A Critical Compilation of Experimental Data for Spectral Lines and Energy Levels of Hydrogen, Deuterium, and Tritium

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For more than 50 years, Charlotte Moore's Atomic Energy Levels compilation and its subsequent revisions have been the standard source of reference data for the spectra of hydrogen and its isotopes. In these compilations, QED-calculated data have been given. This reflects the fact that the theory of the hydrogen spectrum has been perfected to an extent far exceeding the capabilities of the best experimental measurements. However, rapid advances in laser spectroscopy have recently brought experiment to be on a par with theory. This calls for replacement of the old reference data sets with the new data based entirely on experiments. The present work compiles several tens of recent measurements of the H, D, and T fine and hyperfine structure intervals and presents reference sets of energy levels and Ritz wavelengths derived from these measurements. Fine structure data exist for levels up to n = 12 in hydrogen and deuterium. Above that, there are many observed lines with unresolved fine structure. We systematize these observations and correct for several systematic errors. For tritium, we derive the n = 2 and 3 energy levels relative to $2P_{1/2}$ from observations.

In general, the compiled experimental and semiempirical data in most cases agree well with the QED theory. The largest discrepancies are for the n = 3 levels in H (determined by the laser-interferometric measurements of the $2S$–$3P_{1/2,3/2}$ transitions [1]) and $2P_{3/2}$ in D (determined by the radio-frequency measurement of the $2P_{1/2}$–$2P_{3/2}$ interval [2]).

In most of the the high-precision experiments, the quantities actually measured are intervals between the hfs or Zeeman components of the levels. They are affected by various systematic shifts. To extract the fine structure data from these measurements, it is necessary to apply corrections for the hfs and for the systematic effects. Some of the corrections can be inferred from experimental data, and some can only be calculated theoretically. The largest theoretical corrections are related to hfs. Although they are small compared to measured quantities, uncertainties of their prediction are only slightly less than measurement uncertainties. The size of the fine structure shifts due to the off-diagonal magnetic hyperfine interaction (in H) and electric quadrupole hyperfine interaction (in D) exceeds the QED calculation uncertainties of the fine structure of the low-n energy levels. These effects can become measurable as precision of experiments improves. This calls for further theoretical and experimental work on the hfs.

[1] P. Zhao, W. Lichten, H. Layer, J. C. Bergquist, Phys. Rev. A **34** (1986) 5138.

[2] E. S. Dayhoff, S. Triebwasser, W. E. Lamb, Jr., Phys. Rev. **89** (1953) 106.