vations, it became evident that the main reason for the difference was the lack of potassium ions in the synthetically formed system. As soon as these, or other ions comparable to potassium in size and charge, were introduced into the film by a simple chemical process, a product resulted that was comparable in every respect to the finest mica available. It was this material that helped our nation during World War II to overcome the serious shortage of natural mica, which had previously been imported from India (*17*).

I have selected these examples because a survey of the textbooks now used to educate our young people reveals a serious lack of this type of information. The inclusion of such material explains to the reader in terms he can understand, even if he does not intend to become a scientist, not only what science stands for and how new discoveries are made, but also on what logical reasoning the latter are based. This would give the educator a unique opportunity for impressing on his students that the introduction of the history of science into general education need not be limited to prospective scientists. Its main purpose would be to offer the younger generation factual evidence of the importance of clear and logical thinking in the evolution of mankind, and to impress on them that this deserves more respect than acquiring a command of mathematical equations, chemical formulas, and the like. It is of far greater significance in a general education than a smattering of specific sciences without the basis really to understand them. In a world such as ours it is our duty to change the educational system so that every citizen is taught science in a manner he can understand, and without unnecessary and frequently outdated dogmas. At the Regional Conference on Teacher Education and Professional Standards held at Harvard University on December 15, 1950, Finis E. Engleman, Connecticut Commissioner of Education, said that "in this time of international strain, children are likely to be our first casualties through neglect of education." The true purpose of education should be not to make living textbooks, so to speak, but to do what Socrates proclaimed—namely, to achieve individual independence and spiritual self-reliance. The true purpose of science always has been, and should remain, to serve life and not to dominate it. What we must do is to give our young people such a grounding in the philosophical principles on which the evolution of science is based as will prove to them that textbook knowledge alone is insufficient. To accomplish this we must change our curricula so that more emphasis is placed on the disciplines that teach proficiency in doing and thinking—for example, by offering courses on the historical development of science and technology and what has been accomplished thereby in other countries, as well as in our own.

In addition, we must also realize that such a change will be difficult, if at all possible, as long as those responsible for the selection of high-school headmasters and college and university presidents are more interested in satisfying political, religious, economic, and local interests than in obtaining for such positions individuals who can offer proof that they already have devoted, and are prepared to continue to devote, their lives primarily to science in education.

References

1. Murphy, W. J. *Ind. Eng. Chem.*, **38**, 665 (1946).
2. Brown, C. L. *Chemist*, **27**, 161 (1950).
3. Frey, A. M. *Ibid.*, 165.
4. Cunningham, J. D. *Paper Trade J.*, **131**, (9), 26 (1950).
5. Plato. *The Dialogues of Plato.* Trans. by B. Jowett, Oxford Univ. Press (1892).
6. McGrath, E. J. *Sci. Monthly*, **71**, 118 (1950).
7. Bell, B. I. *Crisis in Education.* New York: McGraw-Hill (1949); *Life*, **89** (Oct. 16, 1950).
8. Ostwald, Wi. *Die Forderung des Tages.* Leipzig: Akad. Verlagsges (1911).
9. Planck, R. *Chem. Eng. News*, **27**, 1784 (1949).
10. Conant, J. B. *Education in a Divided World.* Cambridge: Harvard Univ. Press (1948).
11. ———. *On Understanding Science.* New Haven: Yale Univ. Press (1947).
12. Cohen, I. B. Lecture presented at 258th mtg., New England Assoc. Chem. Teachers (Dec. 2, 1950).
13. Hauser, E. A. *J. Chem. Education*, **28**, 208 (1951).
14. Faraday, M. *Trans. Roy. Soc.*, **A147**, 145 (1857).
15. Siedentopf, H., and Zsigmondy, R. *Ann. Physik*, **10**, 1 (1903).
16. Hauser, E. A. *Colloidal Phenomena.* New York: McGraw-Hill (1939).
17. ———. *Chem. Rev.*, **37**, 287 (1945).

Technical Papers

Studies on Pollination of *Hevea Brasiliensis* in Puerto Rico[1]

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Although many studies of pollination in the Para rubber tree, *Hevea Brasiliensis* (Willd. ex Adr. Juss.) Muell. Arg., have been made, the actual method of pollination in nature has remained a puzzle. The fact that *Hevea* is monoecious, with the anthers and stigmas borne on the same inflorescence but in separate flowers, makes it necessary that a transfer of pollen occur. Moreover, the indication that at least certain clones are highly self-sterile makes it necessary that pollen be transferred not only from male to female flowers, but also from one tree to another, for sexual reproduction to occur.

Evidence has pointed strongly to insect pollination in Hevea. The flowers are colored, have a character-

[1] Cooperative investigation with the Division of Rubber Plant Investigations, BPISAE, Beltsville, Md.

[2] Administered by the Office of Experiment Stations, Agricultural Research Administration, USDA.

istic odor, and the reproductive portions are well enclosed within the corolla. Inflorescences containing numerous male and female flowers, when enclosed in insectproof bags, fail to set fruits (*1, 2*), even on trees known to be partially self-fertile. The pollen grains themselves are heavy and sticky and are not produced so abundantly as among the common wind-pollinated species. Vaseline-coated slides have failed to collect pollen when placed among Hevea flowers (*2*).

In no instance, however, has an insect been shown to be the pollinating agent. In Indonesia and Malaya various small flies and bees, bugs, ants, weevils, and caterpillars (*1, 3*) have been observed about Hevea flowers. Morris captured and examined 3 or 4 sorts of bees, which he watched enter male flowers for pollen. The baskets on the legs of these insects were filled with pollen which was identified under the microscope as that of Hevea. Nevertheless, not one of these insects was seen to enter a female flower. Seibert (*4*), working in South and Central America, reports finding many ants on Hevea flowers and considers that these may be factors in self-pollination, but not in cross-pollination. He suggests species of *Melipona, Trigona,* and *Augochlora* as possible night-flying pollinators. Muzik (*2*), working in Liberia, reports that during months spent in hand-pollinating rubber trees practically no insects were ever seen. He was not able to determine how natural pollination is accomplished.

Last spring (1950), during the examination of the stigmas of a large number of female flowers under a dissecting microscope, to determine whether the low fertility in Hevea (frequently 5%, or less) was possibly due to inadequate pollination, a discovery was made that throws new light on the problem of insect pollination in this species. A majority of open flowers were found to have small brown hairs or bristles caught on the sticky stigmatic surfaces. These hairs were so small they could be seen only under a dissecting binocular. They generally were found in patches, and then usually on the sides of the stigmas—as if brushed off on the sticky surfaces by some small insect which crawled in between the stigma and the narrow corolla tube. These hairs were found on a large portion of Hevea flowers; in one series of counts, hairs were found on 101 of 128 stigmas examined at random.

There also appeared to be a positive correlation between the presence of hairs on the stigmas and the presence of pollen grains. In the same group of 128 stigmas, pollen grains were found to be present on 98. On 88 of these 98 stigmas with pollen, hairs also were found. Thirteen of the 30 stigmas without pollen had hairs, and 17 had none. Further evidence of a relation between the presence of hairs and pollination was afforded by a study of another group of flowers, selected as having been open only a few hours. In these flowers (where a possible relation between the position of hairs and pollen grains on the stigmas was not complicated by multiple insect visits), pollen grains and hairs were found to be located in the same general area on the stigma in 33 of 38 flowers. This would suggest that pollination of *Hevea*, in a majority of cases in Puerto Rico, is associated with the visits of insects which leave telltale hairs on the sticky stigmas on entering and leaving the flowers.

No insects were observed to enter the female flowers. In an attempt to capture the unidentified insect, $3'' \times 5''$ cards were spread thinly on one side with an adhesive compound[3] and wrapped in loose cylinders around the branches, just below the inflorescences. During 24 hr, these cards captured scores of insects, mostly thrips, *Frankliniella cephalica* (Crawf.);[4] numerous small flies, among them *Eugarax insularis* Mall, *Oscinella forbesi* Curr.; various unidentified species of *Chrysotus, Thrypticus, Hybos, Megaselia, Pholeomyia, Drapetis,* and *Gaurax*; and several heleid midges of the genus *Dasyhelea.* These midges were found to have body bristles and antennal hairs very similar to those observed on the stigmas of pollinated flowers.

To limit the captured insects more precisely to those that entered, or at least rested on, the flowers a quantity of the adhesive compound was warmed and touched lightly to the recurved petal tips of a group of young female flowers. After 24 hr, 111 treated flowers were removed from the trees and brought to the laboratory for examination. These were found to have 26 thrips; 15 heleid midges of the genera *Dasyhelea, Atrichopogon,* and *Forcipomyia*; 9 small flies, including *Palaeosepsis furcata* (Mel. & Spuler) and *Platophrymia nigra* Will., and others similar to those caught on cards; and 2 or 3 small wasps of the genera *Pseudeucoila* and *Goniozus.* When stigmas from fresh flowers were touched to the wings and backs of these insects, only the midges were found to shed hairs freely. The hairs from the midges, when mounted and studied under the compound microscope, appeared to be identical with those previously recovered from the stigmas and similarly mounted.

It would thus appear that the insects responsible for shedding the hairs on Hevea stigmas are midges of the family Heleidae. Subsequently, some 22 living and dead specimens (6 males and 16 females) were found stuck to the stigmas of untreated flowers. Apparently the stigmatic surfaces are sufficiently sticky that these small insects not only lose bristles when entering and leaving the flowers but are themselves sometimes caught. This is especially true when the wings happen to come in contact with the stigma. Among the midges caught in Hevea flowers, many were found to carry pollen grains on their bodies. As many as 12 grains were counted on a single male on the bristles of the thorax, head, and antennae. These grains are held loosely among the bristles, where they could easily be deposited on the sticky stigmas by chance contact.

It was noted above that another small insect, thrips,

[3] Tree Tanglefoot, manufactured by the Tanglefoot Co., Grand Rapids, Mich.

[4] All insect identifications were made by members of the Division of Insect Identification, Bureau of Entomology and Plant Quarantine, USDA, Washington, D. C.

was also abundant on Hevea flowers. Thrips were found to be so numerous during the course of these investigations that probably very few flowers escaped their visits. There are indications, however, that thrips are not as important pollinators of Hevea as are the midges. It is clear that thrips are not responsible for leaving the hairs on the stigmas. Although placed on the stigmas and roughly rubbed back and forth with a dissecting needle, several live thrips failed to leave any hairs on the sticky surfaces. Thrips also were observed to carry very little pollen on their bodies, and this was usually stuck in masses of latex with which the insect had come in contact. Pollen so held is extremely difficult to dislodge. Finally, this species of thrips appears to move largely by crawling and hopping and to have little or no capacity for sustained flight. This suggests that any pollination accomplished by thrips would likely be from pollen of the same inflorescence (self-pollination). In fact, the stigmas observed to have pollen grains but not hairs may be in part the result of thrips' activity. This viewpoint is strengthened by the observation that stigmas with pollen grains only are less adequately pollinated than those with both hairs and pollen (22 stigmas with pollen only had an average of 4 grains/stigma, as compared with more than 16 grains/stigma for 38 having both hairs and pollen).[5]

The various small flies caught in the adhesive on the cards and petals, though numerous, are not believed to be of importance in pollination. They were never seen to be carrying pollen on their bodies, and none was ever observed to enter a female flower. Any pollination accomplished by them would seem to be accidental rather than systematic.

Pollination in cacao (*Theobroma cacao*), prior to the recent work in Trinidad, had been about as much of a puzzle as that of Hevea, and it is interesting that eventually midges of the same family as those described in the present report were found to be the effective pollinating agents. Posnette (*5*) showed beyond any question that heleid midges (identified as *Forcipomyia quasi-ingrami* Macfie, *Lasiohelea nana* Macfie, and *L. stylifer* Lutz [*6*]) are the chief pollinators of cacao in Trinidad. Midges of this group are thus known to carry pollen and to be effective pollinating agents in another plant species.

The habits and life histories of the heleid midges are not well known. Some species have aquatic larvae, and others are thought to breed in damp soil or decaying organic matter. The breeding places of the midges found in the Hevea plantings at Mayaguez are not known; nor is it known whether these insects are of importance in Hevea pollination outside Puerto Rico. The family has a wide distribution, however, and it is possible that their habits and small size (about 1 mm in length) may have caused them to be overlooked in previous pollination studies. Actually, at no time during the present studies have these insects been observed in flight around Hevea inflorescences. If the hairs or bristles had not accidentally been found on the stigmas and the midges identified from this clue, their potential role in pollination might not have been discovered.

[5] That thrips are responsible for some pollination in Hevea seems certain after a recent observation. Female flowers tightly covered with soda straws immediately before anthesis sometimes were found to have pollen grains on their stigmas when carefully examined some days later. An occasional thrips was found inside such covered flowers, and it is highly unlikely that any other insect could have gained access to these stigmas.

References

1. Morris, L. E. *J. Rubber Research Inst. Malaya*, **1**, 41 (1929). (Repr. in *Trop. Agr.* (*Ceylon*), **72**, 135 (1929).
2. Muzik, T. J. *Science*, **108**, 540 (1948).
3. Maas, J. G. J. A. *Arch Rubbercult. Nederland.-Indië*, **3**, 288 (1919).
4. Seibert, R. J. *Ann. Missouri Botan. Garden*, **34**, 261 (1947).
5. Posnette, A. F. *Trop. Agr.* (*Trinidad*), **21**, 115 (1944).
6. Macfie, J. W. S. *Bull. Entomol. Research*, **35**, 297 (1944).

Rate of Circulation of the Body Fluid in Adult *Tenebrio molitor* Linnaeus, *Anasa tristis* (de Geer), and *Murgantia histrionica* (Hahn)

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The rate of circulation of body fluid in insects and the time for an introduced material to become homogeneously mixed with it are important factors in certain studies in insect physiology and toxicology. Only brief, incidental references to the rate of circulation of insect body fluid have been found in the literature (*1–5*). Much more is known about the rate of movement and mixing of mammalian blood. The times for blood movement between comparable points in various mammals are: rabbit, 7.5 sec; dog, 16 sec; man, 23 sec; and horse, 28.8 sec (*6*). The time for complete mixing of the blood in man has been estimated to be between 2 and 4 min (*7–9*). The time for complete mixing of the blood in dogs is about 5 min (*10*).

Since insects have an open circulatory system, it may be more nearly correct to speak of the time for uniform mixing of insect blood rather than of the time for a complete circuit of any portion of it. One of the standard (and best) ways to determine the time of circulation of the blood of an animal is to introduce a substance whose concentration can be determined in a small portion of the blood. Elements such as phosphorus, which are normal constituents of insect blood, and which can be made radioactive, make it possible to use this method on even the smaller insects.

The usual path of the circulating blood in an insect is anteriorly through the dorsal vessel and posteriorly through the ventral portion of the body cavity (*11, 12*). A substance injected near the posterior end of the heart would be expected to reach first the wings, then the antenna, and first, second, and third pairs of legs in order. As the blood containing the injected substance reaches an appendage, e.g., the antenna, the amount present will increase to a maximum in each of the pair and then decrease as unadulterated blood fol-