bees to associate a floral scent with sugar reward (11). If this deficit is prolonged by chronic exposure, impacts on colony function will accumulate. As expected for these brain deficits, exposed bumblebees demonstrate reduced foraging ability (12) and poor colony growth if exposure continues for weeks (3, 8, 9, 12).

Neonicotinoids are not identical in their effects. Each compound activates a different, but overlapping, neuronal populations (9) and differentially affects learning (11), preference-seeking for a particular compound type (10), and cross-sensitization, in which heightened responses and toxicity resulting from exposure to one compound extend to related compounds (9). Therefore, the effects of the multiple neonicotinoids found to coexist in honey by Mitchell et al. may be additive (if they operate on the same receptor types) or different (if they act on different receptor types). Within an intensive agricultural system that is already depleted of natural forage opportunities, chronic bee brain dysfunction due to neonicotinoid exposure would be expected to decrease bee foraging performance further. The resulting lack of incoming forage may then limit bee fecundity.

Mitchell et al.’s study highlights two key knowledge gaps: the risks from chronic exposure to individual neonicotinoids, and possible cocktail effects when multiple neonicotinoids coexist. A major scientific challenge is that hundreds of agrochemicals are available to mix on site or use independently on adjacent farms. Although this potential complexity appears to create a scientific impasse, Mitchell et al.’s study draws attention to two important untapped opportunities (4), namely to monitor honey contamination as an indicator of local habitat contamination and to gather data on actual local pesticide application rates.

Although recording pesticide use is required in the EU (EC no. 1107/2009) and the United States (1990 Farm Bill), it is not collated into a searchable database that might allow correlation of pesticide use with human disease (such as incidence of chronic idiopathic diseases) or ecosystem damage (insect abundance and diversity) (13). Systematic collection of these data could provide the statistical power lacking from existing field studies, allowing identification of possible cocktail effects that may then be confirmed in laboratory studies to demonstrate cause-and-effect relationships.

**REFERENCES**


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**PHYSICS**

The proton radius revisited

Hydrogen spectroscopy brings a surprise in the search for a solution to a long-standing puzzle

By Wim Vassen

The nucleus of all atoms consists of protons and neutrons, and the simplest of all atoms, hydrogen, has just one proton. The radius of the proton is very small, about 1 fm (1 fm is 10^{-15} m), smaller than the radius of a hydrogen atom by a factor of 60,000. As a proton is such a fundamental particle, much effort is devoted to measuring its size. Since 2010, proton size has been puzzling theorists and experimentalists alike. Measuring transition frequencies in an exotic form of hydrogen, where instead of an electron a muon—an elementary particle 200 times heavier than the electron—is orbiting the proton, a 4% smaller proton size was found (1). The near-6σ discrepancy with both regular hydrogen spectroscopy and results from electron-proton scattering was coined the “proton-size puzzle” and finding a solution initiated intense scientific debate, so far without a definite outcome (2). On page 79 of this issue, Beyer et al. (3) present a measurement of the 2S-4P transition frequency in regular hydrogen, one of the lines of the Balmer series. The value of the proton size they deduce from their spectra agrees with the value from muonic hydrogen spectroscopy and disagrees with most previous measurements in regular hydrogen—and there were many. They also find a value for one of the most accurately determined constants of nature, the Rydberg constant, which disagrees with the literature value by more than three standard deviations.

The efforts of Beyer et al. were a tour-de-force toward reaching the required accuracy. In the experiment, the frequency of the blue Balmer-β line—a line with an inherent linewidth of more than 10 MHz—was mea-

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**Nerve agents in honey**

Bees provide services through crop and wildflower pollination and honey production. Neonicotinoids applied to crops are transported in pollen and nectar back to the bee hives, where their consumption disrupts bee brain function.
Proton size from hydrogen spectroscopy

Tiny shifts of level energies occur when an electron spends some of its time inside the nucleus, providing a handle on the proton radius $r_p$. The shift is largest for low S states. To measure $r_p$ accurately, two transition frequencies are compared.

The 1S-2S transition is excited by two photons at 243 nm. Its excitation is monitored by observing 121.6-nm Lyman-$\alpha$ radiation from the 2P state, populated from the 2S state in an electric field.

Discrepancies

The proton radius (1 fm $= 10^{-15}$ m) is measured by various techniques. The Beyer et al. value agrees with the more accurate result from muonic hydrogen spectroscopy and not with electron-proton scattering data and earlier laser spectroscopy in regular hydrogen.

Discrepancies on the proton radius of $\pm 40$ ppm are compared. 

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