In Honor of John Hall on the Occasion of his 70th Birthday

Proceedings of the John Hall Symposium
This symposium was a dedication to John L. Hall, who was recently awarded the Nobel Prize in Physics. The symposium was a celebration of his striking career in physics and his impressive record of achievements.

Papers included in this volume offer brief and personal glimpses of some of his achievements, the research he inspired, and the great friendships he has built.
JAN'S GREATEST GIFTS TO MY SCIENTIFIC CAREER

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When I first came to JILA as a graduate student in 1992, Jan greeted me with the words "you are certainly a brave boy, welcome to JILA." In his usually simple and yet subtle manner, Jan had prepared me for many years of hard work, challenge, and excitement ahead. From the first day on, I have been able to share freely with Jan's insightful thoughts and clever tricks. Of equal importance is his encouragement for my independent research activities and imaginations. He passed on his passion and enthusiasm for science and technology to everybody around him. This has been extremely valuable to me during the time when I faced uncertainties and difficult choices. The interaction with Jan not only made it possible for me to complete the stage of Ph.D. studies, but has also prepared me for a life-long endeavor in my scientific career. For this I am forever indebted to Jan.

Jan's influence on my growth as a scientist includes many aspects. I list below a few of the most important examples (in my mind) Jan has set for all of us. Yes, I have learned many useful experimental tricks from Jan. However, I think the most important lesson I have learned from Jan is the right attitude and approach towards science and technology: the attitude and the inner working of how to become a first rate experimental scientist.

"Man, it's fun to work in the lab!"

The first day I came to tour JILA as a perspective student, I saw Jan working in his laboratory looking for a lens mount to realign a light beam through one of the electro-optic modulators (EOM) into his stable optical cavity. After a brief introduction to the general relativity and how his experiment may lead to a better check of the theory, Jan went on to tell me about every individual component in the setup. From this first conversation it became clear to me that Jan took a genuine pleasure from working in the lab instead of sitting in his office. His
comment of "I cannot believe I am getting paid to have fun like this!" rings in my ears to this day. Indeed, only when one has a great interest in what s/he is pursuing can some nicest accomplishments and best results be achieved. Soon I came to realize why his laboratory had been so effective in producing the highest quality research results. Jan virtually knew about every experimental detail in any experiment going on inside his lab. As soon as a technical problem or a new finding arose, Jan could quickly work together with his "highly skilled associates" to efficiently find a solution.

Of course, to prepare oneself to work efficiently in a laboratory, one needs to spend time outside the lab to think about problems and various approaches to solve them, and be creative about future improvements and directions. Jan has also been remarkably efficient in that matter. During my graduate studies, often he would come to the lab and say "You know, last night just before I went to sleep, I was thinking about adjusting the laser in this way ..." Most of the times the solution Jan found during his "half-awakened state" would turn out to be effective in the lab. These experiences were extremely powerful to a young and relatively un-experienced person such as myself. Of course during high school days I read about crazy scientists who cooked up weird schemes in dark laboratories. But here was a living example who somehow magically turned things to work.

I do not know (and I haven't asked Jan about it) whether Jan did these sorts of things on purpose so as to lead a young colleague by example or they simply came from his great enthusiasm about science and technology. In either case, he did it so successfully that a young person like myself would never forget those experiences. If anything, I think he had achieved both goals at the same time, education and science. Surely it's not a coincidence that many colleagues who are now at the forefront of science and technology in various organizations can trace their roots back to Jan's laboratory.

**Make (and fix) things on your own**

Jan's motto is that "if people are interested enough to pursue an experiment, then they should be able to figure out how to make it happen on their own." And Jan has practiced it to the utmost degree. It was overwhelming to a person just joining Jan's laboratory to find out the number of instruments that were homemade. Indeed, even some commercial laser systems had Jan's signature circuitry all over the place. Throughout these years I have found several important benefits in making one's own instruments. The most important one for a graduate student is the opportunity to learn about the art of measurement science itself. The experience of designing and building experimental physics, in a sense, brings to a challenging but rewarding, unique scientific problem-solving experience. It's not just about learning to do experiments; it's about the hands-on experience of building and testing your own equipment. It's also a significant way to develop a sense of ownership and pride in your work, which can be both personally and professionally rewarding.

It takes a solid foundation of understanding, as well as persistence and patience, to succeed in this field. Jan has been a true mentor and role model, guiding me through the twists and turns of experimental physics. His teaching style is unique and effective, always challenging us to think outside the box and be creative in our approach to solving problems. I have learned a lot from him, not only about science, but also about the importance of perseverance and hard work. As a graduate student, I look back on those days with great fondness and gratitude. Jan's laboratory was a place where creativity and innovation were encouraged, and I feel blessed to have been a part of it.
itself. The experience would greatly enhance a student’s confidence in experimental physics, knowing that one can tackle any difficult problems with a sufficient degree of technical competence. This is certainly the aura Jan usually brings to a challenging problem. I also strongly believe in Jan’s teaching that unique scientific problems need unique solutions. Home-made instruments can not only meet our own working schedule in a timely fashion, but in many cases are simply better made with superior technical specifications and/or unique capabilities.

It takes a solid foundation of technical know-how to be able to find unique or superior experimental solutions. When I first joined Jan’s laboratory, I felt I had walked into a gold mine of experimental knowledge. Prior to that I had some limited experimental experiences and my strong background was actually on theoretical physics obtained from my undergraduate days in Shanghai, China. In a little electronics room inside Jan’s laboratory, there was a large collection of books on experimental techniques. I would forget about time when I stayed in that room, reading the books and practicing the techniques I just read about on a neighboring table to check out their truth. It was truly a remarkable, career-changing experience that I had as a first year graduate student at the University of Colorado.

**How to get to the next decimal point?**

Being a demanding experimentalist in his gentle way, Jan is always interested in improvement of laboratory results. He seems to have an insatiable appetite for more precision. When I discussed about a nice result with Jan, after some lengthy exchanges of ideas, he always ended our conversation in “So, how are we going to get the next decimal point?” If not, then what is the technical hurdle we can overcome or are we reaching the fundamental limit? In thinking along these lines, I often found that my understanding to the problem was limited or better yet, an imaginative spark was ignited. Below I provide an example on the initial stage of working out an ultra-sensitive laser spectroscopy technique.

The technique we developed is cavity-enhanced frequency modulation spectroscopy that provided a record absorption detection sensitivity of $5 \times 10^{-13}$ at 1-s averaging time. The work was motivated by earlier work of Prof. Ma, Long-Sheng, who in 1995 and 96 was a visiting scholar in Jan’s laboratory. I had a good fortune to work very closely with Prof. Ma in the lab, who also had a profound impact to my growth as an experimental scientist. The power of our technique lies in its combination of cavity enhancement with FM spectroscopy for signal recovery. By using the cavity, the signal is enhanced by a factor of tens
of thousands while the technical noise associated with the laser source can be almost completely eliminated. This remarkable increase of the signal-to-noise ratio comes from the fact that the exact match between the FM sideband frequency and the cavity free-spectral-range frequency renders the signal detection insensitive to the laser’s frequency noise relative to the cavity. I came up with an acronym to reflect the powerful nature of this technique, NICE-OHMS, which stands for Noise-Immune Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy. (In fact, Jan still owes me a Big-Mac lunch in McDonald’s for having invented this acronym.) Indeed, the improved sensitivity by a factor of more than 1000 over other techniques has attracted a great deal of attention to NICE-OHMS that will offer tangible benefits for trace gas detection, atmospheric sensing, fundamental studies on molecular dynamics, and optical frequency metrology.

During the period of trying to reach the ultimate sensitivity limited only by fundamental physical processes, we worked hard on all sorts of technical issues. Figure 1 illustrates the steps we took in a rapid march to improve the sensitivity by more than 4 orders of magnitude in less than 5 months during the spring of 1996, each step at the request of Jan on finding out what’s limiting the sensitivity. It became a daily routine to me that at the end of the day (or perhaps at the beginning of the day, since Ma and I often worked after midnight) I would write an email message to Jan explaining what problems were solved and getting advice from Jan on what would be the next “most likely suspect”. The high frequency of the FM sideband, which helped to bring the laser amplitude noise down to the shot noise level, was carefully matched to the cavity FSR with a sub-Hz precision. Extra laser/cavity frequency dither helped to reduce the DC noise and drift associated with the thermal fluctuation of the EO modulator. Optical isolations were critical and were provided by acousto-optic modulators placed in between the laser source and the cavity, as well as in between the cavity and the detector. The power received by the detector was adjusted so that technical noise from the receiver system was minimum compared to the shot noise. To maximize the sensitivity, we chose the FM modulation index to maximize the cross product between the carrier and the sideband while at the same time ensuring there was still sufficient power left in the carrier to saturate the molecular transition. Finally, the sensitivity we achieved was a mere factor of 1.3 above what is the lowest attainable level dictated by quantum fluctuations of the photon stream we detected (Fig. 1). And Jan’s next question was “how about we detect the signal in the cavity reflection to minimize the shot noise contribution?”

Check, check, and check... Jan is a very rigorous scientist, so a reputation out there is the key if you want him to publish. Double-checking with him. Manuscript revisions one of those rare presentations.

revolutionary developments in science when the two sides
Figure 1 March towards the ultimate detection sensitivity in NICE-OHMS.

Check, check, and recheck

Jan is a very rigorous scientist and treats his work with the greatest care. He has a reputation out there for being slow in publishing his results. When asked about it, he would smile and say “Well, one cannot change the printing once it’s published.” Double-checking an experimental result is surely not enough for him. Manuscript revisions better go beyond 20 times. The year of 2000 marked one of those rare periods of truly spectacular scientific explosions of revolutionary developments in both optical frequency metrology and ultrafast science when the two fields unexpectedly merged at that time. (Thanks are due
to Prof Ted Hänsch’s remarkable insights and visions to this adventure.) At that
time I had already become a JILA faculty member, armed with Jan’s generous
gift of much of his laboratory space and equipment. Our JILA groups have been
in the forefront of this revolution. I inherited one of the optical frequency
standards that I helped develop during my graduate days with Jan, namely the
hyperfine-transition-based molecular-iodine spectrometer that offered fractional
instability less than $4 \times 10^{-14}$ at 1 s averaging time. Along with Scott Diddams,
David Jones, and Steve Cundiff, we made absolute frequency measurements of
the iodine transition using a self-referenced optical frequency comb, which just
became available at that time for frequency metrology. Later in 2001, Prof. Ma
and I also made the experimental demonstration of reliable optical clock
operation based on this optical frequency standard. Throughout this productive
period of great excitement and activities, Jan constantly requested that I verify
the absolute transition frequency from our iodine spectrometer. I admit at times
my mind was somewhere else thinking about the next cool demonstration of
another effective use of femtosecond comb. However, here it is, Jan, the long
record of the absolute iodine transition frequency from the “JILA West”
spectrometer you and Mark Eichhoff so named (Fig. 2).

![Diagram](image)

**Figure 2** Long record of the absolute optical frequency of a hyperfine transition
in iodine molecules as determined from the “JILA West” spectrometer and a
femtosecond optical comb.

Overall, a gentleman

Jan is an incredibly give-and-take individual, neither holds secrets nor holds grudges.
He relies on open exchange in a true gestalt sense of responsibility to
relationships with all laboratories throughout the world.

I can speak from personal experience. After my postdoctoral research
leave, I returned to the laboratory. I completed the book on another wonderful project
and engaged in further discussions and some explorations. Jan is a
faculty member and a mentor. This is perhaps the real meaning of
listening the gift of talent and perceiving the depth of generosity.
A great gift Jan has bestowed is that he continues to evolve, equipment,
devices, and techniques. And his teachings, on the other hand, will
continue to unfold as time goes on.

Thank you, Jan.
Overall, a gentleman with a generous heart

Jan is an incredibly generous scientist who does not mind sharing any technical secrets nor holds back information on any recent advances made in his laboratory. This is of course an important attitude for science, as its advance relies on open exchange of information among all scientists. Partly this practice may come from his confidence that he can always come up with a better solution in the near future, but I think in a large part this is due to Jan’s belief and a deep sense of responsibility of helping other people. Jan has wonderful collaborative relationships with almost all major (or minor, for that matter) national metrology laboratories throughout the world.

I can speak for myself that Jan also takes care of his own students and postdoctoral researchers. After learning so much from working with him in his laboratory, I completed my Ph.D. work in 1997. Under his recommendation, I went on to work for Jeff Kimble at Caltech as a postdoc. There I experienced another wonderful period of my research career, facing intellectually challenging questions and coworkers everyday. In 1999 I came back to JILA as a starting faculty member and Jan’s gift of lab space and equipment made the launch of my independent career so much more efficient and rewarding. However, I am not listing the gift of the lab, whatever the money scale it might have, as among the greatest gifts Jan had given to me. Our thinking will change, experiments will evolve, equipment will become obsolete, funds can always be applied for, etc. Jan’s teachings, on the other hand, are a lifetime gift that is growing in values as time goes on.

Thank you, Jan, and wish you another 50 years of happy life with Lindy!