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Lasers, Spectroscopy and New Ideas

A Tribute to Arthur L. Schawlow

Editors:
W. M. Yen and M. D. Levenson

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Preface

It occurred to some of us as the occasion of Art Schawlow's sixty-fifth birthday approached in 1986 that we needed to make an appropriate gesture to honor this man, not only for his well-recognized scientific contributions, but also for the personal legacy which he is leaving to, and the influence he has exerted on, everyone who has had the privilege of coming into contact with him through the years. After some false starts, it was decided that a collection of articles and reminiscences would serve as an appropriate vehicle for such a tribute, and it is thus that this venture came into existence.

To quantify or enumerate Art's contributions to the scientific literature is a relatively easy task, and his articles and reviews, many of which are classics, are clear, concise and numerous. He has co-authored papers with almost one hundred different people and he has worked with nearly seventy-five collaborators with varying functions during his period at Stanford. The range of topics to which his contributions are addressed is impressively wide-ranging and spans subjects as diverse as Doppler-free atomic spectroscopy and the properties of xenon flash lamp discharges. Needless to say, this volume of scientific work has had undeniable influence and impact in a number of areas of scientific and technical importance, which we need not belabor here. The nature of Art's influence is sampled in the articles presented here and is evinced by the accomplishments of the many researchers he has trained.

It is much more difficult to provide an adequate measure of Art's other contributions, especially those concerned with the fostering of scientific ideas and scientific talent and attitudes. Indeed, it is because of the very positive influence he exerted on many of us with respect to our professional growth that we decided to organize this celebratory volume. For those of us who have had the privilege of falling under his tutelage, it is generally agreed that he attempted to teach us (sometimes successfully, many times not) that very simple concepts are normally sufficient to explain even the most complex observations. This principle has served us all well in our subsequent careers. In addition to developing and encouraging new scientific ideas and approaches, Art has always provided a personal touch in his interactions; in these he reveals without fail his patience, his intrinsic kindness, his humanism, and his humor. This touch was most welcome as it nurtured self-confidence in the many raw and inexperienced graduate students and postdocs that joined his effort at Stanford, including the two editors of this volume.

It was the humanistic side of his influence that led us to choose the general tone of this collection of writings. The authors who graciously agreed to participate in this effort represent a sample of the many scientific areas in which Art has left a legacy or made an impact. We suggested to all the contributors that they write their articles in such a way as to include not only some description of some phase of their present area of scientific endeavors but also to include impressions as to how their personal attitudes and development were affected by interactions with Art. Some of the contributions describe work in which the authors are currently engaged, while others are archival, as they are concerned with the evolution of areas in which Art has made seminal contributions. By and large, we are pleased by the results of the effort, and we believe that in this collection a number of the contributions will remain relevant well into the future, especially those which were designed to be historical. We have incorporated, between parts, anecdotes and other items which address only the humanistic side and are exemplary of the joy and humor which normally prevail in any association with Art. Indeed, we would also have liked to provide recordings of his jazz clarinet playing dating from his graduate school days, but unfortunately he would not allow their release for circulation.

The volume is organized as follows: The contributed articles are divided into four areas. The first three parts include material devoted to areas in which Art has had an undeniable role, either in establishing a field of endeavor or in exercising exceptional leadership. These are, in sequence, lasers and laser spectroscopy, spectroscopy of atomic and molecular systems, and spectroscopy in the condensed phases. Each of these parts contain four to six papers from authors who have made recognizable contributions in each of the respective areas and who, following their contact with Art, have gone on to distinguished careers of their own. The fourth part consists of three contributions which are illustrative of areas where Art has had an indirect influence, in these cases by training a cadre of scientists who have advanced other frontiers by utilizing those attitudes which are so characteristic of "The Boss". The picture we have succeeded in presenting in this sampling does not totally summarize all the accomplishments of Art Schawlow. Many of us are cognizant of the fact that Art made a pioneering attempt at laser isotope separation in the early 1960s, that he played a principal role in interpreting the spectra of magnetically ordered materials, and that methods to induce cooling in atoms with lasers were suggested by him in the early 1970s. Regardless of the shortcomings of this collection, for which we, the editors, assume full responsibility, we believe that each of the contributions has its own worth; in some instances the articles are important reviews in their own right, albeit softened somewhat from the usual austere scientific format because of the nature of this enterprise. The advantage in return is that the majority of the contributions are eminently readable and will be understood by a wide range of readers not directly involved in the specific areas of scientific endeavor.

It is always difficult to take time out from the many pursuits which normally engage our time to participate in extracurricular ventures. It is indeed gratifying that so many people readily agreed to contribute to this volume and, for the most part, produced their manuscripts on time. The editors would thus like to take this opportunity to express their thanks to all who participated in this worthwhile cause and also to Dr. Helmut Lotsch and Springer-Verlag for their cooperation, which made this volume possible. Ms. Nancy Bachman of the University of Georgia is thankfully acknowledged for her assistance in sundry editorial tasks. And, of course, Mrs. Fred-a Jurian is acknowledged to be the true "boss of bosses" of the operations at Stanford, and she bears direct responsibility for many of us having survived the vicissitudes of our youth, perhaps at times to her regret. Indeed, this volume is also a tribute to her wisdom, concern and kindness.

San Jose, California
April 1987

W.M. Yen
M.D. Levenson

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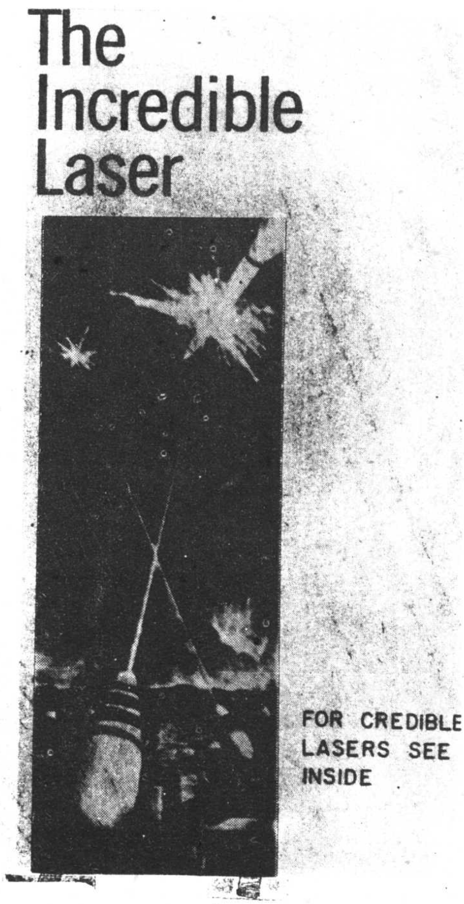
Lasers and Laser Spectroscopic Techniques



Sign on entrance to Schawlow's Stanford laboratory

From (Incr)edible Lasers to New Spectroscopy

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Arthur L. Schawlow was already a very famous man when I first met him at a summer school in Scotland in 1969, a few months after I had received my doctorate from the University of Heidelberg in Germany. Immediately captivated by his personality, his quick and sharp mind, and his warm humor, I wrote to him, asking if he would take me on as a postdoc for a year or two. Fortunately, he agreed, and I arrived at his laboratory in May 1970 with a NATO Fellowship. Little did I know that I would join the faculty of the Physics Department at Stanford University two years later, and that I would be able to enjoy a close association and friendship with Art Schawlow for the next 16 years.

The early years of this period were most exhilarating, since we found ourselves at the heart of a revolution in laser spectroscopy. Many accounts have been written of the research at Stanford during this time [1-3]. Here I hope to add some personal impressions and anecdotes which capture a little bit of the human side of this great scientist.

The Incredible Laser

After arriving at Stanford, I was fascinated by a special "magic" atmosphere in Art Schawlow's laboratory. Walking down the hallway on the second floor of the Varian Physics building, a futuristic poster on one of the doors caught my eye. It showed an enormous laser gun blasting at some attacking rockets in the sky. The caption in bold letters read: "The Incredible Laser". In smaller letters below, someone had written "for credible lasers, see inside".

There could be no doubt that to Art Schawlow science is great fun. Despite his extremely busy schedule, he would often find the time to treat visitors to some amazing and entertaining demonstrations. Rummaging in a huge briefcase, he would for instance pull out his famous red toy laser gun, into which his technician has skillfully installed a real small ruby laser. With serious voice at first, he would begin to explain: "We found the whole idea of the laser was some kind of a death ray. So Mr. Sherwin built us this ray gun. Having a weapon, we had to do a little hunting and went looking for some animals. Around Stanford, the only place you find animals is in the zoo. But at the zoo the animals were all rather big and fierce. So we just bought a balloon for the kids."

At this point he would begin to noisily inflate a large clear balloon. "But when we looked at the balloon there was something funny about it - there was something inside it." Gradually, a blue balloon begins to appear inside, with big ears like Mickey Mouse. "There was a mouse inside that balloon. You know it is terrible the way mice get into everything! So we had to get our more or less trusty laser and dispose of it." With a pull of the trigger, the ray gun flashes, and the inner balloon bursts with a loud pop while the outer balloon remains unharmed. This instant is captured in Fig. 1.

Figure 1. Art Schawlow using his ruby laser ray gun to dispose of a mouse.

"Now this is a very serious experiment. It works because the outer balloon is clear so that the red light flash of the laser passes through it without being absorbed. The inner balloon is dark blue and absorbs red light so that a hot spot was formed on the surface. This illustrates how, with lasers, light is no longer something to look with, it is something you can do things with, and you can do them at places where you can see but not touch, as for instance at the retina of the eye. One of the very first applications of lasers was for surgery inside the eye, to prevent blindness from either a detached retina or leaky blood vessels." Art Schawlow likes to add that he had never heard of such diseases when he started his work on lasers. And if he had set out to find a treatment, he certainly would not have been fooling around with atoms and stimulated emission of radiation.

Sometimes the laser ray gun fails to work, but Art Schawlow is ready for such mishaps. By pulling another trigger, he can fire a small spring-loaded arrow with a rubber tip. "This is our second-strike capability."

Another of Art Schawlow's favorite demonstrations is his "laser eraser", a small flashlamp pumped Nd:glass laser which can be used to evaporate the ink from type-written or printed paper. With an impish twinkle in his eye, he would ask an unsuspecting visitor for a one-dollar bill. Pointing the eraser at the eye of George Washington, he innocently asks his victim to push a button. With a pop the eye vanishes so that Washington now appears to wear a monocle. "What have you done?", Art Schawlow would exclaim. "You know that it is illegal to deface US-currency!" Quite a few of these dollar bills are probably still being treasured as souvenirs, even though the future of the laser eraser may have become somewhat clouded by the success of personal computers and word processors.

Art Schawlow has little patience with abstract theory or tedious mathematical derivations. But he combines a vast range of knowledge and interests with a brilliant intuition. He has a unique gift of seeing the significance of new discoveries, and he can explain complex ideas in the most simple and lucid terms. To make a point in a public lecture, he can draw on all the skills of a good comedian. To give an example, I will never forget his explanation of "coherence":

"Now, nearly everybody knows what is meant by 'coherent'. But in case there is a chemist in the audience, let me explain: you see from the beginning of time until the last twenty years or so, all light sources have been essentially hot bodies, whether it is the sun, or a tungsten filament in a lamp, a flame, or the atoms in a neon sign. The atoms are jostled around by the thermal agitation, and as an atom gets struck, for a moment it stores a little bit of energy. But in a millionth of a second or so, it releases it and sends out another light wave. Now, there are a lot of these atoms and you can picture this process as being like raindrops falling into a still pond. As each drop lands - or as each atom emits - the waves spread out in ever widening circles." With movements of his arms and hands he would illustrate this spreading of waves. "So you have atoms here going ping, and ping - the big ones go pong - ..." Gesticulating with ever increasing speed, he bursts into a wild and hilarious jumble of "ping, ping, pong, pong, ping..." Suddenly he would stop and explain, after a measured pause: "Now, for some reason, people call this kind of light 'incoherent'..."

Art Schawlow has not only made immense contributions to the public understanding of lasers and optical science. With his keen interest in fundamental physics and his contagious enthusiasm, he has a rare ability to inspire students and co-workers to high achievements. Sometimes, he would visit a young graduate student in his laboratory and ask: "What have you discovered?" To most, the thought that they were there to discover something new came almost as a revelation. But how does one do that? Art Schawlow gives very important encouragement when he emphasizes that one does not have to study everything that is known about a subject in order to discover something new. One only has to find one thing that was not known.

Edible and Other Dye Lasers

After the "Sputnik-shock" in the sixties, quite a lot of money had flown into university laboratories in the United States, and Art Schawlow had managed to accumulate an enviable collection of instruments and expensive components. "I have been poor, and I have been rich," he sometimes quipped, "and let me tell you, rich is better! As experimentalists, we always can find something to do, even if we have to work with string and sealing wax. But then, a lot of talent, time and effort gets wasted. One problem is, one never knows what remains undiscovered simply because the right equipment is not there at the right time."

I soon started to enjoy my work in the laboratory tremendously, since Art Schawlow left me complete freedom in my research while giving me access to all his treasures. He even agreed to let me purchase an AVCO nitrogen laser which I was planning to use as pump source for a tunable dye laser. Laser action in dyes had been discovered a few years earlier by Peter Sorokin and independently by Fritz Schäfer. I felt that it should somehow be possible to make such a dye laser so highly monochromatic that it would permit us to study spectral lines of free atoms and molecules by the powerful new methods of Doppler-free saturation spectroscopy which Peter Toschek and I had begun to develop during my thesis work at Heidelberg.

The new nitrogen laser turned out to be a marvellous toy. By simply focusing its ultraviolet output beam with a cylindrical lens into a glass cell filled with an organic dye solution, we could produce spectacularly colorful intense beams of laser-like amplified spontaneous emission. By adding a diffraction grating and a mirror to form an optical cavity, the color of the output beam could be changed at will. At one time I focused the blue light of such a dye laser into a single drop of watery solution of fluorescein. This drop then became a dye laser all of its own, emitting an intense beam of green light. The laser cavity was simply formed by the surfaces of the liquid.

Observing this droplet laser with obvious delight, Art Schawlow postulated that "anything will lase if you hit it hard enough." Thinking about challenges to prove such a claim, we wondered if the colorful gelatine desserts popular with children would show laser action when pumped with the nitrogen laser. The next morning, Art Schawlow came to work waving a package with twelve different flavors of "Knox Jello". Using the hot water supply in the darkroom, we prepared two of the desserts in plastic cups, following the manufacturer's instructions. After they had begun to gel, we took them to the lab and focused the nitrogen laser beam to illuminate a line on the flat surface of the wobbly substance. There was distinct fluorescence, but no laser action. In resignation, Art Schawlow would return to his office and enjoy the obstinate experiment as a snack. This ritual was repeated every morning for a week until we had tried all twelve flavors without luck.

Determined to demonstrate an edible laser, we finally mixed up a packet of clear, flavorless gelatine and added some sodium fluorescein. This experiment was an instant success. With a knife we could cut the new laser material into rods or other shapes. The paper describing this laser would soon be posted on many bulletin boards [4]. A few people considered this experiment a frivolity, but it actually led to some rather important technical developments. Soon afterwards, Kogelnik and Shank [5] exposed a dichromated gelatine film to the interference pattern of two ultraviolet laser beams and demonstrated the first distributed feedback laser. Today, distributed feedback plays an increasingly important role in semiconductor diode lasers for optical communications.

From the beginning, Art Schawlow was very enthusiastic about my plans to develop a highly monochromatic tunable dye laser. Such a tool would open many exciting new possibilities for studying the structure of atoms, molecules, and solids. The nitrogen laser appeared as a particularly attractive pump source, because many dyes spanning the visible spectrum could be pumped with good efficiency at high pulse repetition rates. Past attempts to achieve narrow linewidths with a nitrogen-pumped dye laser had remained unsuccessful. But I was hopeful that it should be possible to isolate a single axial mode with the help of a holographic diffraction grating and a birefringent Lyot filter. After encouraging preliminary experiments, I submitted a paper for presentation at the APS Meeting at Stanford University in December 1970 [6].

As the conference approached, I became rather panicky, because the envisioned scheme did not work reliably. Almost in desperation, I tried an entirely different approach. I moved the grating far away from the dye cell, took out the Lyot filter, and inserted into the cavity a small Zeiss telescope which I happened to carry in my pocket so that I could read the slides during a lecture from the backrow. The idea was that a beam-expanding telescope would illuminate more lines at the grating and so improve the resolution. This little trick worked well beyond my expectations [7]. With a larger telescope, the linewidth could be reduced to a few hundredths of an angstrom. Even narrower lines could be achieved by inserting a tilted Fabry-Perot etalon into the cavity. With this suprisingly simple scheme, we could now produce coherent light of a spectral purity and brightness that was previously only available from gas lasers with very limited tuning range.

Spectroscopy without Doppler Broadening.

During my thesis work at the University of Heidelberg I had become intrigued by the potential of lasers for high resolution spectroscopy. By exploiting the spectral hole-burning effect discovered by Willis Lamb, Bill Bennett and Ali Javan, I was able to develop an early form of saturation spectroscopy [8] which could circumvent the Doppler broadening of spectral lines. With Peter Toschek, we used this method to study collision processes and nonlinear optical phenomena in neon discharges. When I came to Stanford, I collaborated with Peter Smith, then on sabbatical at Berkeley. We demonstrated a simple new method of saturation spectroscopy, using just one single He-Ne laser and an external gas cell [9]. A very similar technique was developed independently by Christian Bordé in Paris [10].

In Art Schawlow's laboratory, Marc Levenson, then a graduate student, was working with a krypton ion laser. By placing a prism and etalon into the cavity, he could make the laser work in a single axial mode, manually tunable over a few gigahertz. During a visit of Peter Toschek in the summer of 1970, we decided jointly to try and use this laser for saturation spectroscopy of iodine vapor, since it was known that the diatomic iodine molecule has several absorption lines in accidental coincidence with krypton and argon ion laser wavelengths. The experiment was at first unsuccessful. A few weeks later, Marc Levenson found out that we had worked with a contaminated iodine cell. With a new cell, we soon obtained very pretty spectra, showing all 21 hyperfine components of one line completely resolved [11].

Art Schawlow was delighted with these results. Even then, he was so much in demand as a public speaker that he sometimes defined "genius" as "an infinite capacity to take planes." In his lectures, he would describe the new experiment with his unique clarity and simplicity by first reminding people of the Doppler effect: "If an object is moving towards you - like a train - the emitted sound goes up in pitch." While making this point he would walk towards the audience and his voice assumed a funny high pitch. Next he would walk backwards and explain in a deep bass voice: "...and if it is moving away from you, it goes down in pitch." Returning to his normal voice: "Now the same is true for light. So in a gas, where the molecules are moving in all directions, the spectral lines appear blurred and spread out by the Doppler effect."

Then he would go on to explain the method of Doppler-free saturation spectroscopy. Showing a drawing of the apparatus as in Fig. 2, he would point out: "The light from a tunable laser is divided by a beam splitter into a strong saturating beam and a weaker probe beam. These light beams are sent through the absorbing gas in nearly opposite directions. When the saturating beam is on, it bleaches a path through the cell, and a stronger probe signal is received at the detector. As the saturating beam is alternately stopped and transmitted by the chopper, the probe signal is

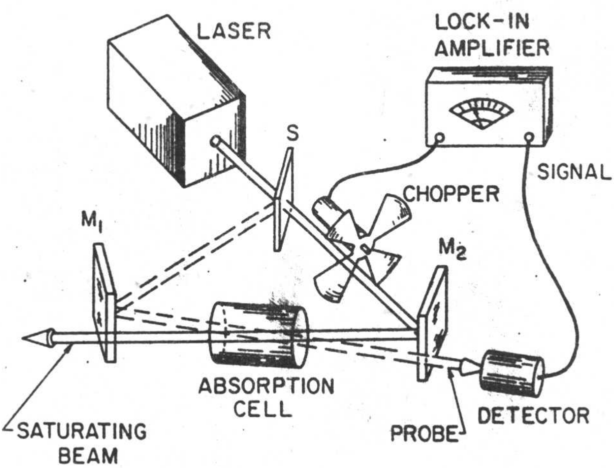

Figure 2. Apparatus for saturation spectroscopy without Doppler broadening.