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The laser linewidth - Fairy tales and physical evidence

By understanding the Fabry-Perot resonator, one can better understand the laser that oscillates in such a resonator. Recently, we clarified various aspects of the Fabry-Perot resonator, namely the existence of two counter-propagating modes at each resonance frequency and polarization, the relation between mode profiles and airy distributions, the Lorentzian and Airy linewidths and finesses, and the spectral response under frequency-dependent mirror reflectivities and under intrinsic gain or loss.

Based on the assumption that stimulated emission occurs in phase with the incident field, whereas spontaneous emission occurs under an arbitrary phase difference with respect to an incident field, Lax and Haken derived quantum-mechanically the Schawlow-Townes laser linewidth and predicted its narrowing by a factor of two around the laser threshold, and Henry predicted its re-broadening due to amplitude-phase coupling, resulting in the α-factor. However, Maxwell's equations suggest that both stimulated and spontaneous emission would violate the law of energy conservation. We have shown that the phase of the emitted field is 90° in lead of the incident field. When combining Weisskopf's idea that vacuum fluctuations trigger spontaneous emission with Einstein's semi-classical rate-equation approach to Planck's law of blackbody radiation, a direct consequence is that an optical mode contains a vacuum energy of $h\nu$. This result contradicts with Heisenberg's proof that a quantum-harmonic oscillator contains a zero-point energy of ½ $h\nu$. We show that this factor-of-two difference and the factor-of-two narrowing of the laser linewidth have the same origin. Finally, we derive straight-forwardly the general laser linewidth and the Schawlow-Townes approximation in a semi-classical manner.

Speaker Biography

Markus Pollnau received MSc and PhD in physics from the University of Hamburg, Germany in 1992 and the University of Bern, Switzerland in 1996, respectively. In 2004, he became a full professor at the University of Twente, The Netherlands. Currently, he works as a full professor in photonics at the University of Surrey, UK. He has contributed to more than 600 reviewed journal and international conference papers and 14 book chapters. He served as program and general co-chair of the conference on Lasers and Electro-Optics (2006/2008) and the conference on Lasers and Electro-Optics Europe (2009/2011), inaugurated the Europhoton conference (2004), and served as topical editor for the Journal of the Optical Society of America B and Laser Physics Letters. He is a fellow of the Optical Society of America and the European Physical Society.

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