THE LASER'S GRANDFATHER

A Nobel Lesson in How Science Really Works

By GRACE MARMOR SPRUCH

WHEN the 1966 Nobel Prize for Physics was awarded, two major French weekly magazines, *Paris Match* and *L'Express*, published photographs of the French recipient of the prize, Professor Alfred Kastler, on their covers. The cover of *L'Express* displayed the headline, THE GRANDFATHER OF THE LASER.

The headline about the award in the French newspaper *Le Monde* proclaimed, THE REPAIR OF AN INJUSTICE, and the article beneath the headline said: "The conferring of the Nobel Prize in Physics on Professor Kastler doesn't come exactly as a surprise. For several years, in effect, people in certain scientific circles and in official places were in the habit of making clear the disappointment they felt at seeing the Stockholm committee turn its back on a physicist whose work on optical pumping is found right at the origin of a scientific achievement of scope, that of lasers, and . . . has made an appreciable contribution to the development of our knowledge of optical spectroscopy. What is more, the *original* work on masers and lasers already merited its American and Russian authors . . . a Nobel Physics Prize in 1964. . . .The decision the Nobel Prize Committee just took constitutes, therefore, above all the just repair of what could appear to be an injustice."

Although political considerations are perhaps an inevitable factor in the Nobel awards, Kastler did not feel he had been mistreated. He emphatically stated that the men who received the prize for the laser two years before the award came to him unquestionably deserved the honor. He attributed use of his prize-winning technique of optical pumping in the first laser to "chance," and pointed out that subsequent lasers had outgrown dependence on his work.

Chance has much to do with how science really works, how research by one man stimulates or inspires research by others or provides a vital link in the chain of inspiration. Scientists urge continuous support of basic research not simply out of starry-eyed attachment to science for science's sake but from realization that this is also the pragmatic way of providing a fund of knowledge from which withdrawals can be made without delay when an unpredicted need arises. This is what Kastler means when he says he contributed to the laser by "chance."

Kastler, a singularly modest man, whose kindliness and genuineness are apparent in even the most casual encounter with him, was familiar to newspaper readers before his Nobel award because of his pacifist activities, his statements against the war in Vietnam, and the bombing of his apartment by the OAS (the secret organization that opposed independence for Algeria) in 1961. He began his work on optical pumping in 1950.

OPTICAL pumping is a technique of bombarding atoms with light in order to raise their energy from normal levels to higher levels, known as *excited states*, which very soon free the extra energy and return the atoms to normal. Since the *excited states* are normally empty, they are not amenable to detection until the extra energy is supplied. It was for the purpose of studying the properties of the *excited states* that Kastler developed and refined optical pumping. This fundamental research added greatly to knowledge of atomic structure.

Optical pumping is applied to the laser for a different purpose than Kastler's original one. Optical pumping is analogous to lifting water from a lake at the base of a mountain to a place high up on the mountain, and optical pumping in the laser is analogous to lifting water from the same lake up the mountain for the purpose of damming the water there until a new lake is formed and then opening the sluices to make a crashing waterfall.

But let us define what a laser is, in order to understand it without analogy. And, to gain additional insight into its character, let us introduce the laser's parent, the maser.

Lasers in the beginning were called optical masers. Maser is an acronym, standing for *M*icrowave *A*mplification by the *S*timulated *E*mission of *R*adiation. Laser is an acronym for *L*ight *A*mplification by the *S*timulated *E*mission of *R*adiation. Maser and laser operate on the same principle to yield an electromagnetic beam with very special properties.

The special properties of laser light can perhaps best be understood in relation to light from an ordinary source such as a fluorescent lamp. For a fluorescent lamp to emit light, the atoms of the gas it contains must first be excited to a state of higher energy than their normal, or ground, state. Then, in falling back down to the ground state, the atoms give up in the form of light the excess energy they had earlier acquired.

The atoms of a fluorescent lamp are excited by the flipping of a switch, which sends through the lamp a current of electrons, which bombard the atoms. The atoms return to the ground state from the unstable excited state spontaneously and individualistically; their light is therefore emitted in a disorganized manner, randomly in time, and in all directions. This type of light, common to all ordinary sources, is known as *incoherent* light.

Laser light is quite different. The excited atoms in a laser do not emit as individualists, contributing to a general anarchy. After excitation, the atoms are held in the excited state until there is a large collection of them; then they are stimulated to emit, not independently but in a regimented fashion, with all the light waves pointed in the same direction, their crests and troughs aligned. This kind of light is called *coherent*. Coherence is the property that gives laser light its remarkable characteristics.

Coherence is a concept that has long been part of standard electromagnetic theory. Stimulated emission was treated by the ubiquitous Einstein in 1917. What was introduced by the maser and laser scientists was the idea of getting up a collection of excited atoms and stimulating them in such a way as to amplify their light.

Optical spectroscopy was an established field at the beginning of the century. So lasers might have been developed long ago. But their ancestors, the masers, could not have been invented before World War II, for only then did the field of microwave research open. The notion that stimulated emission could lead to amplification apparently had to wait until the 1950s.

Then the concept of "togetherness" was introduced independently in Russia by Nikolai G. Basov and Alexander M. Prokhorov, and in the United States by Charles H. Townes and his students at Columbia University and by Joseph Weber at the University of Maryland.

The amplification principles were first successfully applied to an ammonia gas maser in 1954 by James P. Gordon, Herbert J. Zeiger, and Professor Townes. Despite the fact that microwave spectroscopy was so much newer than optical spectroscopy, the maser preceded the laser because amplification had always been associated with electrical circuits, and microwave devices had been components of circuits since the war. The first masers were followed by considerable speculation about how to extend the amplification principles from microwaves to light. In 1958, in a theoretical paper, Arthur L. Schawlow and Townes explored the conditions that would be required for this transition.

Drawing on the research that had already been done by Kastler, these two stated that in principle one ought to be able to make a laser from a crystal, such as ruby, if one used optical pumping to get the atoms into the excited state. They added that it would be extremely difficult to do so in practice, however, because the amount of energy required for the optical pumping was greater than could be obtained from commercial lamps then available. But Theodore H. Maiman, then at the Hughes Research Laboratories, "souped up" his apparatus to provide a greater intensity of excitation than had been thought possible. His laser, made of a rod of synthetic ruby, was the first light amplifier to be constructed in this country. That was 1960.

Meanwhile, in the U.S.S.R., F. A. Butayeva and V. A. Fabrikant, using mercury, amplified light in 1957, but their work wasn't published until two years later and then not in the usual scientific journals (which are extensively translated—some with U.S. Government funds) but in a memorial volume to a scientist little known in this country. For this reason the work of the Russians received almost no attention in the western world. But the 1964 Nobel Prize for Physics shared the credit among Basov, Prokhorov, and Townes.

The material from which the laser is fabricated is of fundamental importance: It must be one in which the excited state of the atoms lasts long enough for a collection of excited atoms to be built up. The next phases of laser action—stimulation and amplification—are essentially problems in engineering: that is, in how to construct the laser from the chosen material.

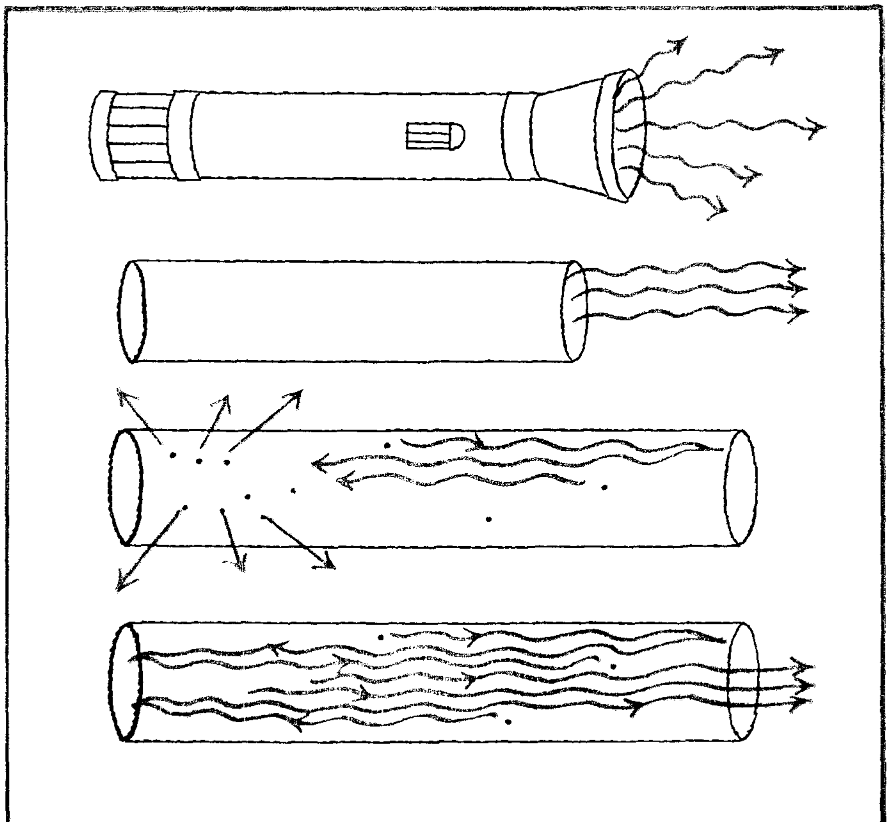
Now it is a property of stimulated emission that the stimulated light waves will be exactly aligned, with respect to direction and to wave crest and trough, with the radiation that does the stimulating. Out of the collection of excited atoms waiting to be stimulated, one atom falls to its ground state, and, in the process, emits light. That light will come into physical contact with one of the other excited atoms and will stimulate it to fall to *its* ground state and emit light; and the stimulat*ing* and the stimulat*ed* light will be exactly in step. The light from these two atoms will hit other excited atoms, will stimulate them to emit in step, and the light from these will stimulate still more atoms, and so on, until that first atom that fell to the lower state has loosed an avalanche.

IF, however, while the light from the first atom is being amplified in this coherent manner, another atom should chance to fall and emit in a different direction, its light would also be amplified. The light of this second atom would have a disturbing effect owing to its lack of coherence with the light initiated by the first atom. One must get rid of the disturbing light.

That is where the elaborate construction requirements for a laser originated. A typical early laser was a single crystal of synthetic ruby machined in the form of a cylindrical rod about four centimeters long and half a centimeter across. The ends were polished flat and made parallel to within about a millionth of a centimeter; then they were coated with silver to turn them into mirrors.

IF the first atom emitted light in a direction parallel to the length of the cylinder, all the light stimulated by that light would also travel along the length of the cylinder. When the light reached the end of the cylinder, the mirror there would reflect this light and stimulate more light in the same direction. All this light would hit the mirror at the opposite end of the cylinder, be reflected back again, stimulate still more light in the same direction, and, in this way, build up a steadily growing intensity of light.

If the disturbing atom mentioned earlier should emit light in any direction other than parallel to the length of the cylinder, either immediately or after a few reflections by the mirrors, the disturbing light would bounce through the



WHY THE LASER WORKS: Flashlight (top) throws incoherent light in all directions and beam soon dissipates. Laser light (second sketch from top) travels in one direction only and coherence holds beam in narrow compass. Diverging light waves escape through laser cylinder walls (third sketch from top), leaving remaining waves to move in step, crests and troughs aligned, over long distances.

curved walls of the rod, which do not reflect light. Therefore, *no light except that traveling along the length of the rod can build up in intensity (be amplified).* If, now, the mirror at one end of the rod is so constructed as not to reflect 100 per cent of the parallel light but to let through a few per cent of the light, the beam will come out straight ahead with almost no spread, *coherent,* ready to perform.

THE initial excitation by optical pumping was achieved in the following way. Maiman used as his source of excitation a lamp similar to those used by photographers, one that puts out an enormous burst of incoherent light in a fraction of a second. His lamp was shaped in the form of a helix wrapped around his ruby rod, so that as much of the exciting light as possible would reach the rod. The lamp was connected to a large bank of condensers carrying a tremendous charge of electricity. That charge produced enough energy to excite the atoms of the ruby to lase.

By 1961 there was furious activity in the search for new materials, solid, liquid, and gaseous, and in the improvement of existing lasers. Some of the new materials were superior to the ruby in that they did not require as much energy for excitation. Others provided light of a color different from the characteristic red of the ruby. Substitutes were found for the metal end-mirrors, which burned up after a few bursts of laser light. At the same time there was equally furious activity in publicity touting the near-miraculous potentialities of the new device. Applications covering the spectrum from death rays to eternal light bulbs were proposed.

It might be well to stop at this point to separate fact from science fiction and examine the meaning of the extravagant numbers. It is true that the ruby laser can put forth a million watts in one flash (compare it to a kitchen light bulb, which uses 150 watts of power and puts out about 10 per cent of that in light) but it is also true that that energy is not enough to boil a teaspoonful of water.

One must make distinctions between power, energy, power density, and energy density. The watt is a measure of power which is energy per second, and the million-watt figure for the laser is arrived at by an output of about 1,000 units of energy (not phenomenal in itself) in a thousandth of a second. One thousand divided by a thousandth gives the million watts. The household unit of electrical energy is the kilowatt-hour (one kilowatt-hour is one watt for a thousand hours); by using it as a scale of measurement, one sees why a million-watt flash is not able to boil a teaspoonful of water. One million watts of power, lasting only a thousandth of a second, make only 1/3600 of a kilowatt-hour.

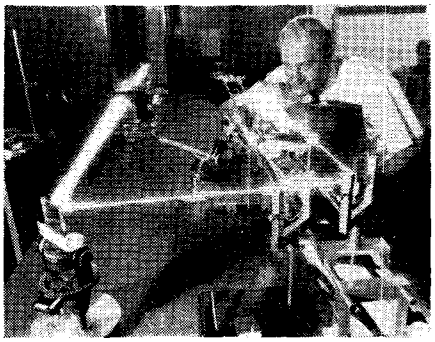
The co-inventor of the laser, Dr. Schawlow, himself called attention to the gulf between present laser beams and the heat rays some people predict will be capable of destroying ballistic missiles. But he stressed that with proper focusing a laser beam can melt, weld, or vaporize a small amount of any substance. The key words are *small amount.* When the beam is focused to a tiny spot, there is such a dense concentration of energy and power in that spot as to penetrate a steel plate an eighth of an inch thick.

Do you remember, as a child, burning a hole in a piece of paper by focusing the light from the sun with a magnifying glass? Well, although one can burn a hole in paper by concentrating sunlight with a lens, one thing one cannot do with sunlight, with the best lens system in the world, is produce a spot brighter than the sun. Why not? Because the sun's light is incoherent, and incoherent light cannot be made to form an image brighter than the source of the light. The best one could do, using lenses of cosmic proportions, would be to get a spot as bright as the sun.

Not so with the coherent light of the laser. Coherent light can be focused to a spot many times brighter than the source. If one were to focus a laser beam with a square inch of area to a spot a millionth of a square inch in area, the spot would be a million times brighter than the original beam. If the spot is made still smaller it becomes still brighter, until we reach phenomenal figures such as a million million watts per square centimeter, 100 million times that at the surface of the sun. This tremendous concentration of power in a tiny area is what gives rise to the astronomical temperatures that enable the beam to burn through steel plates.

Because of its high power requirements, the ruby laser cannot operate continuously and therefore emits its light in bursts. Continuous output in one of the several gas lasers has, in the past few months, become comparable with that of the 150-watt kitchen light bulb, which is also continuous and visible, whereas the laser light is infrared.

That the ruby laser puts forth its radiation in a thousandth of a second has made the laser extremely helpful in the surgical welding of a torn or detached retina of the eye. The eye cannot move in this short time. The same operation, using incoherent light, not only requires an anaesthetic but is more dangerous and painful because of the greater amount of heat the eye receives.



—Wide World.

How a laser beam takes three-dimensional photographs.

Some of the most important uses to which the laser has been put are in the realm of pure science. One experiment which physicists hope to perform in the not too distant future is the scattering of light by light—a significant check of present theoretical physics. According to classical theory, two light beams crossing each other in a vacuum will be unaffected by each other. According to modern theory, there is no such thing as a vacuum—there is instead a sea of charges, which do not manifest themselves, because, there being as many positives as negatives, they neutralize each other. The charges interact with light.

If modern theory is right, then the net effect of scattering of light by light, owing to the interaction of the beams with the charges, should be deflection of the beams. Scientists are optimistic that, with the laser, they will before long be able to test experimentally whether the vacuum contains plenty of charges or Porgy's "plenty of nothin'."

Apart from medical and scientific applications, the laser has found use in areas where its high directionality has been of value. A powerful searchlight beam, such as the ones seen at airports, although intended to be parallel, will spread to a third of a mile across, 10 miles from the lamp, while a laser beam one inch across will spread to less than a foot 10 miles away. Recently, a laser beam illuminated a mile-wide spot on the moon—an impossibility with ordinary light. The directionality of laser beams has also been used in precision surveying.

A kind of photography, called holography, in which three-dimensional pictures are produced, without lenses, was invented about twenty years ago; but it was limited in usefulness because, to be really effective, it required coherent radiation. Holography was given new energy by the advent of the laser, and the potential applications of holography rival that of the laser by itself for box office appeal. Imagine taking pictures of documents through ground glass windows, and not being able to make "prints" of the pictures without having exactly that section of ground glass through which the pictures were taken. It will revolutionize the spying industry! A more significant future use for the laser may be the taking of three-dimensional pictures of our spinal columns. But these await an X-ray laser.

The area in which the laser has been most publicized, communications, has yielded little commercial success. One laser beam, because of its extremely high frequency (a thousand million million cycles per second, compared to radio frequencies of millions of cycles per second) has more information-carrying capacity than all the radio, TV, and other communications channels now in existence. Up to now, however, no one has succeeded in utilizing this capacity in a practical way. There have been schemes to put the information on the beam, and others to get it off again. Some of them work in the laboratory. But outside the lab rain, fog, hail, and snow work drastic effects on the laser beam—they scatter it. One scheme now under consideration calls for the laying of a kind of pipe across the country. Through that pipe the laser beam could be sent. Hardly what one would deem practical! But it might prove less complicated than present telephone equipment, and it could carry a billion conversations.

THE question that must be asked about the laser, according to Dr. James P. Gordon, present head of a research division at Bell Telephone Laboratories—he was a graduate student when he published the first paper on masers with Townes and Zeiger—is: "Are there communications applications for which laser techniques are *superior* to any other?" The answer does not seem to be "yes" unless *superior* is changed to *potentially superior*. Even with potential superiority, however, one might hesitate before attempting to solve the technological problems associated with the laser's use for communications. With present technology in areas such as microwaves, it would be possible right now for everyone on the East Coast to talk to everyone on the West Coast by television phone; the reason it doesn't happen is not because it cannot be done but because not much demand for it has been evidenced.

The meteorologists have found a silver lining in the clouds that scatter the laser beam. They have put to positive use what is a negative effect for the communications people. From the amount of scattering of the beam, they determine the size and density of the clouds, which they then apply to prediction of the weather.

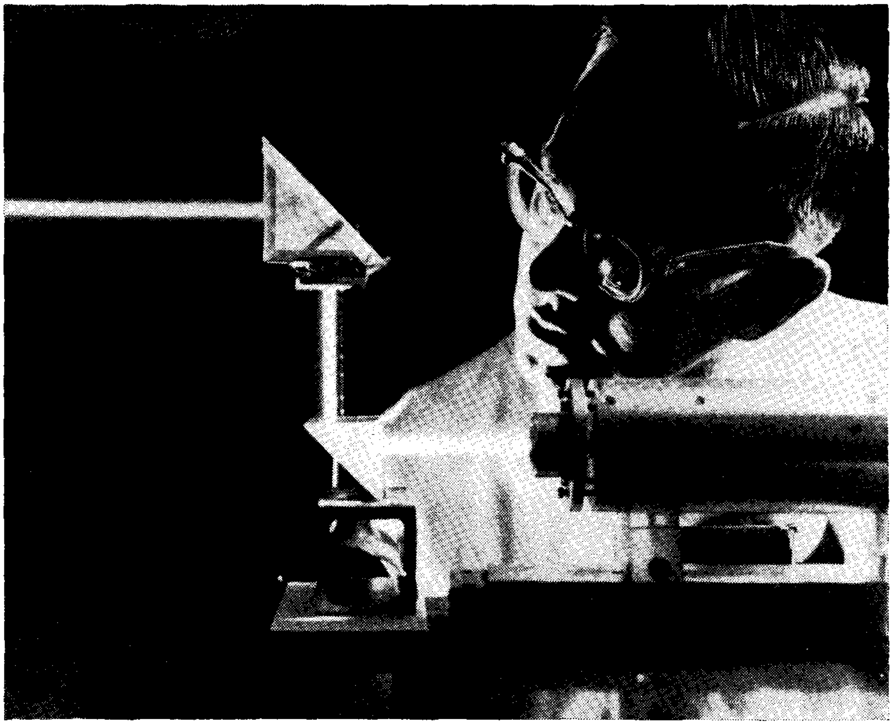
With so many possibilities for commercial application it was almost to be expected that there would be at least one lawsuit involving the laser, and one was indeed instituted last year. R. Gordon Gould petitioned to have patent rights granted him for a feature he claims to have invented, that of placing mirrors facing one another at opposite ends of the laser. Gould says he thought of the idea in his Bronx apartment in November 1957 while a student at Columbia; he had his notes notarized in a local candy store. He applied for a patent in 1959, half a year after Townes and Schawlow made their application. According to the law, Mr. Gould still could have gotten the patent if he could have proved that he conceived the idea first and preserved his rights to the patent by working diligently to perfect the device. His diligence allegedly caused him to fail to obtain his doctorate; and his estranged wife said his constant work on the laser caused the breakup of their marriage. Gould lost his case.

A Danish thinker said, "We live forwards but we understand backwards." Recalling the great expectations regarding the laser when it first appeared, the passing of six years allows for a certain amount of perspective in assessing where they remain in the realm of promise and where they have passed over into fulfillment. Hundreds of different groups all over the United States are working on laser development, on applications to range finding, satellite tracking, TV transmission, yet up to now the laser has been more important scientifically than commercially.

Some detractors of the laser have gone so far as to call the device a solution in search of a problem. But according to Professor Ben Bederson of New York University, "There is disappointment because there was oversell. Serious scientists had put no credence in the extravagant claims, and are not disappointed. They are satisfied with the laser's achievements in pure science, and they believe that in other areas the short-term benefits may not have been as great as was hoped, but progress is being made, and, in the end, many of the predictions made for the laser will be realized. When greater control and power levels are attained, there will be drilling of teeth and surgery and welding by laser. There may even be a death ray."

THE reply to the laser's detractors might well be that of Michael Faraday, when, on demonstrating the very first experiments on electromagnetic effects—which form the very foundation of modern civilization, since virtually everything electrical utilizes them—he was asked of what use his experiments were. He is said to have quoted, "What is the use of a baby?" That reply might also be given to those who ask what is the use of basic research like that of the winner of the 1966 Nobel Prize for Physics.

Dr. Grace Marmor Spruch is an associate research scientist in the Physics Department of New York University.



—UPI.

Deflecting a laser beam through prisms.

LETTERS TO THE SCIENCE EDITOR

The Hospital Crisis

THIS IS A fan letter. I enjoy what you write and the way you write it.

I particularly got a kick out of your article, "What's Wrong with American Hospitals?" [*SR*, Feb. 4]. You must have had quite a time. I sympathize with you but not nearly as much as you deserve. The reason is that you are just a "hard-luck fellow." You're the kind of chap who always has the wrong thing happen to him at the wrong time. (I can appreciate this because I suffer from the same infirmity.) I particularly noted on page 59 "the dry breakfast I hadn't ordered was brought," and I thought the crowning example of your difficult, inherently personal problem was to be found on page 60 at the beginning of the last paragraph where you said, "Beginning on the page facing this page is an excerpt from a formal position paper drawn up by the American Nurses' Association. . . ." As you can imagine, I was not surprised to find, instead of the American Nurses' Association statement, a wonderful picture of Napoleon returning from Elba. This is a good example of how the unexpected and unplanned, and indeed unsought for, incident seems to fall your lot.

Good luck and best wishes, and better luck next time you're sick.

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Chief of the Division of Urology,
School of Medicine,
University of California.
Los Angeles, Calif.

AS ONE WHO bears a portion of responsibility for making hospitals and their personnel *right* for patients and their problems, I was especially pleased to read the SR/RESEARCH evaluation of "What's Wrong With American Hospitals?"

Knowing your deserved reputation for editorial integrity, I believe you will not mind my calling for one correction in the interest of accuracy. Dr. John W. Goldschmidt has been appointed dean of a new School of Allied Health Sciences at the Jefferson Medical College of Philadelphia to work closely with me on experimental education in health services, rather than as stated in *SR*.

Though there are other minor misinterpretations, the spirit of the article is correct. Exciting and important planning is going on at Jefferson. We do have projects for the future based upon long institutional tradition and experience in medical education. We feel that medical educators do have a contribution to make in the solution of medical care problems if given the same hearing and support that has recently been given to other planners.

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Jefferson Medical College
and Medical Center.
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THE AMERICAN NURSES' ASSOCIATION expresses its appreciation that so much of the text of its position paper on education was carried in the February 4 issue of *Saturday Review*. We are pleased that it was presented in a clear and forthright manner.

Articles such as those in the same issue help to point out the need for concentrated and cooperative planning among health care personnel and agencies in all communities. A clearly defined plan for action is needed. As more persons become informed through similar forums, this nation will move closer to optimum use of its health care resources.

(MRS.) JUDITH G. WHITAKER, R.N.,
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SINCE I AM CONCERNED with nursing, public health, and the care of patients, I read the articles on hospital care and nursing education with considerable interest. After reading [Dr. Luther] Christman's proposal, I could not help thinking that your problems—primarily those of comfort and housekeeping—could have been avoided had a stewardess been there. The Detroit experiment with the stewardess system will be one to watch.

However, my main concern is with Dr. [Thomas] Hale's article. Dr. Hale would keep nursing education back in the "good old days"—apprenticeship education, tied to a service agency—while other types of education move into the colleges and universities. He would have nurses—but not social workers, dieticians, physicians, or even laboratory technicians—penalized by education outside the established pattern.

It is true that the present-day graduate in nursing is not a complete product, ready to take on all and any tasks in the complicated care of few or many patients. But the newly graduated school teacher is not ready to supervise an entire school, nor is the newly graduated engineer ready to build a George Washington Bridge. Why, then, should the newly graduated nurse be expected to take charge of a thirty-bed ward of patients in the evening or at night, or direct a team of workers responsible for six to ten patients? The newly graduated nurse needs to practice the skills she has learned in school, to acquire speed and judgment as she continues in practice.

Unfortunately, employers, having a short supply of nurses, tend to rush the new graduate, especially the graduate of a college program, headlong into activities for which she is not prepared. The new graduate finds it hard to resist the temptation of higher pay and better hours that go with the teaching and supervisory jobs she is not equipped to handle. And so the hospital and the new graduate muddle through, both dissatisfied with the results, and the public critical of the efforts.

Whether the hospital should permit acquisition of skills during employment, such as is done with schoolteachers and librarians, or whether there should be an internship such as there is with doctors, is a question that has been raised by schools and employers; but no answer has yet been forthcoming.

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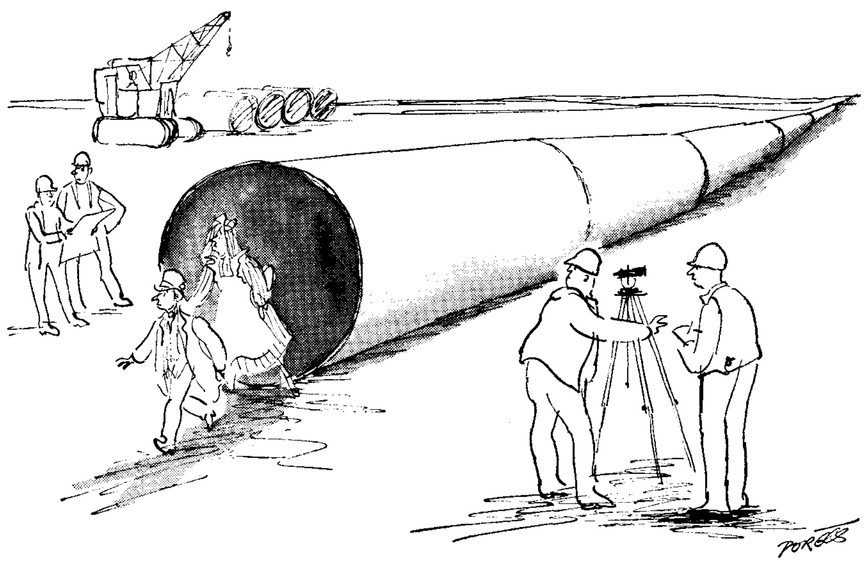

AS A NURSE (graduate of a three-year education program), I must comment on the American Nurses' Association stand on nursing education.

First, only a small percentage of nurses in the United States belong to the ANA, which, like many small groups, loves to speak with great authority. It might be interesting to hear the opinions of the majority of nurses.

Upon graduation, I entered a large university with a nursing department to seek a B.S. in nursing. I soon transferred to Liberal Arts (arts and sciences) after being subjected to "Mickey Mouse" courses in nursing organization. The professors knew absolutely nothing about the reality of nursing and its many problems, such as understaffing. They could understand only the ideal situation. They left me wondering when they last saw a patient.

Nursing is at a crucial point. Certainly we must be better educated, receive the best experience and guidance, *but* we must never forget we belong at the patient's bedside, giving him reassurance.

This brings me to the glorification of psychology by the ANA and collegiate programs of nursing. The ridiculous statements and questions they would have you ask a patient would convince him you are ready for a lock-up ward. Everyone is a