Energy and momentum transfer in electron-ion elastic collisions

Łukasz Kłosowski[1]**, Mariusz Piwiński**

Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, Grudziadzka 5, 87-100 Torun, Poland

Synopsis Heating of cold trapped calcium ions by elastic collisions with electrons of various energies was observed. The effect is analyzed theoretically using a multi-center Coulomb potential model.

A new experimental setup using ion trap with electronic beam for ionization process was applied for investigation of trapped ions [1]. There are two interesting phenomena connected with such technique: heating of the trapped ions by Coulomb interactions between ions and the incoming electrons and pressure of electrons acting on the trapped ion cloud. Only the former was observed in the experiment.

The experiment has been performed in a Paul trap with Ca^+ ions as a target. The experimental procedure includes loading the trap by electron-impact ionization of calcium atoms at chosen collision energy. After cutting off the electronic and atomic beams, the trapped ions are Doppler-cooled to the temperature below 1 mK using 397 nm and 866 nm laser beams. They are detected by observation of 397 nm fluorescence using a CCD camera.

After introduction of electron beam to the ion cloud, the image of the ion ensemble becomes less explicit, which can be explained by increase in amplitude of ion motion in the trap's potential well. Example of such effect is presented in Fig. 1. Shifting of ion cloud was not observed.

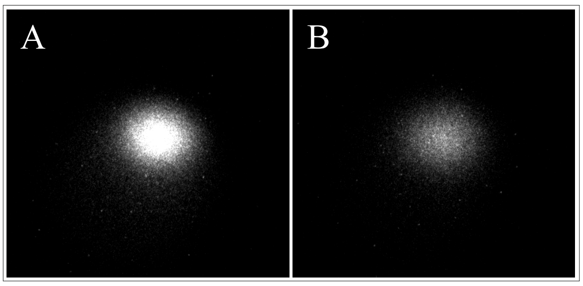

Figure 1. Example of cold ion clouds with the electron beam turned off (A) and on (B). Several thousand of ions interacting with 1 μA, 100 eV electron beam were observed. Size of the cloud was approximately 100 μm. The electrons propagated from the top to the bottom of the image.

Both effects of heating and pushing of the ion ensemble can be described using classical scattering model applying sum of Coulomb potentials from all the ions present in the ion trap. In such model the average energy transfer from a single electron passing the ion cloud is given by equation:

$$\Delta E = \frac{4\eta^2 m_e}{E m_{Ca}} \log\left(1 + (E/\eta)^2\right), \qquad (1)$$

where $\eta = \frac{e^2}{2\pi\varepsilon_0 r}$ (r is a geometrical parameter depending on cloud thickness and density). At typical experimental conditions, the parameter has value of $\eta = 0.3$ meV. The average momentum transfer is given by equation:

$$\Delta p = \frac{\sqrt{8}\eta^2 m_e^{1/2}}{E^{3/2}} \log\left(1 + (E/\eta)^2\right). \qquad (2)$$

The energy and momentum transfer dependences on electron energy are presented in Fig. 2.

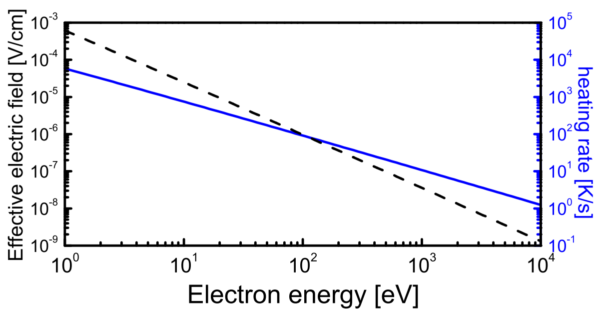

Figure 2. Heating rate (solid) and dislocating force (dash) of electron beam acting on calcium ion cloud. Both graphs are normalized to 1 μA electron beam. The force has been presented in electric field units (normalized to single elementary charge).

According to the proposed model, the pressure of electrons is negligible comparing to the trap's field. Despite of relatively high heating rates, the heated-up ion cloud stays in equilibrium defined by electronic heating and optical cooling.

This work has been supported by the National Science Centre, Poland, project no. 2014/13/B/ST2/02684.

References

[1] Ł. Kłosowski *et al.* 2015 *J. Phys. Conf. Ser.* **635** 072003

[1] E-mail: lklos@fizyka.umk.pl