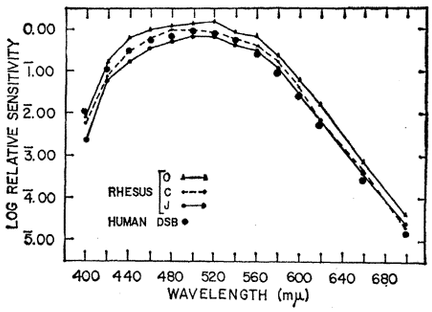

Fig. 2. Mean sensitivity curves of three monkeys and one human subject. Each point of the monkey data includes 15 to 18 separate determinations. The human data agree closely with the standard scotopic function defined by the International Commission on Illumination.

nance or the monkey's threshold brought a prompt compensating adjustment. Figure 1 shows a sample of the precise way in which monkeys followed threshold changes. It records the intensity adjustments made by one monkey as its threshold fell during dark adaptation.

For the spectral work, a Bausch & Lomb grating monochromator delivered light of selected wavelengths (bandwidth 6.6 mμ) to the stimulus patch. During experimental sessions the only light in the monkey's room came from this patch. The light passed through neutral filters, color filters designed to reduce stray light, and finally through the motor-driven optical wedge. The position of the wedge was recorded on a strip chart (see Fig. 1) and thresholds were determined from these records by taking account of energy and transmission values at the several stimulus wavelengths.

Before each experimental session the monkey spent at least 1 hour in complete darkness, out of reach of the response keys. Then, in dim light, it was wheeled into position and the apparatus was turned on. Eight or more wavelengths were presented each day, in a randomized sequence, for 15 minutes each. Data from the first 10 minutes of each session were discarded. Between 15 and 18 threshold determinations at each wavelength were averaged to produce each monkey's sensitivity function.

The results appear in Fig. 2. Curves for each of three monkeys are shown, and, for comparison, the values obtained from one human subject in the same apparatus appear also. The human data may perhaps be considered representative, for they deviate little from the standard scotopic spectral sensitivity function for young eyes defined by the International Commission on Illumination. The relative deviation amounts to less than 0.1 log unit at all wavelengths.

It may be seen that the monkey functions agree well with one another. They are also quite similar to the human sensitivity curve, although in the long wavelength region (560 mμ and greater) the monkey's relative sensitivity appears to be slightly but consistently greater than the human's. General agreement with the human function is not unexpected, since both are presumably based on the absorption spectrum of rhodopsin, the photosensitive pigment in the "rod" elements of both monkey and human eyes. The significance of the slightly deviant long wavelength sensitivity is not clear.

DONALD S. BLOUGH
ALLAN M. SCHRIER
Walter S. Hunter Laboratory of Psychology, Brown University, Providence 12, Rhode Island

References and Notes

1. Supported by Public Health Service grant B-2485.
2. D. S. Blough, *Science* **121**, 703 (1955); *J. Comp. Physiol. Psychol.* **49**, 425 (1956); *J. Opt. Soc. Am.* **47**, 827 (1957).
3. G. v. Békésy, *Acta Oto-Laryngol.* **35**, 411 (1947).
4. The food pellets were provided through the courtesy of CIBA Pharmaceutical Products, Inc.
5. D. S. Blough, *J. Exptl. Analysis Behav.* **1**, 31 (1958).

19 November 1962

Polymer Structure: Cross-Linking of a Polybenzimidazole

Abstract. *The torsional braid technique was used to monitor the changes in rigidity and damping characteristics of a polybenzimidazole as it changes from a thermoplastic polymer to a thermoset resin at about 450°C. In an intermediate process the thermoplastic backbone of the polymer becomes flexible.*

By thermal treatment at about 500°C, a polybenzimidazole becomes insoluble; this has been attributed to cross-linking (*1*). This report presents the results of an investigation of the thermomechanical properties of a composite of glass braid and polybenzimidazole, in which changes in dynamic mechanical properties of the composite were monitored by torsional braid analysis (*2, 3*). The changes in mechanical properties of the composite are interpreted in terms of changes in the polymer. Two concurrently determined parameters are used in the technique as a qualitative measure of the mechanical properties. The relative rigidity, G_T/G_{100}, expresses the rigidity modulus at some temperature T, relative to the arbitrary reference state of the initial composite of polymer and substrate at 100°C. The damping-index parameter, $1/n$, which is introduced in this short report represents an attempt to obtain a measure of the mechanical damping by counting the number of oscillations, n, which the eye can distinguish upon the induction of a free vibration. The two parameters have a physical basis, and the approach supplies reproducible data. The apparatus and experimental methods have been described previously (*3*). The polybenzimidazole (*4*), poly-2,2′-(*o*-biphenylene)-5,5′-bibenzimidazole, is soluble in formic acid and has an intrinsic viscosity of 2.95. Polymer (0.1 gram) was deposited on the glass braid from a 10 percent solution in formic acid.

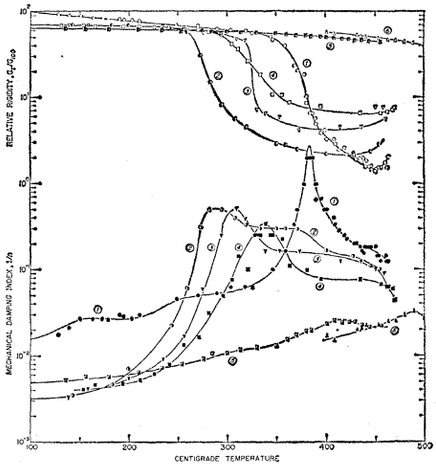

Fig. 1. Cross-linking of polybenzimidazole.

The thermal softening behavior of the initial polymer-glass composite (cycle No. 1 of Fig. 1, in 4 hours) demonstrates the thermoplastic nature of the polymer. A glass region, a glass transition region (about 390°C), and a rubbery region are each well defined. Since the polymer as synthesized was linear, albeit conjugated, the characteristics are not unexpected. Above about 450°C, the increase in rigidity and decrease in damping are attributed to cross-linking. After cooling, the heating

cycle was repeated (cycle No. 2) on the same sample. The irreversible change which resulted from the first treatment apparently lowered the glass transition temperature about 100°C. Cooling and repeating the cycle (Nos. 3 and 4) caused the glass transition temperature to rise somewhat. At the end of cycle number 4, the temperature was held at 460°C for 15 hours. The thermoset nature of the product is apparent from the next treatment (cycle No. 5). The sample was then cooled to 400°C, held at 400°C for 15 hours, cooled to 100°C, so that cycle No. 6 demonstrates the effect of further cross-linking.

Analysis in terms of the relative-rigidity and damping-index parameters provides a picture of the overall molecular changes which occur. The change from thermoplastic polymer to thermoset resin at about 450°C occurs with an intermediate process, possibly independent of the cross-linking, in which the thermoplastic backbone of the polymer is made flexible. Parallel analysis by infrared spectroscopy demonstrated that during a treatment represented by the first curve, the nature of the bonding of the hydrogen atom which is linked to nitrogen in the imidazole ring is altered drastically. Reduction of hydrogen bonding could account for the initial increase in mechanical flexibility. Subsequent chemical changes which accompany the cross-linking process are much less obvious. Cross-linking in the polybenzimidazole is accompanied by increasing rigidity in the rubbery region, a progressive increase in the glass transition temperature, and decreased damping in the thermosetting rubber (*5*).

J. K. GILLHAM

American Cyanamid Company,
Stamford Laboratories,
Stamford, Connecticut

References and Notes

1. H. Vogel and C. S. Marvel, *J. Polymer Sci.* **154**, 511 (1961).
2. A. F. Lewis and J. K. Gillham, *J. Appl. Polymer Sci.* **6**, 422 (1962); ———, abstract of paper presented at the meeting of the American Chemical Society in Washington, D.C. (March 1962), preprint issued by the Polymer Division, p. 332; J. K. Gillham and A. F. Lewis, *Nature* **195**, 1199 (1962).
3. A. F. Lewis and J. K. Gillham, abstract of paper presented at the meeting of the American Chemical Society, Atlantic City, N.J. (Sept. 1962), preprint issued by the Organic Coatings and Plastics Chemistry Division.
4. The polybenzimidazole was supplied by Dr. G. F. L. Ehlers of the Aeronautical Systems Development Laboratories, Dayton, Ohio.
5. I am indebted to Armand F. Lewis for an analysis of the method for estimating the damping characteristics and to Norman B. Colthup for advice on the interpretation of the infrared analyses.

4 January 1963

Observation of Internal Structures of Teeth by Ultrasonography

Abstract. *Preliminary experiments with high-resolution intensity-modulated ultrasonography techniques developed for ophthalmological diagnosis have demonstrated that at a frequency of 15 megacycles per second some internal structures can be seen in vital teeth. A relationship between time, tooth vitality, and ultrasonic viewing was observed.*

Some aspects of diagnostic ultrasonography warrant emphasis here. The intensity of ultrasound used in diagnostic ultrasonography has been shown to have no immediate, delayed, or cumulative injurious effect on tissue (*1*). Ultrasonography yields cross-sectional views without the superimposition of structure characteristic of x-rays. The observed increase in ultrasonic absorption with loss of tooth vitality forms the basis for a sensitive method of measuring viability.

Fifty pilot dental studies were made, with ultrasound provided by the General Precision Laboratories' ophthalmic ultrasonoscope, designed by Baum and Greenwood (*2*). Results of two of these studies are shown in Fig. 1. These demonstrate that internal viewing of tooth structure has been accomplished, although not with the desired clarity.

Studies were then made of freshly extracted teeth and of teeth extracted 1½ hours, 3 hours, and 5 weeks prior to the study. It was observed that as the time after extraction increased, the clarity with which the internal structure was revealed decreased. The internal structure of teeth extracted more than 3 hours prior to the study could not be seen. It appears that a relationship exists between the vitality of the tooth and the degree to which the internal structure is revealed by ultrasonography.

In the pilot studies frequencies of 15 Mcy/sec were used (Fig. 1). It may be observed that the resolution is not sufficient for differentiation of

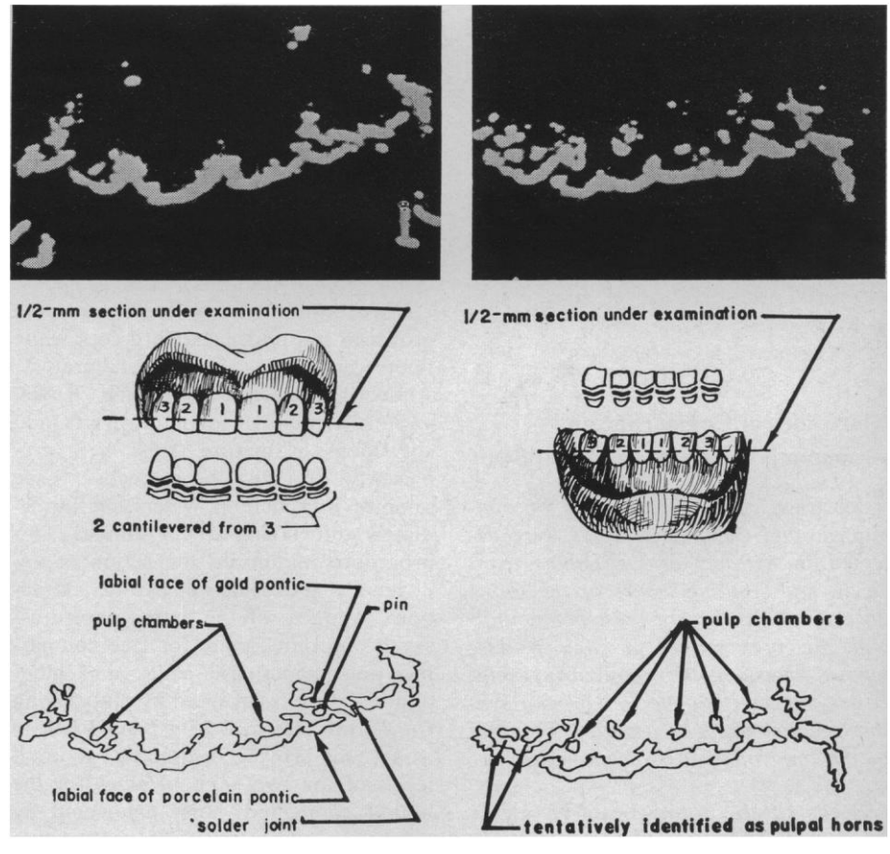

Fig. 1. Cross-sectional views obtained with ultrasound, and explanatory schematic drawings. The pulp chambers of the teeth do not appear in the correct anatomical positions because the ultrasonic energy is not normal to the tooth. The resultant echo is transposed away from the proper position. This is a result of using ophthalmological equipment for dental work.