'PATHOLOGICAL SCIENCE': ERRONEOUS EPILOGUE?

In Robert N. Hall's brief epilogue to Irving Langmuir's posthumously published "Pathological Science" (October 1989, page 36) he attaches the label "pathological science" to "*the* photomechanical and electromechanical effects" (our italics). Such terms, naming real or alleged physical effects by the degrees of freedom that they connect, aren't unique. *What* electromechanical effect is meant, in what materials, and under elastic or plastic deformation? If the elastic realm were to be included, the paragraph might deny the piezoelectric effect! Having determined Hall's intended context by looking up the papers[1,2] cited in his reference 11, we find that context even more inobvious than it first appeared. It seems necessary to correct erroneous impressions that reasonable readings of Hall's epilogue seem to convey.

The cited papers turn out to be refutations of claims by Jack H. Westbrook, John J. Gilman[3] and others for a "decrease in the indentation microhardness of semiconductors when subjected to light of the appropriate wavelength and intensity . . . or electric fields."[1] These do not seem to be "threshold effects" (to use Langmuir's term), although there may be some element of subjectivity in the interpretation of microhardness experiments; we leave their defense to Gilman and the others.

In the text of John P. Hirth and Jens Lothe,[4] chapter 12, "Dislocations in Ionic Crystals," opens by citing an extended string of electromechanical effects: the Gulyai–Hartly, Stepanov and Joffé effects, and three others not given names of men. These are by no means "threshold effects"; they can be rather spectacular. The Stepanov effect, in particular, involves charge separation and consequent electric fields produced in the course of plastic deformation. Studies of such phenomena have not experienced a "decline toward oblivion," as Hall asserted. A significant literature, dominantly but not exclusively Soviet (with especially notable contributions by Yuri Osip'yan and coworkers), extends to recent years. This work deals principally with II–VI crystals.

Thus the existence seems assured, in some materials at least, of effects in plastic flow that reasonably may be termed "photomechanical" and "electromechanical." However, the original claims in dispute were for "pronounced decreases in indentation microhardness among many different semiconductors (Ge, Si, SiC, InSb and CdS) and semimetals (Sb and Bi) due to irradiation with light or the application of an electric field."[2] Evidently very interesting questions remain: Just what is the scope of materials in which such effects occur? What commonality of mechanism is there, or what diversity of mechanisms?

References

1. R. E. Hannemann, P. J. Jorgenson, J. Appl. Phys. **38**, 4099 (1967).
2. R. N. Hall, in *Proc. 9th Int. Conf. on Physics of Semiconductors*, Moscow (1968), p. 481.
3. J. H. Westbrook, J. J. Gilman, J. Appl. Phys. **33**, 2360 (1962).
4. J. P. Hirth, J. Lothe, *Theory of Dislocations*, 2nd ed., Wiley, New York (1982).

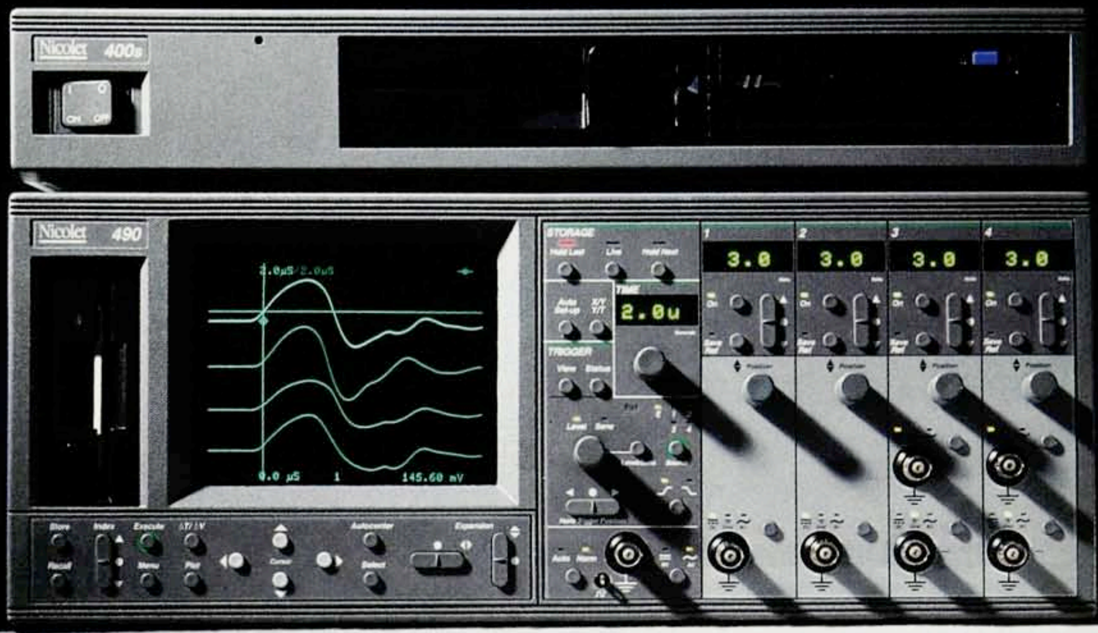
WALTER L. FAUST
DAVID J. MICHEL
Naval Research Laboratory
Washington, DC

10/89

We were privileged to hear Irving Langmuir present his lecture on "pathological science" in person many years ago at what was the General Electric Research Laboratory. It made a strong and lasting impression. Therefore, the recent article publishing that talk, as transcribed and edited by our former colleague Robert Hall, caught our interest. Much to our dismay, in Hall's epilogue, he classifies some work that we did[1] as "pathological" because, he claims, it was based on "subjective" observations.

After rereading James Thurber's fable "The Unicorn in the Garden" to confirm our faith that we are not the boobies, we wish to make the following comments.

We could run 200 ads like this and still not show you every Nicolet 400 model available.



Which means you have *some* choice in the matter.

Like selecting two or four channels, with 64K to 256K memory in each. Then opting for single ended or differential inputs. A 3½" or 5½" floppy drive. And anywhere from one to 200 MS/s digitizing rates.

From there, maybe add a 44MB removable hard disk or 40MB internal disk. Then perhaps a dual timebase, or powerful *Nicolet-Windows*™ PC software for instant remote control. It's all up to you.

Keep in mind that, as standard equipment, you'd already have 8 or 12 bit digitizing resolution, or even a combination of both. A built-in MS-DOS disk drive. A LEARN mode to help automate test sequences. And FFT and averaging for complete waveform processing.

One last thing. You can have one of our 224 high precision configurations in any color you like. As long as it's grey.

Discover the world's new DSO technology of choice, only from Nicolet. Send for a new 400 brochure today.

Nicolet Test Instruments Division

5225 Verona Road, Madison, WI 53711-4495
608/273-5008 or 800/356-3090

Nicolet
INSTRUMENTS OF DISCOVERY

Circle number 12 on Reader Service Card

The fact that Rodney E. Hannemann and Paul J. Jorgenson[2] did not reproduce our results showing decreases in the microhardness of semiconductors exposed to light or electric fields sheds little light on the subject, like most null observations. At least nine other authors had reported positive effects. Since we had shown that the effects are localized to a near-surface region less than 2–3 microns thick, one possible explanation for Hannemann and Jorgenson's null results is that their surfaces were not appropriately prepared. Their report would suggest to those skilled in the art that they may not have chemically polished their surfaces deeply enough to completely remove the damage induced by their previous grinding operations. There are other possible explanations, as is usually the case when attempts to reproduce previous observations lead to null results.

It is certainly disconcerting to make observations that fall outside expectations and orthodoxy. We were very disconcerted by ours. But that does not make them pathological, especially when they did not even come close to satisfying Langmuir's "symptoms of pathological science"—in spite of Hall's erroneous comment to the contrary. In fact, the differential is so large that we must wonder whether he actually read our paper!

Let's consider the symptoms one by one:

▷ *The effect is barely detectable, and nearly independent of the cause.* Actuality: Figure 3 of our paper shows changes of up to a factor of 2 that depend systematically (that is, they are obviously larger than the error bars shown in figure 2 of the same paper) on current and temperature. Other unmistakable dependences are also shown in 14 of the figures and five tables of the paper. Furthermore, we showed a corollary surface effect—the current-enhanced Dember effect, which changed by an order of magnitude! Barely detectable indeed!

▷ *The effect's magnitude is close to the limit of detectability.* Actuality: Not the case, as just indicated.

▷ *There are claims of great accuracy.* Actuality: See the error bars.

▷ *Fantastic theories contrary to experience are suggested.* Actuality: We wrote, "The body of experiments described above convinces us that we have observed a real and not a spurious effect." Some fantastic theory!

▷ *Criticisms are met by* ad hoc *excuses thought up on the spur of the moment.* Actuality: There is nothing to excuse regarding the measurements. We are apologetic that we don't understand what underlies them, but neither does Hall.

Hall appears to condemn all electro- and photomechanical effects. He states that after a flurry of activity in the 1960s studies of them have disappeared from the scene. Not so. About three years ago Yuri Osip'yan and his colleagues reviewed several of them.[3] They have been used to measure mobile dislocation concentrations in salt crystals by James C. M. Li and his collaborators. James M. Galligan has measured the effects on dislocation mobilities more directly than we did, and H. Alexander has measured mobilities directly in silicon.[4] A conference to discuss electromagnetic and ultrasonic effects was sponsored by the Army Research Office and held just this past July. Effects of electric fields on the plastic flow of metals were reported there by Hans Conrad and others.[5] Thus the field remains active. It may even provide opportunities for rich rewards, since the unknowns in it far exceed the knowns to date.

References

1. J. H. Westbrook, J. J. Gilman, J. Appl. Phys. **33**, 2360 (1962).
2. R. E. Hannemann, P. J. Jorgenson, J. Appl. Phys. **38**, 4099 (1967).
3. Yu. A. Osip'yan, V. F. Petrenko, A. V. Zaretski, R. W. Whitworth, Adv. Phys. **35**, 115 (1986).
4. K. H. Kusters, H. Alexander, Physica (Utrecht) **116B**, 594 (1983).
5. H. Conrad, A. F. Sprecher, in *Dislocations in Solids*, F. R. N. Nabarro, ed., Elsevier, New York (1989), p. 499.

John J. Gilman
Lawrence Berkeley Laboratory
Berkeley, California
Jack H. Westbrook
Sci-Tech Knowledge Systems
Scotia, New York

11/89

The article on pathological science was fascinating reading—that is, until you reached the epilogue by Robert N. Hall. There Hall falls, ironically, into the same trap exposed in the previous pages; that is, his knowledge of the literature was preconceived in such a way that it led him to discount a phenomenon based on extremely limited information. The photomechanical effect in semiconductors is readily observed.[1,2] For example, the magnitude of the effect is far from the limit of detectability—changes in flow stress[2] are of the order of factors of 2 or larger for light levels on the order of 0.01 watts/cm^2. There are well-defined spectral, temperature and composition dependences; each of

continued on page 108

continued from page 15
these depencences has been extensively cataloged.[3]

In relying on outdated and disputed references, Hall has obviously slanted his own comments down an extremely narrow, if not pathological, path.

References

1. Yu. A. Osip'yan, I. B. Savchenko, Zh. Eksp. Teor. Fiz. Pis'ma Red. **7**, 130 (1968) [Sov. Phys. JETP Lett. **7**, 100 (1968)]. V. Mayer, J. M. Galligan, Appl. Phys. Lett. **40**, 1020 (1982).
2. J. Pellegrino, J. M. Galligan, J. Mater. Res. **1**, 3 (1986). J. H. Westbrook, J. J. Gilman, J. Appl. Phys. **33**, 2360 (1962).
3. Yu. A. Osip'yan, V. F. Petrenko, A. V. Zaretski, R. W. Whitworth, Adv. Phys. **35**, 115 (1986).

JAMES M. GALLIGAN
University of Connecticut
11/89 *Storrs, Connecticut*

I reread Irving Langmuir's "Pathological Science" with great interest. One day in 1974, I visited Bob Hall at the General Electric R&D Center, in Schenectady, New York.

I talked about the degradation of semiconductor lasers. In those days double-heterostructure lasers degraded rapidly, and it was known that the degradation was caused by the glide-and-climb motion of dislocations. I told Hall that to explain the high speed[1] of the dislocation motion in GaAs we might as well assume an effect such as the photomechanical effect[2] that was originally reported in Ge.

Bob responded with a smile and a copy of a laboratory report in hand. He was just back from Moscow, where he had presented a paper reporting that the photomechanical effect in Ge was not a bulk (intrinsic) effect but a surface effect and that adatoms caused the effect. He suggested that I read the report, which turned out to be Langmuir's "Pathological Science." I could not resist his authority but only insisted that things could be different in GaAs, with which he agreed.

I still sometimes discuss Langmuir's talk in my lectures. But it is now well established that dislocation climb[3] and glide[4] both are enhanced by carrier recombination in GaAs—a variation of the photomechanical effect.

References

1. Y. Nannichi, I. Matsui, K. Ishida, Jpn. J. Appl. Phys. **14**, 1561 (1975).
2. G. Kuczynski, R. Hochman, J. Appl. Phys. **43**, 1337 (1972).
3. D. Lang, L. Kimerling, Phys. Rev. Lett. **33**, 489 (1974).
4. K. Maeda, M. Sato, K. Kubo, S. Takeuchi, J. Appl. Phys. **54**, 161 (1983).

YASUO NANNICHI
University of Tsukuba
12/89 *Tsukuba, Japan*

The remarks introducing Robert N. Hall's transcription of Irving Langmuir's lecture indicate that the recording from which the talk was transcribed "is of poor quality, but most of what Langmuir said can be understood with a little practice." Here we have an indication that the observations upon which the transcription was based were at or near threshold value. Also, like René-Prosper Blondlot's visual observation of the effects of N rays, special skill ("a little practice") was required to detect what Langmuir was saying.

Like J. B. Rhine in his experiments aimed at demonstrating the existence of clairvoyance, Hall rejected some of the data observed for *ad hoc* reasons: "Some abortive or repetitious sentences were eliminated." Additions by the editors of PHYSICS TODAY ("to improve the readability") have a similar *ad hoc* flavor.

In spite of the transcription's exhibiting these symptoms of pathological science, we do not propose that it be consigned to the place where mitogenetic rays and the Allison effect dwell. For whether they were a product of Langmuir's talk or of Hall's pathology, the contents of the article indisputably exist. We merely point out that if what Hall says Langmuir said is true, Langmuir probably didn't say it.

KYLE FORINASH
WILLIAM D. RUMSEY
Indiana University Southeast
11/89 *New Albany, Indiana*

HALL REPLIES: I wish to offer my apology to those who thought that I was expressing skepticism about all classes of photomechanical and electromechanical phenomena. My comments were directed to experiments in which the hardness of a semiconductor or semimetal was measured using a diamond indenter, as is commonly done in metallurgical studies. I thought that this would have been evident from the fact that all of the experiments on electromechanical and photomechanical effects described or referred to in the papers[1,2] cited in my reference 11 were of this kind, and I did not expect that my reservations about the interpretation of these microhardness measurements would be extended to other fields, such as studies of dislocation motion or the deformation of bulk crystals as reported in the publications from Yuri Osip'yan's group or those of James M. Galligan and colleagues.

To John J. Gilman and Jack H. Westbrook's complaint, I will point out that on five separate occasions I was invited to satisfy myself as to the validity of claimed electromechanical or photomechanical effects. The demonstrations I witnessed were carried out by the same technician who had made the measurements reported in the original publication,[3] using the same procedures and the same or similar equipment. However, as I reported at the Moscow conference,[2] this technician was able to produce a positive result only if he knew while he was measuring the indentation whether the light or electric field had been on or off when the indentation was made. If someone else controlled the light or electric field so that he did not have this knowledge, he was unable to distinguish any difference in size between the indentations made under the "on" or "off" conditions. (Diffraction effects were severe in the microscope he used, and the measurement could be greatly influenced by the setting of the focus. In conducting my own experiments I recognized that it would be difficult to avoid such prejudice in adjusting the focus, so I took care to avoid knowing the earlier "on" or "off" conditions.)

In further response to Gilman and Westbrook's comments, I will describe the applicability of Irving Langmuir's "symptoms" to the effects under discussion:

▷ *"... the magnitude of the effect is substantially independent of the intensity of the cause."* In at least 25 of the 30 or more publications describing electromechanical and photomechanical effects in many different semiconductors and semimetals the reported hardness changes always reached saturation: Further increases in light intensity or electric field failed to produce further softening.

▷ *"The effect is of a magnitude that remains close to the limit of detectability. ..."* As described above, the uncertainties in the experiments referred to in references 1 and 2 were sufficient to allow subjective effects to influence the measurements. I can only surmise that reports from other laboratories may have been similarly influenced.

▷ *"... claims of great accuracy."* When I first measured indentations without knowing the earlier "on" or "off" conditions, my results showed considerable scatter. I was told, "Our technician can do much better than that." But as described above, when

he did not know what result to expect, he could no longer achieve such accuracy.

▷ *"Fantastic theories. . . ."* In 1966 I talked with the director of the Leningrad institute from which many of the electromechanical-effect publications originated. He told me that the researchers there initially failed to observe these effects using equipment that was located in a laboratory that had been used previously for work with radioactive materials. When the equipment was moved to a clean area they were then able to observe pronounced hardness changes. The idea that the residual radioactivity in a laboratory where scientists were permitted to work could cause pronounced changes in the hardness of a material like Ge or Si struck me as rather fantastic.

▷ "*. . . ad hoc excuses.*" The day after the technician failed to detect the effect when he repeated the experiment under "blind" conditions, I was informed that the reason for the failure was that a wire was loose and the indenter was out of balance. Yet the technician had been "observing" the effect immediately before I asked to see the experiment repeated.

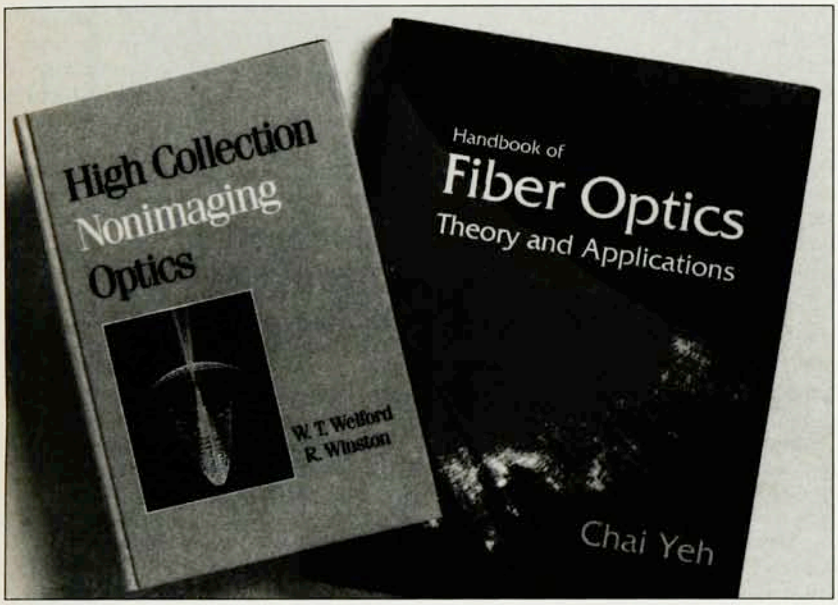
To reduce the measurement uncertainty I used an oil-immersion metallographic microscope to record in the same field of view the images of six indentations the technician had made—three made in the dark and three with the light on. The resulting photographic images, all made under the same focal conditions, were clear and sharp, but no difference in size could be detected among the indentations. I was told: "Look at those cracks at the corner of each indentation. Those cracks developed overnight and relieved the strain, so now they are the same size. We would have rejected any indentation that showed these cracks." In fact, the indentations *always* showed these cracks immediately after being made, but nobody had paid much attention to them before.

▷ *"The ratio of supporters to critics . . . declines to oblivion."* I counted 29 publications describing the effects under discussion in the period 1962–70. If these effects had been real, one might have anticipated that our papers[1,2] reporting them to be subjective would have stimulated an outpouring of indignant responses. I found two in 1971 and one the following year. Two more appeared in 1974, but one of these[4] described a null result. To my knowledge there have been no further publications supporting the existence of these effects.

Perhaps this discussion will stimu-

For the Latest in Lasers

Visit Us at CLEO Booth #1050



High Collection Nonimaging Optics

W.T. Welford and R. Winston

This book explains how light from conventional and laser sources is collected and re-directed most efficiently. Topics include the properties of different kinds of sources, conventional condenser optics, and Fresnel lenses.

December 1989, 284 pages, $49.50
ISBN: 0-12-742885-2

Free-Electron Lasers

C.A. Brau

Free-Electron Lasers is a survey work suitable for a free-electron laser course at the graduate level or for workers new to the field coming from either laser, accelerator, or other backgrounds.

Key Features:

- Introduces free-electron lasers and electron accelerators
- Contains useful references for basic formulas, which can be a starting point for research

In Paperback: $39.95/ISBN: 0-12-1260003
Casebound: $79.95/ISBN: 0-12-014596-0
March 1990, 432 pages

New!

Handbook of Fiber Optics

Theory and Applications

Chai Yeh

Here is a comprehensive reference with state-of-the-art information on fiber optics. It includes data on optic fibers and fiber materials, light sources and detectors, and couplers, LEDs, and other individual components. Published in an 8-1/2 x 11 inch format.

April 1990, 382 pages, $89.95
ISBN: 0-12-770455-8

New!

Dye Laser Principles

With Applications

edited by

F.J. Duarte and Lloyd W. Hillman

A tutorial introduction to the field of dye lasers, **Dye Laser Principles** also serves as an up-to-date overview for those using dye lasers as research and industrial tools. A number of the issues discussed in this book are pertinent not only to dye lasers but also to lasers in general.

May 1990, 472 pages, $64.50
ISBN: 0-12-222700-X

Coming in June

Polarized Light in Optics and Spectroscopy

David S. Kliger, James W. Lewis, and Cora Einterz Randall

This practical guide:

- Describes polarized light at laser powers, including power handling capabilities of optical elements and limitations of laser depolarizers
- Starts at a basic level and develops tools for research problems
- Compares the Jones, Mueller, and Poincaré sphere methods of analysis

June 1990, c. 293 pages, $59.95 (tentative)
ISBN: 0-12-414975-8

New!

An Introduction to Dynamic Light Scattering by Macromolecules

Kenneth S. Schmitz

This reference offers a comprehensive study of dynamic light scattering (DLS) by macromolecular and polyelectrolyte solutions. With an emphasis on the interpretation of DLS data, the material is organized according to the increasing complexity of the system, ranging from dilute solutions of noninteracting small particles to the more complex multi-component systems of strongly interacting large particles.

April 1990, c. 472 pages, $79.95
ISBN: 0-12-627260-3

Order from your local bookseller or directly from

AP

ACADEMIC PRESS
Harcourt Brace Jovanovich, Publishers
Book Marketing Department #23040
1250 Sixth Avenue, San Diego, CA 92101

CALL TOLL FREE
1-800-321-5068

Quote this reference number for *free postage and handling* on your prepaid order ➡ **23040**

Circle number 65 on Reader Service Card

late further work that could dispel any doubts that might remain about these strange effects. The high resolution that can be achieved with the scanning electron microscope should make it possible to achieve much greater accuracy in measuring hardness using a diamond indenter and eliminate the subjective factors that appear to have influenced the earlier investigations.

To Yasuo Nannichi I extend greetings, along with assurance that I have no difficulty believing that the high density of injected carriers and their recombination radiation can contribute to dislocation motion and degradation during the operation of semiconductor lasers.

Kyle Forinash and William D. Rumsey question the accuracy of the transcription of Langmuir's lecture. As stated in the introduction to the PHYSICS TODAY article, a copy of Langmuir's talk is on file with the Whitney Library of the General Electric Research and Development Center in Schenectady, as a cassette tape. Those interested are more than welcome to listen to it and satisfy themselves as to the accuracy of the version published in PHYSICS TODAY.

References

1. R. E. Hannemann, P. J. Jorgenson, J. Appl. Phys. **38**, 4099 (1967).
2. R. N. Hall, in *Proc. 9th Int. Conf. on Physics of Semiconductors*, Moscow (1968), p. 481.
3. J. H. Westbrook, J. J. Gilman, J. Appl. Phys. **33**, 2360 (1962).
4. H. Checinska, G. Chendor, Acta Phys. Pol. **A45**, 477 (1974).

ROBERT N. HALL
2/90 Schenectady, New York

Rehabilitating Romania's Research

I recently received a letter (dated late January 1990) from fellow physicists working at the Institute of Physics of the Romanian Academy of Sciences, on the outskirts of Bucharest. I was, of course, relieved to learn that personnel and facilities (for what they are worth) survived the dramatic and unexpected upheaval of late December relatively unscathed. Anyone who has visited Romania in the past decade undoubtedly shares with me a feeling of admiration for the dedication and determination shown by some of our colleagues in Romania, who strove to continue their research under incredibly dire circumstances, physical, financial and intellectual. These facts are, however, not the point of this communication. I wish instead to forward an appeal for assistance from my Romanian friends. They write:

> In the past year, the Security censorship became so effective that all our correspondence was stopped. Please be so kind as to send us information about [a specific conference] and any other conferences which are being held in the next year or so. We believe that we will be able to attend in the future.
>
> We are entering now the most difficult part of our revolution: building. This is why I . . . request: If you know any laboratories which have some equipment they wish to get rid of, please ask them to contact me: Dr. V. Lupei, Institute for Atomic Physics, Romanian Academy of Sciences, 76900 Bucharest—Magurele, Romania.
>
> We are in need of almost everything: equipment for lasers, detection and signal processing, computers, oscilloscopes, spectrometers and so on, even typing or copying machines, books and journals.

I suspect that they are not in a position to defray shipping costs; nevertheless, it seems to me that our community has an opportunity to make a humanitarian gesture by answering this appeal, even in some minor way. Their needs are real, and time has come to reintegrate our Romanian colleagues into the greater scientific community. I assume that this also the case with other Eastern Bloc nations. Please feel free to contact me if you have any comments, suggestions or questions.

WILLIAM M. YEN
Department of Physics and Astronomy
University of Georgia
2/90 Athens, GA 30602

Contributions of a Nobelist's Colleagues

I very much appreciated the excellent review of the work of the three 1989 physics Nobel laureates (December, page 17), especially because my thesis research at Columbia in molecular beams brought me into contact with Norman Ramsey's and Wolfgang Paul's contributions and because my long association with the University of Washington has made me a witness to the remarkable development of particle-trapping techniques by Hans Dehmelt. In all but one instance I believe proper acknowledgment was given to Dehmelt's colleagues who have participated with him in this development.

The exception is related to the idea of Dehmelt's termed the "quantum jump" in the Royal Swedish Academy's press release or the "shelved optical electron amplifier" in the PHYSICS TODAY news story, an idea central to realizing, in a practical way, the incredible precision inherent in the measurement of an optical frequency of a stored ion. In all his recent ion work as well as in the first observation of a quantum jump (*Physical Review Letters* **56**, 2797, 1986) Dehmelt has benefited from a collaboration with his colleague Warren Nagourney. In the quantum jump work cited he also had the assistance of Jon Sandberg, then a University of Washington undergraduate. A history of ion-trapping development would not be complete without these two names.

MARK N. MCDERMOTT
University of Washington
1/90 Seattle, Washington

DEHMELT REPLIES: Given *in toto*, the citation in my colleague Mark McDermott's letter would read, "Warren Nagourney, Jon Sandberg, Hans Dehmelt, 'Shelved Optical Electron Amplifier: Observation of Quantum Jumps,' *Physical Review Letters* **56**, 2797 (1986)," and I fully agree with the contents of the letter.

HANS DEHMELT
University of Washington
3/90 Seattle, Washington

Why Few Take Physics: Educated Guesses

The AIP–AAPT high school physics teacher survey (August 1989, page 30) points up the education problems of our profession. The results should not surprise us, for they are a consequence of the priorities of nearly every PhD-granting physics department in the country: research at the top, followed by doctoral dissertations, graduate courses and undergraduate physics major courses. At the bottom are the introductory courses for science and engineering students and perhaps, if the department is especially broad-minded, a course for the remaining 80% of the student population.

The course for nonscientists, if offered at all, is not taught by those physics faculty members who aspire to publications and tenure. This is the "watered down" physics course, generally a boring image of "real" physics—that is, of the courses that have lots of equations and problems on such fascinating topics as blocks on