To whom it may concern,

Below is a summary of the amendments I have made in response to the examiners' comments.

Professor Treutlein writes:

> I *repeatedly stumbled over the statement that "Bose-Einstein condensates are well modelled by mean-field theory" (e.g. in the first paragraph of the abstract, the second to last paragraph on page 1 of the introduction, the first sentence of section 2.2). This was true for the early BEC experiments in the 1990s, but it is nowadays only true for a few subfields of BEC research. There is a large number of experiments in the field that explore "beyond mean-field physics" with BECs, in particular in optical lattices, with BECs in entangled states (squeezing etc), in experiments creating Rydberg excitations in BECs, BECs in optical cavities and many more. I therefore recommend to weaken the statement about the applicability of mean-field theory and explicitly mention some of the beyond mean-field experiments*

To address this, I have weakened these statements, provided a citation to an appropriate book chapter on models beyond mean-field theory, and brielfly mentioned a number of phenomena to which models beyond mean-field theory apply.

I have modified the first two paragraphs of the abstract to read:

> Studies in cold quantum gases enjoy a tight coupling between theory and experiment. Many properties of Bose–Einstein condensates are well modelled by mean-field theory and related methods, with which one may efficiently simulate a large number of Bose-condensed atoms. The efficacy and tractability of ~~this and other~~ such approximate models make them powerful tools for guiding experiments in cold quantum gases for precision measurement, quantum computation, quantum simulation, and studies of superfluid turbulence.
>
> Whilst, within its domain of validity, mean-field theory well describes the motional state of atoms in a Bose–Einstein condensate, their internal states—the motion of their electrons relative to the nucleus—are instead described by the Schrödinger equation.

I have modified the second-to-last paragraph on page 1 of the introduction to read:

> The fields of Bose–Einstein condensation and cold atoms more generally enjoy a tight coupling between theory and experiment, not least because of the enduring usefulness and accuracy of mean-field theory and its extensions \cite{proukakis_beyond_2008}.

Where proukakis_beyond_2008 is a citation to:

> N. P. Proukakis. Beyond Gross-Pitaevskii Mean-Field Theory. In P. G. Kevrekidis, D. J. Frantzeskakis, and R. Carretero-González (editors), Emergent Nonlinear Phenomena in Bose-Einstein Condensates: Theory and Experiment, Atomic, Optical, and Plasma Physics, pages 353–373. Springer Berlin Heidelberg, Berlin, Heidelberg (2008). doi: 10.1007/978-3-540-73591-5_18.

I have modified the beginning of section 2.2 to read:

> Many features of Bose–Einstein condensates are described well by *mean-field* theory, ~~whereby~~ in which the many-body wavefunction is approximated by a product of identical single-particle wavefunctions. Indeed, that the majority of the atoms are in the same quantum state is one of the defining features of BEC. As such, more accurate models that take into account quantum and thermal fluctuations, finite-temperature effects and interactions with thermal atoms \cite{proukakis_beyond_2008}—relevant to excitations such solitons and vortices, and to the onset of condensation at the critical temperature—all feature such a 'macroscopic wavefunction' at their core.

Professor Treutlein writes:

> *I was confused by the statement about the atomic trajectories in the Stern-Gerlach experiment being "irrefutably classical" (beginning of section 1.1). The atoms in the Stern-Gerlach apparatus are in a superposition of two trajectories before they are measured, like in a double-slit experiment, which is not a classical state of motion.*

The sense in which the trajectories are classical is that they are well modelled without considering the wave nature of the atoms, but Prof. Treutlein is correct that the motional state is not enturely classical, in that it is a superposition. To clarify, I have modified this statement to read:

> During a collaboration with Drs Turner and Anderson and Christopher Watkins on this topic, we had the sobering realisation that a bedrock experiment of quantum mechanics—the Stern–Gerlach experiment—was not simulable with oft-used semiclassical methods, despite the ~~motional degree of freedom~~superposed trajectories being ~~irrefutably~~otherwise classical (i.e. lacking wavelike behaviour).

Professor Treutlein writes:

> *I have a minor comment, end of 2 paragraph in section 2.3: it should read "... for other alkali metals..." and not "... for other alkali earth metals..." (Rb is an alkali, not an alkaline earth metal).*

I have corrected this minor error:

> This Hamiltonian is the starting point for any calculations regarding cooling, trapping, and coherent control of ^{87}Rb, and for other alkali ~~earth~~ metals is much the same.

Prefessor Treurlein writes:

> *A minor typo on page 89, 1 paragraph, where it should read "...MOT beams to output 100 mW at t = 3 s..." (not 3 mW).*

I have corrected this minor error:

> Thus the user writes a line of code such as MOT_beams.constant(t=3, 100, 'mW') and this will add an entry to the table of instructions for whichever digital-to-analogue converter DAC is controlling the MOT beams to output ~~3~~100 mW at t = 3 s after the beginning of the experiment.

Regards,

Christopher Billington