give quite useful results. Specifically, it has shown that GC/MS is a powerful survey technique by which it is possible to identify the general nature of the organic pollutants and that LC is a rapid and sensitive technique for monitoring, in this case, aromatic compounds.

RONALD A. HITES*
K. BIEMANN

Department of Chemistry, Massachusetts Institute of Technology, Cambridge 02139

References and Notes

1. L. M. Cook, Ed., *Cleaning Our Environment, the Chemical Basis for Action* (American Chemical Society, Washington, D.C., 1969), pp. 95–99.
2. P. H. Abelson, *Science* **170**, 495 (1970).
3. W. H. Walker, Jr., thesis, Massachusetts Institute of Technology (1971).
4. Subsequent investigations revealed that stirring times as short as 6 hours are effective for extraction.
5. R. A. Hites and K. Biemann, *Anal. Chem.* **40**, 1217 (1968).
6. ———, *ibid.* **42**, 855 (1970).
7. H. S. Hertz, R. A. Hites, K. Biemann, *ibid.* **43**, 681 (1971).
8. The LC conditions were as follows: liquid-solid chromatography on a Porasil T column (120 by 0.32 cm) with heptane as the eluent; pressure, 27.0 atm; temperature, 23°C; ultraviolet detector at 254 nm.
9. The LC peak areas were calibrated on the basis of a known concentration of 1-methylnaphthalene. The concentrations (given in parts per billion) have an estimated accuracy of 10 to 15 percent.
10. M. Blumer, G. Souza, J. Sass, *Mar. Biol.* **5**, 195 (1970); M. Blumer, in *Man's Impact on Environment*, T. R. Detwyler, Ed. (McGraw-Hill, New York, 1971), p. 295; M. Blumer and J. Sass, *Science* **176**, 1120 (1972).
11. M. Blumer, personal communication.
12. J. Han and M. Calvin, *Proc. Nat. Acad. Sci. U.S.A.* **64**, 436 (1969).
13. W. W. Youngblood, M. Blumer, R. L. Guillard, F. Fiore, *Mar. Biol.* **8**, 190 (1971).
14. R. J. Jaeger and R. J. Rubin, *Science* **170**, 460 (1970); *Lancet* **1971-II**, 151 (1971); G. Ogner and M. Schnitzer, *Science* **170**, 317 (1970); D. J. Nazir, A. P. Alcaraz, B. A. Bierl, M. Beroza, P. P. Nair, *Biochemistry* **10**, 4228 (1971); for a review, see K. P. Shea, *Environment* **13** (No. 8), 2 (1971).
15. R. K. Bower, S. Haberman, P. D. Minton, *J. Pharmacol. Exp. Ther.* **171**, 314 (1970); A. R. Singh, W. H. Lawrence, J. Autian, *J. Pharm. Sci.* **61**, 51 (1972); F. L. Mayer Jr., paper presented at the 27th midwest regional meeting of the American Chemical Society, St. Louis, October 1971.
16. We thank B. D. Andresen, R. Bopp, and L. S. Ramos for assistance and Dr. M. Blumer for comments regarding possible sources. This work was supported by a National Institutes of Health grant (RR00317) from the Biotechnology Resources Branch, Division of Research Resources, and by a research grant (22-009-005) from the National Aeronautics and Space Administration.
* Present address: Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge 02139.

11 April 1972; revised 28 August 1972

Visual Sensations Induced by Relativistic Nitrogen Nuclei

Abstract. *The ability of the human eye to detect nitrogen nuclei that enter the retina at speeds just above the Cerenkov threshold has been confirmed in an experiment at the Princeton Particle Accelerator. A system for beam transport and subject alignment delivered individual nitrogen nuclei onto a spot 3 millimeters in diameter on the retina at a visual angle of 7 degrees on the temporal side of the fovea. The beam particles entered the retina within 25 degrees of normal and induced visual sensations that had the appearance of streaks for three out of four subjects.*

The light flash phenomena (*1*) described by astronauts on Apollo missions 11 through 16 have stimulated research on visual sensations induced by radiation. Theoretical models suggested for these phenomena include Cerenkov radiation (*2*), isomerization of the photochemical rhodopsin molecules in collisions (*3*), and scintillations produced in the lens (*4*). Stars and streaks have been reported by subjects exposed to neutrons with kinetic energies above a threshold of 3 to 4 Mev (*5*). Both stars and streaks have been observed when helium (*6*) and nitrogen (*7*) nuclei near the end of their range (linear energy transfer 10 Kev/μm or more) intersect the posterior portion of the retina at angles close to grazing. At near normal incidence to the peripheral retina 1 cm anterior to the posterior portion of the eyeball, no visual sensations were observed with either helium or nitrogen. A small but distinct correlation between star-type phosphenes and individual relativistic cosmic ray muons that pass through the eye was first reported by D'Arcy and Porter (*8*) and confirmed by Charman and Rowlands (*9*), who attributed it to non-Cerenkov effects at the retina. The passage through the eye of thousands of muons in large 0.44-second bursts has been shown (*10*) to result in bright extended flashes that come and go with each burst and are similar in appearance to the "lightning behind the cloud" phenomena described by some Apollo astronauts (*1*). The visible Cerenkov radiation generated by the burst during each 0.1-second interval (in which the retina is known to integrate signals) was calculated to be above the threshold for peripheral vision, whereas the ionization produced at the retina was much less than that required with other forms of radiation to produce haze. We report here on visual sensations of stars and streaks experienced by four subjects when exposed to individual relativistic nitrogen nuclei that are incident within 25° of the normal to the retina at a visual angle of 7° on the temporal side of the fovea.

A schematic outline of the facility for these investigations at the Princeton Particle Accelerator (PPA) is shown in Fig. 1. The brass collimator, which is 9.4 cm thick, was positioned upstream, mounted on a motor-driven mechanism that allowed quick and accurate insertion in the beam. The electronics of the motor drive were removed after insertion to avoid accidental removal of the collimator. The insertion of the collimator, which has a channel 0.25 by 0.25 mm in cross section, resulted in a reduction of the beam intensity by a factor of 10^5. Thus, the synchrotron could be operated near its maximum intensity while the subjects were exposed to beam rates as low as 1 particle per minute. Failures of the equipment or changes in the timing of extraction would only result in a further reduction of the beam intensity. The beam particles that emerged from the collimator were separated from any secondary particles by a dipole magnet before they arrived at the subject alignment table. This table consisted of a steel frame 180 cm long, which supported a collimator (diameter 0.32 cm) and a shield at its downstream end (Fig. 1). A pivot at the upstream end and leveling screws were used to align the collimator with the nitrogen ion beam.

Each subject maintained the align-

Table 1. Summary of the first round of exposures.

Subject	Counter triggers	Subject marks: Coincidences	Subject marks: Misses	Description of coincidence phenomena
L.P.	51	5	18	Diffuse streaks with slight curvature; one point flash
V.B.	33	2	0	Streaks
V.P.	108	11	4	Thin, sharply defined streaks with slight curvature
P.M.	85	9	20	Diffuse flashes

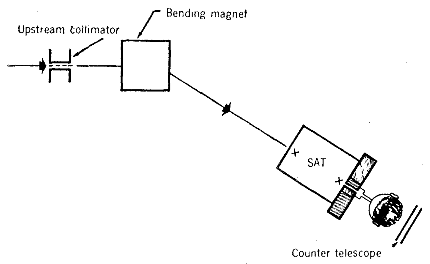

Fig. 1. Schematic of the irradiation facility set up at the Princeton Particle Accelerator for this investigation; *SAT*, subject alignment table.

ment of his eye to the emerging beam by biting into his personal dental impression plate, which was clamped onto an *x-y* positioning mechanism. Changing to a new subject was accomplished by switching the dental impression plate and dialing the new coordinates. For final alignment of the retina to the beam, the subject stared at a diode emitting a very dim red light, which served as a fixation point. The diode was masked to produce an image in the shape of a cross that would subtend a visual angle of 2°30′, which corresponds to a length of 0.72 mm at the subject's retina, and thereby provide a convenient scale with which to measure the size at the retina of any induced visual phenomena. Beam particles or heavy fragments with an atomic number of 3 or greater that emerged from the rear of the subject's head were detected by a counter-telescope arrangement, and visual sensations were marked when the subject pressed a button. To allow the subjects time to comment on their observations, the average time interval between beam particles was kept at roughly 1 minute.

For this investigation four subjects were exposed to nitrogen nuclei with energies of 531 Mev per atomic mass unit. The alignment of the left eye and the location of the fixation cross were arranged to produce the relative orientation of the retina to the beam shown in Fig. 2. On entering the eye, the nitrogen nuclei missed the lens and arrived at the temporal retina at a point that corresponded to a visual angle of about 7° from the fovea. This location has a sensitivity to visible light that is typical of much of the peripheral retina, and any visual sensations induced would appear conveniently close to the fixation cross. The beam particles entered the retinal layers at an angle of about 20° with the normal.

In the first round of exposures, four subjects received a total of 277 nitrogen nuclei, 27 of which were accompanied by a visual sensation of a dim streak or a flash about 5° to 10° to the right of the fixation cross. The observations are summarized in Table 1. The typical streak appeared colorless, somewhat curved, and no longer than twice the length of a stroke of the fixation cross, or 1.54 mm at the retina. Subject L.P. reported that he required a rather long interval between first observing a faint streak and finally signaling the flash. Subjects V.B. and V.P. had a similar lag; for these two subjects 10 of the 13 coincidences between the counter signal and the observed signal required between 4.5 and 7 seconds. No streaks were observed in the period of 1 to 3 hours each of the four subjects spent dark-adapted, but not in the beam. While subject V.P. was in the beam, he observed a single streak at 5° to 10° on the right side of the fovea that was not registered by the counter telescope. This nitrogen nucleus might have undergone a subsequent nuclear interaction in the head, with no heavy fragment emerging to trigger the counters. The 18 missing marks recorded by subject L.P. and the 4 recorded by V.P. were described as pinpoint flashes and diffuse flashes, respectively. The fourth subject, P.M., marked as quickly as possible "anything that appeared at 5° to 10° to the right of the fovea" in an attempt to eliminate the long time lag. All of his coincidence marks fell within the established 4.5-second gate, but he was unable to describe much of the phenomena and the remainder appeared as diffuse flashes. He did not report any streaks. The different detection criteria employed by the subjects are reflected in the miss column of Table 1.

The streak phenomena described above and those produced at Lawrence Berkeley Laboratory (LBL) with stopping helium (*6*) and nitrogen (*7*) nuclei were similar in appearance, estimated length at the retina, and the efficiency with which they were detected—roughly 4 percent for stopping helium observed one at a time and 10 percent for relativistic nitrogen. Some differences in how they were produced may be even more significant, however. At Berkeley, the streaks resulted from nuclei that entered the retina at near-grazing angles, and they were comparable in length to the path length of a primary particle in the outer layer of rod outer segments. At Princeton, since the beam particles entered the retina within 25° of the normal, the streaks observed were over a hundred times longer than the path length of a particle in this layer. When the LBL helium and nitrogen beams were incident near normal to the far peripheral retina, no visual sensations were reported, despite the considerably higher linear energy transfer of nitrogen nuclei near the end of their range. Finally, the PPA nitrogen nuclei entered the retina with energies of about 503 Mev per atomic mass unit, and, therefore, with velocities above the Cerenkov threshold. We estimate that at least 40 Cerenkov photons with wavelengths in the visible region entered the retina within 150 μm of the primary.

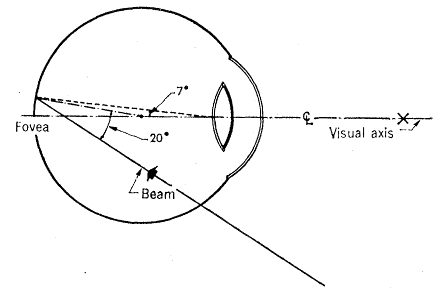

Fig. 2. Orientation of the beam to the subject's retina with the subject staring at fixation point *X*.

Fatigue brought on by prolonged periods of dark adaptation appears to strongly inhibit a subject's ability to detect these faint phenomena. In a second round of exposures, which followed 3 hours of dark adaptation, subjects V.B., V.P., and P.M. were exposed to a total of 239 nitrogen nuclei and observed only one streak. A number of flashes were observed, but there were fewer coincidences than were expected to occur accidentally. This loss of detection efficiency prevented us from directly comparing visual sensations induced by beam particles traversing the retina at speeds just above and just below the Cerenkov threshold. It is hoped that a direct measurement of the Cerenkov contribution will be made at some other accelerator facility, since the Princeton Particle Accelerator has had to cease operations.

P. J. McNulty*
V. P. Pease
Clarkson College of Technology, Potsdam, New York 13676
L. S. Pinsky
NASA Manned Spacecraft Center, Houston, Texas 77058
V. P. Bond
Brookhaven National Laboratory, Upton, Long Island, New York 11973
W. Schimmerling†
K. G. Vosburgh‡
Princeton Particle Accelerator, Princeton, New Jersey 08540

References and Notes

1. P. K. Chapman, L. S. Pinsky, R. E. Benson, T. F. Budinger, in *Proceedings of the National Symposium on Natural and Manmade Radiation in Space*, E. A. Warman, Ed. (NASA-TM X-2440, National Aeronautics and Space Administration, Washington, D.C., 1972), p. 1002.
2. G. G. Fazio, J. V. Jelley, W. N. Charman, *Nature* **228**, 260 (1971); R. Madey and P. J. McNulty, in *Proceedings of the National Symposium on Natural and Manmade Radiation in Space*, E. A. Warman, Ed. (NASA-TM X-2440, National Aeronautics and Space Administration, Washington, D.C., 1972), p. 757.
3. P. J. McNulty and R. Madey, in *ibid.*, p. 767.
4. I. R. McAulay, *Nature* **232**, 241 (1971).
5. J. H. Fremlin, *New Sci.* **47**, 42 (1970); W. N. Charman, J. A. Dennis, G. G. Fazio, J. V. Jelley, *Nature* **230**, 522 (1971); C. A. Tobias, T. F. Budinger, J. T. Lyman, *ibid.*, p. 596; T. F. Budinger, H. Bischel, C. A. Tobias, *Science* **172**, 868 (1971).
6. C. A. Tobias, T. F. Budinger, J. T. Lyman, in *Proceedings of the National Symposium on Natural and Manmade Radiation in Space*, E. A. Warman, Ed. (NASA-TM X-2440, National Aeronautics and Space Administration, Washington, D.C., 1972), p. 416.
7. T. F. Budinger, J. T. Lyman, C. A. Tobias, *Report No. 529* (Lawrence Berkeley Laboratory, Berkeley, Calif., 1971).
8. F. J. D'Arcy and N. A. Porter, *Nature* **196**, 1013 (1962).
9. W. N. Charman and C. M. Rowlands, *ibid.* **232**, 574 (1971).
10. P. J. McNulty, *ibid.* **234**, 110 (1971); *Report No. 71-0377* (Air Force Cambridge Research Laboratories, Cambridge, Mass., 1971).

11. Supported in part by NASA grant T-111813, Air Force Cambridge Research Laboratories grant F19628-72-C-0209, and the Fannie E. Rippel Foundation. We thank J. Fennimore, F. Homan, M. Isaila, the staff of the Princeton Particle Accelerator, and H. Powsner for their help in this experiment.

* Present address: Biology Department, Brookhaven National Laboratory, Upton, N.Y. 11973.
† Present address: Lawrence Berkeley Laboratory, Berkeley, Calif. 94720.
‡ Present address: General Electric Research and Development Center, Schenectady, N.Y. 12305.

20 July 1972

Cracks and Pores: A Closer Look

Abstract. *Most pores and some cracks in several rocks, as directly viewed with a new technique, have a shape that suggests an origin early in the history of these rocks. Thus, behavior in the laboratory may be a reliable indication of behavior in the earth's crust, for electrical resistivity, permeability, or other properties that depend on microporosity.*

Nearly all rocks, even dense, crystalline varieties such as granite, diabase, or dunite, contain cavities. Although in crystalline rocks this void space may amount to less than 1 percent by volume, many physical properties are dramatically affected. This was first recognized by Adams and Williamson (*1*), who suggested that tiny cracklike voids in granite increased its compressibility severalfold. The role played by cracks and more nearly equant voids termed pores was later related quantitatively to elastic, thermal, electrical, and other properties (*2, 3*). In virtually all of these studies, a simple physical model was assumed, namely, a solid matrix with a dilute concentration of isolated cavities of circular or elliptical cross section. From this model, crack or pore parameters were calculated by using observed physical properties. For example, the pressure required to eliminate cracks gave an estimate of crack aspect ratio (*2*); the tensile strength or the low-pressure compressibility gave an estimate of crack length (*2*).

In spite of this rather extensive theoretical work on the effects of microporosity, only in rare cases have theoretical and actual crack and pore parameters been compared (*2, 4*). Direct observation of cracks and pores is difficult, partly because of their small size. In addition, in order to view pristine material in the interior of a rock sample, one has to prepare a section; to date, this has been the standard thin section or polished section (*5*). During the preparation of a section, new cracks and other surface damage are inevitable. Because of this, actual mapping of the microporosity has enjoyed little success, and parameters like crack shape, length, density, and connectivity have, we feel, never been unambiguously determined.

In the technique which we have developed for looking at the microporosity, a specimen suitable for examination with either an optical microscope or a scanning electron microscope (SEM) is obtained. The procedure is in two steps: first, the preparation of a finely ground surface (*6*), and second, removal by ion thinning (*7*) of the damage left by grinding. Vacuum evaporation of 100 to 400 Å of a metal on the rock surface renders detail visible in either a reflecting optical microscope or an SEM. With the latter, cavities and other features down to about 200 Å may be discernible (*8*).

Features typically seen at the boundary of two feldspar grains in Westerly granite (*4*) are shown in Fig. 1. The grain boundary extends from lower left to upper right in the photograph and is marked by a series of slots and irregular cavities. The feldspar grains themselves contain many small, more or less equant cavities 0.5 to about 2 μm in size; it is not known whether these cavities are tubular or more nearly spherical. Near point *a* in Fig. 1 continuous bridges of material cross a long slot; such bridged slots are common in Westerly granite. At *b* a crack is seen with one sharp and one blunt end; its length is about 30 μm and its opening at mid-length is 0.5 μm. The aspect ratio is therefore about 60. Near *c* a crack of irregular (dumbbell) shape is seen; the ends here are rounded, although a sharp-ended crack runs a short distance from one end. The aspect ratio of the crack near *c* is about 100, and that of the whole feature is about 120.

Details near the boundary of quartz and feldspar grains in Rutland quartzite (*4*) are shown in Fig. 2. In many aspects the microporosity is strikingly different from that of Westerly granite, although feldspar grains in both are riddled with tiny equant cavities about a micrometer in size (near *a* in Fig. 2). The boundary in the quartzite (which runs diagonally through *b*) is marked by a fairly continuous system of fine cracks. They are much smaller than in the granite, although the aspect ratios seem comparable; near *b*, the length is 5 to 10 μm and the aspect ratio about 100. Tiny pores of triangular cross section (they appear black in Fig. 2) intersect the cracks above and to the right of *b*. The large oval features in Fig. 2 are topographic and apparently result from the ion thinning.

We have, to date, examined three sections of Westerly granite (taken from two different blocks) and a section each of Rutland quartzite, Maryland diabase (*4*), and Mt. Albert peridotite (*9*). Observations for these rocks can be summarized as follows:

1) Grain boundaries are preferred sites for cracklike cavities, although cracks also occur within grains of biotite and feldspar, and infrequently within quartz. The grain boundary features are typically blunt-ended, are often bridged by thin septa, and occasionally show features which might be attributed to "healing" or late crystallization.

2) Cavities whose cross section is equant, or of low aspect ratio, are abundant both within feldspar (microcline, plagioclase) and at grain boundaries. Within feldspar they seem to occur randomly, whereas at grain boundaries they form rows and may alternate with slots and cracklike openings. It is not known whether equant