Applications of Lattice QCD – Supplement

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The scope of topics which could be discussed by you is very large. The purpose of posing such a broad essay is to provide an experience similar to research. Having freedom to write about any application of lattice QCD actually places the burden on you to decide for yourself your focus. Your essay should not attempt to be broad, but should pick an interesting physics question and discuss how lattice QCD is helping to address that question. Again, you will not be able to work through every detail; but you should choose a few details, trying to identify the important details and/or those which are most intriguing to you, and spend some effort to work through those details.

Below I list 4 subfields of particle and nuclear physics which are active areas of research receiving input from lattice QCD. You should concentrate on only 1 subfield. In each case I ask some questions relevant to that subfield and which affect the lattice calculations. Again these are just examples and can be added or subtracted as appropriate.

I hope that posing this essay in this manner will simulate research, in that you take responsibility for deciding how to spend your time most wisely. The freedom allows you to pursue or develop your own interests. The risk is that you spend too much time casting about or running into dead ends. I am happy to help give further direction and encouragement.

There are textbooks with an emphasis on formulation [1, 2] and some which focus on methods and applications [3]. There are other texts with which I'm not as familiar, but I understand they are useful [4, 5]. Look for occasional updates of this supplement on the web at
`http://www.damtp.cam.ac.uk/user/wingate/acad.html` .

1 Flavor physics

Determining the parameters governing quark flavor-changing interactions within the Standard Model would be interesting in its own right. However, this pursuit also offers a route to looking for new physics effects. This approach requires precise experimental measurements of meson decays and oscillations, and precise theoretical calculations relating properties of mesons to couplings between quark flavors [6, 7]. The role of lattice QCD is to calculate matrix elements of flavor-changing operators between hadronic initial and final states. Effective field theories play an especially important role in controlling lattice spacing effects, extrapolations in light quark mass, and formulations of heavy quarks on the lattice [8].

2 Hot QCD

At temperatures around 150-200 MeV, quarks and gluons undergo a phase transition from being confined into hadrons to a deconfined state called a quark-gluon plasma [9, 10]. Lattice Monte Carlo calculations can study the thermodynamics of QCD [11].

Interesting theoretical questions are being asked about gauge theories at high temperatures. Which properties of QCD are special to 3 light flavors and 3 colors, and which are more generic. See Refs. [12, 13], for example.

3 Nucleon structure

Even though the proton and neutron are the fundamental building blocks of atomic nuclei, there is much to understand about their properties. The naive model of protons and neutrons as bound states of 3 quarks (*uud* and *udd*, respectively) is not the whole story. For example, much of the proton's spin does not come from the 3 "valence" quarks but is due to the glue binding them [14]. Also, what role does the strange quark play inside the nucleons? Numerical calculations of lattice QCD can address these and other questions [15]. D. Richards has written a useful review [16].

4 Nucleon–nucleon scattering, bound states

There are a number of fine tunings in nuclear physics [17]. In particular, the deuteron binding energy is much shallower than one expects on dimensional grounds and NN scattering lengths are larger than one expects. How do these quantities behave as the quark masses are tuned away from their physical values? This is beginning to be addressed by lattice QCD [18]

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