

Casimir-Polder effects in Rydberg atoms

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Before the paper of E. J. Kelsey and Larry Spruch (1978a) physical consideration of Casimir-Polder¹ effects had largely been confined to studies of the interactions between two neutral bodies—two atoms (Casimir and Polder, 1948; Power, 1967; Feinberg and Sucher, 1970; Aldridge and Skofronick, 1972), an atom and a surface (Casimir and Polder, 1948; Shih and Parsegian, 1975), or a charged structureless particle and an atom (Bernabéu and Tarrach, 1976). Looking for a way to measure the very weak Casimir force with a system that did not have the perceived disadvantages of those requiring scattering or surfaces, Kelsey and Spruch considered the interaction between a bound, highly-excited "Rydberg electron" and a He⁺ ionic core. In order to isolate the Casimir effect manifest at large Rydberg electron-core separation r , the bound states studied would possess high enough principal and orbital quantum numbers to ensure that the

¹We draw a distinction between "Casimir effects" involving the interaction between two surfaces (Casimir, 1948) and "Casimir-Polder effects" involving the interaction between two polarizable systems (Casimir and Polder, 1948). There is not a hard distinction (Spruch and Tikoichinsky, 1993).

electron-core system is well-separated. Using quantum electrodynamics Kelsey and Spruch calculated a $1/r^5$ interaction for values of r sufficiently large and showed that under these conditions (and provided the line's radiative width could be split) it might be possible to use the inherent precision of spectroscopy to measure the long-range retardation energy shift arising from the potential².

A separate exploration (Spruch and Kelsey, 1978) around the same time³ into vacuum fluctuations led to simple physical explanations for various Casimir-Polder potentials for pairs of systems where either system is an electron, atom, ion, or wall. The main result was a simple integral bilinear in the dynamic electric and magnetic dipole polarizabilities of each system. It reproduced not only the $1/r^5$ potential for the Rydberg system verifying the more formal QED result, but also the atom-wall (Casimir and Polder, 1948), electron-wall (Barton, 1977) [later dubbed *murium* by Shakeshaft and Spruch (1980)] and the atom-atom potentials (Casimir and Polder, 1948). For the interaction of two electrons the intriguing result was found that the potential is exactly the same as a certain effective

²Larry says he arrived at Rydberg systems after realizing that it would be difficult to do scattering and detect the difference between the van der Waals $1/r^6$ and Casimir-Polder $1/r^7$ potentials and that with walls one can not characterize the wall properties precisely enough. His view on walls, however, has changed, see, for example, Zhou and Spruch (1995).

³Though this paper came out in *Phys. Rev.* after the more formal QED paper, it had been submitted *before it* to a famous letters journal. Larry recalls that he's had "two or three nice papers" and had some trouble getting them into print. On the other hand, he reflects, papers that are extensions of more "standard" calculations are published with relatively little trouble.

potential appearing in positronium calculations. The physical approach to the Casimir-Polder potentials was reformulated slightly and improved upon in two subsequent publications (Spruch, 1986, 1993, 1996) and has been extended to the case of a molecular ion and an electron (Spruch, Babb, and Zhou, 1994).

Another interesting finding of Kelsey and Spruch was that the asymptotic "non-adiabatic" $1/r^6$ interaction, studied previously by Larry and others in a scattering context (Mittleman and Watson, 1959; Kleinman, Hahn, and Spruch, 1968; Dalgarno, Victor, and Drake, 1968) disappears at asymptotically large separations (Kelsey and Spruch, 1978b) in the fully-retarded calculation. Babb and Spruch (1987, 1988, 1989, 1994) extended the QED results of the original paper and reproduced the physical expressions for various cases.

The original papers by Kelsey and Spruch stimulated much related work by other theorists. Necessarily, to measure the tiny Casimir-Polder energy other energy shifts must be well-understood such as the non-relativistic energy of the system (cf. Drake, 1996; Drachman 1985) and the Lamb shift for a Rydberg system (Goldman and Drake, 1992). Larry contributed studies of the radiative width (Marxer and Spruch, 1991; Zhou and Spruch, 1994).

Crucially, Steve Lundeen at Harvard began a series of experiments that continued over the years at Notre Dame and Colorado State on precise measurement of the fine structure of Rydberg helium with a goal of measuring the retardation effect. Eric Hessels, at York University, also made additional measurements (Storey, Rothery, and Hessels, 1995). An

important early finding was that the expected $1/r^5$ potential was too large to be present in the data (Cok and Lundeen, 1981). An additional calculation by Au, Feinberg, and Sucher (1984) extended the validity of the potential to smaller distances. The present status of experimental tests of the retardation potential have been reviewed recently by Stevens and Lundeen (2000). Larry's visits and discussions with colleagues at the Max Planck Institut für Kernphysik led to a study of the feasibility of measuring the retardation energy shift in Rydberg states of multi-charged ions using a storage ring (Habs *et al.*, 1989⁴) and other collaborations (Frischat *et al.*, 1997).

Through his powerful physical arguments and intuition and strong mathematical-physical ability, Larry has contributed in fundamental ways to atomic physics. His initial prediction that there is a Casimir-Polder effect in the Rydberg helium system has inspired experiment and theory alike.

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⁴The first paper co-authored by Larry that was largely experimental and the paper with the greatest number of co-authors.

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