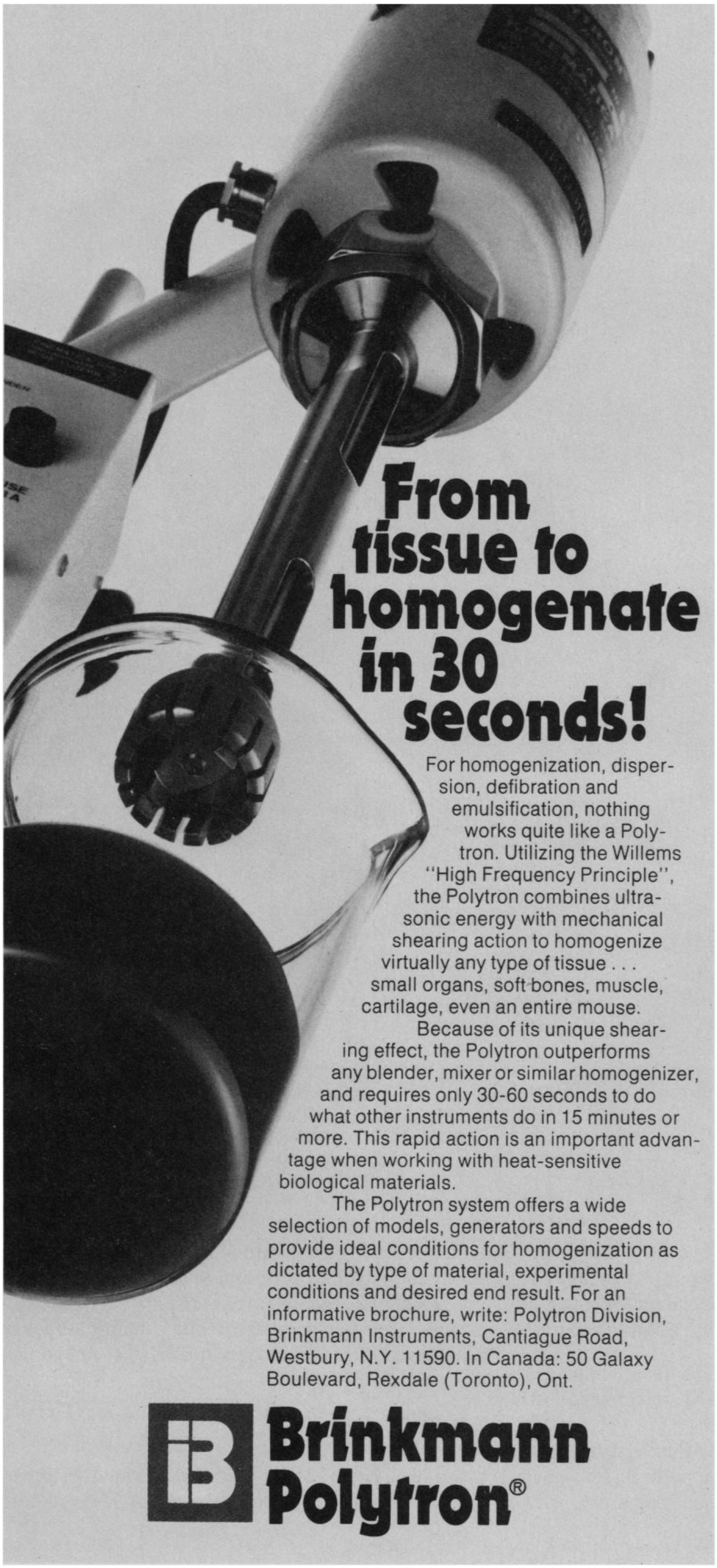

LETTERS

The Origins of the Laser

On 28 October 1977 (p. 379), *Science* published a News and Comment article "Forgotten inventor emerges from epic patent battle with claim to laser" by Nicholas Wade that raises questions about the invention of the laser. The following is a review of the origins and invention of the laser that should shed additional light on these matters and correct some major errors that appeared in this article.

As is so often the case with scientific advances, the laser had its roots in early theoretical and experimental effort that was not applied to practical uses at the time.

Earlier, theoretical workers in quantum mechanics had appreciated that an incident electromagnetic beam of an appropriate resonant frequency passing through a medium might stimulate molecules in an upper quantum energy state to return to a lower quantum energy state and reinforce the primary beam by negative absorption (*1*). In 1940, Fabrikant (*2*) of the Soviet Union proposed experiments to establish the proof of negative absorption, including use of a medium made more conducive to negative absorption by a discharge to effect "collisions of the second kind." A "collision of the second kind" is one in which some of the kinetic energy of motion of the colliding particles is converted to internal energy or a change in energy state of at least one of the colliding particles. In 1950, Lamb and Retherford (*3*) at Columbia University pointed out that, if an upper quantum energy state could be made more highly populated than a lower quantum energy state, there would be a net induced emission to an incident beam and suggested that such a population inversion could be effected between the 2*p* and 2*s* levels in hydrogen. In 1951, Purcell and Pound (*4*) at Harvard University used magnetic techniques to invert the population of a pair of nuclear spin states in lithium fluoride and made the first direct observation of negative absorption of an applied pulse. They described a medium in this condition as at a negative temperature.

Townes at Columbia University was the first to recognize that stimulated emission could provide a new class of useful devices. He capitalized on previous work in molecular beam spectroscopy in Germany (*5*), which involved a quadrupolar focusing technique for separating a beam of molecules into two portions (of which one is predominantly of molecules in the upper of two energy states). Townes proposed dividing an ammonia beam into two portions in this fashion and then passing the high-energy portion through a cavity resonant at the frequency corresponding to the energy separation of the two states. This proposal was first reported in the 31 December 1951 issue of "Columbia Radiation Laboratory Quarterly Reports," and subsequent reports detailed the progress of the experimental work that followed. The original plan, to construct a submillimeter wave generator, was soon modified in favor of a microwave oscillator. The 30 April 1954 issue of the same reports described successful operation of the oscillator, which had by then been named the maser.

In 1959, Townes was awarded U.S. Patent No. 2,879,439, assigned to the Research Corporation. The patent described apparatus using stimulated emission for the amplification and/or generation of oscillatory electromagnetic energy. That patent has been widely licensed to laser manufacturers.

Apparently, others had also been stimulated by the successful Harvard experiments in 1951. In 1953, Weber (*6*) discussed the possibility of a microwave amplifier that involved creation of a population inversion in a suitable medium, with a signal of appropriate frequency supplied. Weber concluded that the amount of amplification produced would be very small under ordinary circumstances and would not be able to compete with other methods, but he felt the approach might have certain special applications. In the Soviet Union, Basov and Prokhorov appear, in the period of 1952–1954, to have independently proposed (*7*) a system rather similar to that of Townes.

Townes's success with the ammonia maser stimulated considerable research aimed at extending the device's applicability and remedying various shortcomings, such as relative complexity and low power. For amplification the research focused on development of a solid-state version that would be simpler and capable of higher power output. This initially involved use of a paramagnetic crystal in which a population inversion was periodically created by application of magnetic fields—which were reversed in a relatively short time as compared to the relaxation times of the energy transitions in the medium (*8*). This however permitted only pulsed operation.

Another approach, followed by Soviet researchers (*9*), aimed at continuous operation and involved applying, to an appropriate gaseous medium, pumping power of a frequency suitable for causing transitions from level E_1 to E_3 of the medium, whereby a population inversion was created between level E_2 and either E_1 or E_3. Some population inversion was reportedly achieved in 1957 (*10*).

Bloembergen (*11*) at Harvard independently envisaged the three-level pumping approach and saw it as a solution to the problem of achieving continuous operation with a solid medium; he proposed a solid-state maser suitable for continuous operation with a paramagnetic crystal, such as nickel fluosilicate or gadolinium ethyl sulfate. On 20 October 1959, U.S. Patent No. 2,909,654 was issued to Bloembergen. The patent described a maser in which a solid was pumped at a high resonant frequency to create a population inversion at a lower resonant frequency. This approach was quickly confirmed by workers at Bell Laboratories, who built the first continuous-wave, solid-state maser (*12*). Rapid development of solid-state masers followed, and such masers were used by workers at Bell Laboratories in their Telstar communications satellite experiments.

Still another approach sought to increase the useful frequency of the ammonia beam maser to the infrared region. In particular, Dicke (*13*) of Princeton proposed a maser which used rotational level transitions in an ammonia beam to achieve resonances in the far infrared, together with a resonator formed by a pair of parallel mirrors and dimensioned to resonate at the far infrared. Dicke, however, did not discuss the need for mode selection, and the particular mirror arrangement described—which involved mirrors more closely spaced than their lateral dimensions—would not have inherently provided mode selection. Quite similar proposals were made by Soviet workers (*14*).

It is clear that in the late 1950's a number of people were considering the extension of maser principles from the microwave into at least the far infrared part of the spectrum. In particular, Townes began to consider more seriously the possibility of extending the maser principles into the optical range and made a proposal for an optically pumped laser in a notebook entry witnessed on 19 September 1957. He then began collaborating with A. L. Schawlow, who was employed at Bell Laboratories. At that time, Townes was serving as a consultant to Bell Laboratories. This collaboration led to the basic laser patent for which an application was filed in July 1958. It was issued in March 1960 as U.S. Patent No. 2,929,922.

In December 1958, Schawlow and Townes (*15*) published a seminal paper in which they analyzed the possibility of lasers. After rigorous analysis, they concluded that adequate gain for sustaining oscillations at optical wavelengths should readily be obtainable in a number of practicable systems employing optical pumping. They discussed in detail the use of a parallel plate interferometer for use as the optical resonator, but one which was characterized by a separation of the plates much greater than their widths to provide discrimination against unwanted modes. Moreover, to achieve mode discrimination necessitated by the expected spontaneous emission, they proposed that the cavity include nonreflective or completely lossy sidewalls.

At about this time, Gordon Gould, a graduate student at Columbia University, where Townes was teaching, had been working on optically excited molecular beams. Gould apparently was also considering structures suitable for extending maser principles into the optical region to form a laser. Townes, in his consideration of a design for an optically pumped laser, had talked with Gould in October 1957 about the properties of the thallium lamps Gould was using in his research. Townes had told Gould at least some of his thinking. Gould has stated that such conversations led him to believe Townes was thinking along lines similar to his for extending maser principles into optical wavelengths and this prompted him to enter his own ideas in a notebook, which he had witnessed on 13 November 1957 by a local notary.

In the fall of 1958, Townes had been circulating at Columbia University and among other physicists a preprint of the Schawlow-Townes paper that had been submitted to the *Physical Review* in August and was to appear in the 15 December issue. Apparently, the imminent publication of this paper stimulated Gould further to record his ideas in his notebook, and a new set of entries was made. These were witnessed on 2 December 1958. Shortly thereafter, Gould visited a patent attorney and, in April 1959, Gould filed a U.S. patent application. This application proposed a wide variety of laser forms and possible uses.

After the Schawlow-Townes patent was issued, Gould precipitated an interference proceeding in the U.S. Patent Office in an attempt to have himself declared the inventor of the laser claimed by Schawlow and Townes (*16*). This interference was based on a claim to a laser that included a chamber for the active medium with sidewalls transparent to the pumping energy, and transparent to—or absorptive of—the other radiated energy. This corresponded to a condition mentioned in the Schawlow-Townes paper—that it was important that the chamber include nonreflective or completely lossy sidewalls for emitted energy to provide the desired mode selection.

After lengthy Patent Office and court proceedings the Court of Customs and Patent Appeals (*17*) concluded unanimously that the laser claim should be awarded to Schawlow and Townes because, as the court concluded, Gould's notebook entries did not adequately disclose the critical limitation discussed above with respect to the sidewalls. A majority of the court further concluded that priority should be awarded in any case to Schawlow-Townes because Gould had not established the "diligence" the law requires.

In 1960, Maiman (*18*) of Hughes Aircraft reported the experimental observation of laser oscillations, generally believed to be the first experimental verification of laser operation. He used a pink ruby cystal which was optically pumped and which radiated in the infrared in a pulsed mode. Maiman received U.S. Patent No. 3,353,115 on 14 November 1967 for his optically pumped ruby laser. Reports of laser action in a number of other solid-state systems soon followed.

In early 1961, Javan and his co-workers at Bell Laboratories (*19*) reported the observation of laser oscillations in a helium-neon gas laser, in which the pumping involved an electrical discharge via the mechanism of "collisions of the second kind." This work had been the subject of a patent application filed on 28 December 1960 (*20*). The earlier-mentioned Gould patent application had proposed, as a possible laser, one in which population inversion would be achieved by means of a gas discharge via "collisions of the second kind" in an appropriate gas mixture, such as sodium-mercury and helium-neon.

The U.S. Patent Office then set up an interference proceeding to resolve the conflict between the Gould application and the Javan *et al.* application with respect to gas lasers involving "collisions of the second kind." After hearings, the Board of Patent Interferences awarded priority to Javan *et al.* on the basis that the Gould disclosure was insufficient in detail to permit an ordinary worker in the art to build an operative gas laser using "collisions of the second kind" without undue experimentation. The Board apparently was influenced by both the inability of TRG (to whom Gould has assigned his application) to make an operative laser of that kind, and by the degree of effort that had been required by the Bell Laboratories workers to make their operative helium-neon laser. Gould appealed this decision to the courts but never followed through, and his suit was ultimately dismissed with prejudice.

Almost contemporaneously, the Patent Office had set up an interference between the Gould application and an application of Hellwarth of Hughes Aircraft with respect to priority of claims to a Q-switched laser. The Gould application had also proposed the Q-switched form of laser. In this contest, Hellwarth maintained that the Gould application had insufficient disclosure to permit an ordinary worker in the art to build a Q-switched laser without undue experimentation, because it failed to teach how to build an operative laser. After a lengthy proceeding, the Court of Customs and Patent Appeals (*21*) agreed with Hellwarth's argument, still influenced by the difficulty TRG had experienced in building an operative laser.

Despite these setbacks, Gould continued his efforts to secure a U.S. patent and on 11 October 1977 he was issued U.S. Patent No. 4,053,845, entitled "Optically Pumped Laser Amplifiers." The issue of this patent has been the subject of much discussion because the expiration of the Townes, Bloembergen, and Schawlow-Townes patents in 1976 and 1977 was thought to mark the expiration of broad, basic patents in the field. Not surprisingly, this patent is already involved in litigation.

It is not the intent of this note to comment in any way on the legal aspects—scope and validity—of the Gould patent. These questions are more properly addressed in litigation which is apt to be prolonged, and it seems appropriate to await the results of this litigation before assessing the impact of this patent. Rather, it is the intent here to show the scientific perspective and evolution of laser technology and to identify the more important contributors to this development.

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15. A. L. Schawlow and C. H. Townes, *Phys. Rev.* **112**, 1940 (1958).
16. In most countries of the world, the first to file a patent application automatically becomes, legally, the first inventor—absent derivation, but in the United States it is possible through an interference proceeding for an applicant who filed later to be declared the first inventor by proving an earlier date of invention. Invention dates are proved by corroborated evidence of conception, reduction to practice, and, in certain cases, by diligence of the inventor.
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Dickens on Statistics

I write with footnotes to June Goodfield's interesting account (11 Nov. 1977, p. 580) of Charles Dickens' antipathy to science—and in particular to statistics. As Goodfield says, Dickens' dislike of statistics arose from his view that statistical treatment of social questions dehumanized human beings and regarded them "solely as numbers in a statistical equation."

First, the humanistic criticism of statistics just summarized is described in my survey article (*1*), with several examples, and with discussion from the viewpoint of one all too human a statistician.

Second, the magazine *Bentley's Miscellany* was not the only vehicle for Dickens' roundhouse swings at statistics. His novel *Hard Times* comments on "gloomy statistical dens" in chapter 3, and on a "deadly statistical clock" in chapter 15; it has similar passages elsewhere.

Hard Times was first published in 1854 in *Household Words*, a journal that Dickens started . . . and ended after a dispute with his publisher.

Third, in the same journal, *Household Words*, there is at least one place where Dickens finds statistics helpful. In the issue of 3 April 1852 (volume 5), Dickens (with Henry Morley) published an article, "Drooping buds." It celebrates the opening of the first children's hospital in London, the Hospital for Sick Children. Dickens and Morley describe in heart-chilling terms the prior absence of adequate medical care. On page 46, there is reference to a committee of the Statistical Society that found in 1843 only 1 out of 100 hospital inmates to be a child with an internal disease. (The inference is that children with internal diseases rarely got to a hospital and died with tragic frequency.) "Drooping buds" is reprinted in (*2*); see also (*3*).

In the medical area one finds perhaps the most perplexing interplay between claims of humanity and those of science in a narrow sense. Let me congratulate *Science* on the treatment of that interplay in the publication of the Birnbaum memorial symposium in the issue of 18 November 1977.

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Health and Habit

Anselm L. Strauss, in his letter (10 Feb., p. 597) regarding John H. Knowles' recent editorial "Responsibility for health" (16 Dec. 1977, p. 1103) makes the statement, "Those who suffer from [cancer, heart disease, diabetes, back disease, arthritis, and chronic respiratory illness] have not chosen them, and medical science can do little more than make palliative gestures on behalf of the sufferers."

Rather brief experience in caring for patients would have quickly led any observer to the conclusion that the patients indeed have played a strong role in choosing the diseases mentioned by smoking, overeating, and not exercising, which aggravate the diseases.

Through individual habit and will, it is possible for the patient to alter these conditions. This is not the responsibility of society or government but rather that of the individual. Currently, many patients, including members of the "white, well-educated, and affluent middle class," refuse to accept this responsibility even when it is forcefully pointed out to them after they develop these chronic illnesses.

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