

Atom Lens Without Chromatic Aberrations

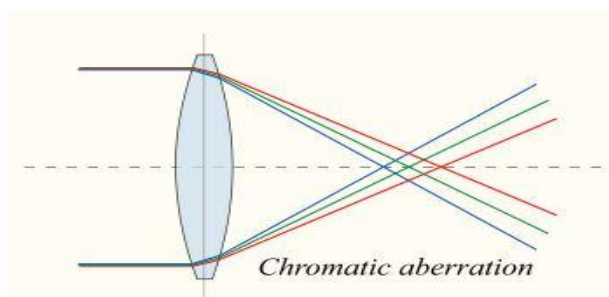
Maxim A. Efremov, Polina V. Mironova, Wolfgang P. Schleich

Published 6 February 2013

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When conducting an experiment in which a lens of any type is in use, it is crucial to use an achromatic lens. You might ask, what is an achromatic lens? An achromatic lens is a lens that is designed to limit the edge effects that signifies a deviation of the device from the norm, i.e., it results in an imperfection². In all lenses there is an increased refraction of light rays when they strike it near its edge in comparison with those that strike the lens nearer the centre creating an image that is out of focus or separates it into its constituent colors. This effect, observed in optical devices, is known as chromatic or spherical aberrations.

This physical review by Efremov, Mironova, and Schleich focuses on atom optics and proposes a lens to focus atom waves that is free of these chromatic aberrations. Their lens is the atom-optics analog of the conventional achromatic lens described above. So why is this important? Why do we care about an achromatic atom lens?



Recently there has been a great deal of interest in atom lithography due to its importance in a multitude of technological applications such as in the carving of microchips. Atom lithography uses atoms, rather than light, to inscribe the features into the chips. This means no etching or use of masks, resulting in greater control and accuracy in the line width and spacing of the features on the microchip.³ In short, a chip that can do more, so where does the atom lens come in and why is this so important? Atom lenses play a crucial role in the realm of atom lithography and many theoretical advances have been made in the field. However limitations occur during experimentation due to these chromatic aberrations. Thus the need for such an aberration free lens as proposed in this paper is crucial for further development in the field of atom lithography. The method brought forth in this physical review, by Efremov, Mironova, and Schleich, to reduce chromatic aberrations relies on the use of a special combination of light waves.

The main proponent for these large chromatic aberrations in the case of these atom lenses is the fact that both the focal length F_0 and the spot size S_0 both depend on the atomic velocity v_y , more specifically:

$$F_0 \propto v_y^2$$

$$S_0 \propto v_y$$

This was the motivation for engineering a phase element for atoms and ultimately a lens with a reduced chromatic aberration. The author's suggestion for this paper relies on the interaction of a two-level atom with

a near-resonant standing wave, providing us with the optical potential inducing the focusing, and a far-detuned traveling light wave removing the chromatic aberrations. Here is where we see the difference to a conventional lens, as we use two level atoms (creating two light fields) as opposed to one light field.

Through rigorous quantum mechanical calculations the final result is one that looks promising. They were able to find the new focal length and spot size of the new achromatic atom lens to be:

$$F = \frac{\Delta}{k_y v_y} F_0$$
$$S = \frac{\Delta}{k_y v_y} S_0$$

Ultimately reducing the dependence on the velocity v_y to being linearly proportional to F_0 and S_0 . This scaling implies “a reduction in the chromatic aberrations in comparison with the conventional technique of focusing atoms.”¹

I was able to interview the leading author of this paper Maximus A. Efremov, who pointed out that, “In theory the result is fine and great but in real life it is of great importance to be able to focus this atom beam.” He understands that there is still much work to be done in confirming these results experimentally, but, he says “

All I can do is make an advertisement of these results and to see if someone can confirm it with experiment and go from there to make more advanced schemes to solve this issue or to improve on this.”

In short, the calculations and the approximations work in proposing a lens with reduced chromatic aberrations. The scheme differs from conventional lenses in that it requires the use of two light fields rather than one, but the improvement to the aberrations is given by the detuned travelling wave and its interaction with the phase of the system.

With these results the next step would be to confirm them through experiment and finally have created an atom lens free of chromatic aberrations. Though this wouldn't completely solve the problem of focusing in atom lithography since there are still other aberrations such as spherical aberrations which would have to be corrected for separately, this is definitely a step in the right direction for atom optics and such technological advances such as atom lithography.

References

1. Efremov M.A., Mironova P.V., Schleich W.P., **Atom Lens Without Chromatic Aberrations**, Physical Review A **87**, 023604 (2013) July 6th
2. http://en.wikipedia.org/wiki/Achromatic_lens
3. <http://physicsworld.com/cws/article/news/2002/oct/01/atom-lithography-sees-the-light>

Interview Questions and Answers:

Q. What is your PhD in, and how many other papers have you published?

A. Yes I have my PHD in theoretical physics and right now I have around 25 papers in many many subjects, most of which in atom optics or free body physics.

Q. What was the motivation that got you interested in this topic and started on the research for this paper?

A. I like very much to work close to the experimentalist group and from what I have studied in atom optics it is very important to create this atom lens without aberrations because it is very practical in applications such as atom lithography. In theoretical the result is fine and great but in real life it is of great importance to be able to focus this atom beam.

Q. How long did it take you to publish this paper, from gathering the information and performing the calculations to the publication of it?

A. In my case, for this particular paper it was very fast for me. The idea came to me in July of 2012 and I am an experienced person so I was able to make quick approximations and make the calculation very quickly it only took me about 2 weeks to get a reasonable theoretical answer. After that I began writing a first draft of the paper which usually takes the longest since you have to make it very clear and concise for readers to understand everything that you have done. After a few revisions it was published within two months on February 6th 2013.

Q. Are the results that you obtained what you expected? Or did you even have an idea of what to expect when you started?

A. Once I discovered the velocity dependence in the focal length and spot size I immediately came to the idea about the focus because any time that you can improve the squared phase on the wave function you can immediately create this focusing effect. From researching chromatic lenses in conventional optics I learnt there is a linear dependence on velocity so I knew I had to reduce the dependence for the focal length to reduce the aberration.

Q. Have any your results been tested or confirmed experimentally to reduce these aberrations?

A. You know for any theoretical physicists this is some sort of a dream but I hope so because I have advertised my results to a small community that works in atom optics and lenses and am trying to get experimental results to confirm this.

Q. What is the next step for you? Does it go to experimentalist groups to test if these results do work? Or are there still more theoretical calculations that need to be made?

A. Well my part is done, it has been published and made available to everyone to read it if they chose to, so someone can see if they can understand it and to see if it is realizable for experiment. Right now I do have another idea however to improve this scheme from a different theoretical point of view but it may not make it easier or more realistic for experimentalists to be able to work with. Although I am not too concerned about this exactly, all I can do is make an advertise of these results and to see if someone can confirm it with experiment and go from there to make more advanced schemes to solve this issue or to improve on this.