10.13 Appendix F: Vacuum Fluctuations Update (As of 2018)

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Note: This material will be in Appendix F appearing for the first time in the fall 2018 revision of the text.

There are two experiments and two theoretical papers related to vacuum fluctuations (ZPE specifically) that were not covered in Chap. 10 of *Student Friendly Quantum Field Theory*. One experiment (actually a cosmological observation) was done in 2012, and I was unaware of it when I wrote the book (2013, 1st edition). The other experiment and the theoretical articles have only been made public in the past couple of years. I review them in chronological order below and supply links to the original articles. I then briefly address the issue of spontaneous emission, which has been linked in the past to vacuum fluctuations.

10.13.1Three Photons Propagating for Billions of Years (2012)

This study of photons received on Earth that propagated together over billions of light-years implies spacetime is not "foamy" at the Planck scale, where vacuum fluctuations should be paramount, and thus lends support to the notion that such fluctuations do not exist.

Popular accounts include "Cosmic race ends in a tie" by R. Cowen, *Nature.* (10 January 2012) http://www.nature.com/news/cosmic-race-ends-in-a-tie-1.9768, and "Spacetime: A smoother brew than we knew" (January 2013) https://phys.org/news/2013-01-spacetime-smoother-brew-knew.html

The original scientific paper by R. J. Nemiroff, R. Connolly,J. Holmes, and A. B. Kostinski1 is "Bounds on Spectral Dispersion from Fermi-detected Gamma Ray Bursts" *Physical Review Letters.* 108 (23): 231103 (2012). https://arxiv.org/abs/1109.5191 18 Apr 2012.

10.13.2 Usual Analysis of Casimir Plate Effect May be Faulty (2016)

The author of the articles cited below notes, among other points, that typical analyses of the Casimir effect use a Hamiltonian that has implicit dependence on matter fields and illegitimately treat it as if the dependence were explicit. He contends the true origin of the Casimir force is the van der Waals force.

See H. Nikolić, "Proof that Casimir forces do not originate from vacuum energy", *Phys. Lett. B* 761 (2016) 197-202. https://arxiv.org/abs/1605.04143, and "Is zero-point energy physical? A toy model for Casimir-like effect", *Ann. of Phys*, **383** (2017) 181-195 https://arxiv.org/abs/1702.03291 .

10.13.3 Vacuum Fluctuations Experiment (2017)

An experimental group at the University of Konstanz claimed the first direct detection of ZPE fluctuations in a laboratory experiment. Their technical article is quite difficult for a non-specialist in nonlinear optics to understand, so I have written a pedagogic introduction to their work at http://www.quantumfieldtheory.info/pedagog_U_Konstanz.pdf . Note that in that article I question whether ZPE fluctuations have really been detected. The result is controversial.

A popular account "Traffic Jam in Empty Space" can be found at https://www.uni-konstanz.de/en/university/news-and-media/current-announcements/news/news-in-detail/verkehrsstau-im-nichts/ Another account of an earlier, similar experiment by the same researchers titled "Physicists observe weird quantum fluctuations of empty space – maybe" is at http://www.sciencemag.org/news/2015/10/physicists-observe-weird-quantum-fluctuations-empty-space-maybe .

The technical article itself is, "Subcycle quantum electrodynamics", C. Riek, P. Sulzer, M. Seeger, A.S. Moskalenko, G. Burkard, D.V. Seletskiy, and A. Leitenstorfer. *Nature* **541**, pp. 376-379 (19 Jan 2017) https://arxiv.org/abs/1611.06773 .

10.13.4 Spontaneous Emission

As early as 1913, A. Einstein and O. Stern (*Ann. Phys.* **40**, 551), noted that a zero-point energy term had to be added to the classical theory to obtain the Planck radiation spectrum formula. Subsequent research, cited and summarized by P. W. Milonni (Different Ways of Looking at the Electromagnetic Vacuum, *Physica Scripta*, T21, 102-109 (1988) and *The Quantum Vacuum: An Introduction to Quantum Electrodynamics*, (Academic Press, 1994)), extended that perspective to spontaneous emission of radiation from an atom. It appeared that a vacuum contribution was needed to help "jiggle" an orbiting electron and "stimulate" it to jump down an energy level, thereby emitting e/m radiation.

However, Milonni, probably the leading expert on the subject, has noted that, similar to the Casimir plates case, there are different ways to carry out the calculations, and in at least one of them, no vacuum contribution is needed. He says (Milonni 1988), ".. the effects usually attributed to vacuum field fluctuations may instead be attributed to radiation reaction."

He goes on to say

> *"..radiation reaction nevertheless offers a valid basis for understanding spontaneous emission, provided the radiation reaction field is handled properly as a quantum-mechanical operator.*
>
> *.. It was shown in the case of spontaneous emission that the physical interpretation suggested by quantum electrodynamics is more or less a consequence of the way we choose to order commuting (underlining added) atomic and field operators.*
>
> *.. The level shifts and widths can be attributed exclusively to radiation reaction ..., or to linear combinations of the two.*
>
> *.. There is no ordering that attributes the radiative decay of a level entirely to the vacuum field.*
>
> *..Furthermore this picture (of the vacuum contribution) offers no explanation as to why there is no spontaneous absorption (underlining added) from the vacuum field."*

Note that it is the order of operators that commute which changes the relative contributions of the ZPE and radiation reaction. In all the work we have done, the order of commuting operators is unimportant. It is the order of non-commuting operators that impacts our results, and about which we need to take special care. Here, Milonni tells us, the order of *commuting* operators affects the degree to which we can attribute spontaneous emission to ZPE or radiation reaction effects. For a certain order, there is no vacuum contribution. For another order, the ZPE quanta play a part, and the radiation reaction plays a part. There is no ordering for which the effect is entirely attributable to the vacuum. For all orderings, the final result is the same. But the attribution of cause varies.

Hence, like we have seen in other cases, most notably the Casimir effect, the experimentally verified result can be determined theoretically without recourse to vacuum fluctuations.

Still further, if the vacuum plays a role in spontaneous emission, why is there no spontaneous absorption from it?

10.13.5 ZPE and Experimental Measurement

If ZPE fluctuations really impact the physical world, we should be able to detect them directly. Yet, a detector picks up the non-vacuum contribution, but nothing from the vacuum.

As noted by E. T. Jaynes (*Coherence and Quantum Optics IV*, edited by L. Mandel and E. Wolf (Plenum Press, New York, 1978), http://bayes.wustl.edu/etj/articles/electrodynamics.today.pdf, pgs. 5-6).

> *"It seems to me that, if you say radiation is "real," you ought to mean by that, that it can be detected by a real detector. But an optical pyrometer sees only the Planck term, and not the zero-point term, in black body-radiation.*
>
> *It is a supple ontology which supposes that vacuum fluctuations are just real enough to shift the hydrogen 2s level by 4 microvolts; but not real enough to be seen by our eyes, although in the optical band they correspond to a flux of over 100 kilowatts/cm^2. Nevertheless, the dark-adapted eye, looking for example at a faint star, can see real radiation of the order of 10^{-15} watts/cm^2."*