R. M. Zeh, in *Advances in Optical and Electron Microscopy*, R. Barer and V. E. Cosslett, Eds. (Academic Press, London, 1966), vol. 1, p. 77; R. D. Allen, J. Brault, R. D. Moore, *J. Cell Biol.* **18**, 112 (1963).

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The most important point I wish to make regarding Baker and Johnston's report (*1*) is that their Fig. 2, which is presented as showing the "differential optical activity of the flowing and nonflowing cytoplasm" in a pseudopod of *Chaos chaos*, is, in fact, merely a doubled image of the pseudopod. The two images have been laterally displaced by about half the maximum width of the pseudopod. The area where the two images overlap appears brighter than its surroundings and is the region of the picture that Baker and Johnston identify as the flow channel. When the individual images are considered, no clear-cut demarcation of a flow channel is visible. The cause of the doubled image cannot be identified from the information in the report, but it could be caused by spurious reflections in the optical system or by an electronic echo in the storage oscilloscope.

Second, the experimental system they describe in their text and Fig. 1 seems to have both electrooptical light modulators (EOLM) driven in phase from the same source. If their figure is correct in this respect and shows all of the significant parts of the system, except the microscope optics, then the two modulators are functionally equivalent to a single unit having properties equal to the sum of the properties of the units shown. In this case, if the band pass filter is in fact a narrow band filter tuned to pass only signals at the EOLM driving frequency, the system will be able to detect birefringence when the birefringent axes of the specimen are not aligned with the plane of polarization of the incoming beam or the analyzer; but it will not respond linearly and will not determine the sign or the azimuth angle of the birefringence detected. Other polarized light phenomena may be detected under favorable circumstances but cannot be distinguished from birefringence without additional components in the system. Successful systems with electrooptical light modulators for automatic measurement of birefringence and other polarized light phenomena have been described by Takasaki (*2*) and by Allen *et al.* (*3*).

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In our paper, we pointed out in several instances that as a result of our method of data collection, the storage cathode-ray tube, our system was, "in fact, incapable of differentiating among several phenomena detectable with polarized light. . . ." We also stated that our work will be directed toward substantiating the type of optical activity and quantifying it. Again we define optical activity as any polarized light phenomenon, information which Allen said could have resulted from a mixture of any of the possible types of "optical activities" detectable with polarized light.

Although our system does not now permit substantiation and quantification of the "optical activities," it is capable of detecting the presence of "a mixture of any of the possible types of optical activity" across amoebic pseudopodia, which as far as we know has heretofore escaped detection.

The conversion of our data from analog to digital form will allow digital filtering techniques to be used in conjunction with a Jones calculus analysis of our system elements. This type of analysis will permit the determination of the specimen matrix necessary to give the recorded system differentiation in a point fashion across the specimen. The specimen matrix specifies the type of optical activity present within the specimen. This method of handling our dynamic scan data will allow substantiation and quantification not possible with the storage cathode-ray tube.

In reply to Ellis' comment regarding the electrooptical light modulator (EOLM) voltage sources, it should be pointed out that the two EOLM's are driven by voltages that are 180 degrees out of phase. Figure 1 of the report was intended to convey this point.

A doubled image of the pseudopod, as described by Ellis, could occur only as a result of backlash between the servo-driven microscope stage and the position-indicating potentiometer. However, a doubled image resulting from servo backlash should result in the brighter portions of alternating scan lines being displaced from each other. This phenomenon is not evident from our scan photographs. At the time of the experiment the backlash was examined and found to be negligible. A method of verifying the effect of backlash, if any, is to orient the pseudopod parallel to the suspected axis of the backlash. Such an experiment is scheduled.

Optical information of these reported observations is obscured by noise requiring vast data to be analyzed. Therefore, computer determinations of the types of optical phenomena by Jones matrices will make it possible to treat with ease the behavior of complex polarizer-retarder combinations of this dynamic system.

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