Charged nano-size clusters as a gas flow diagnostics tool

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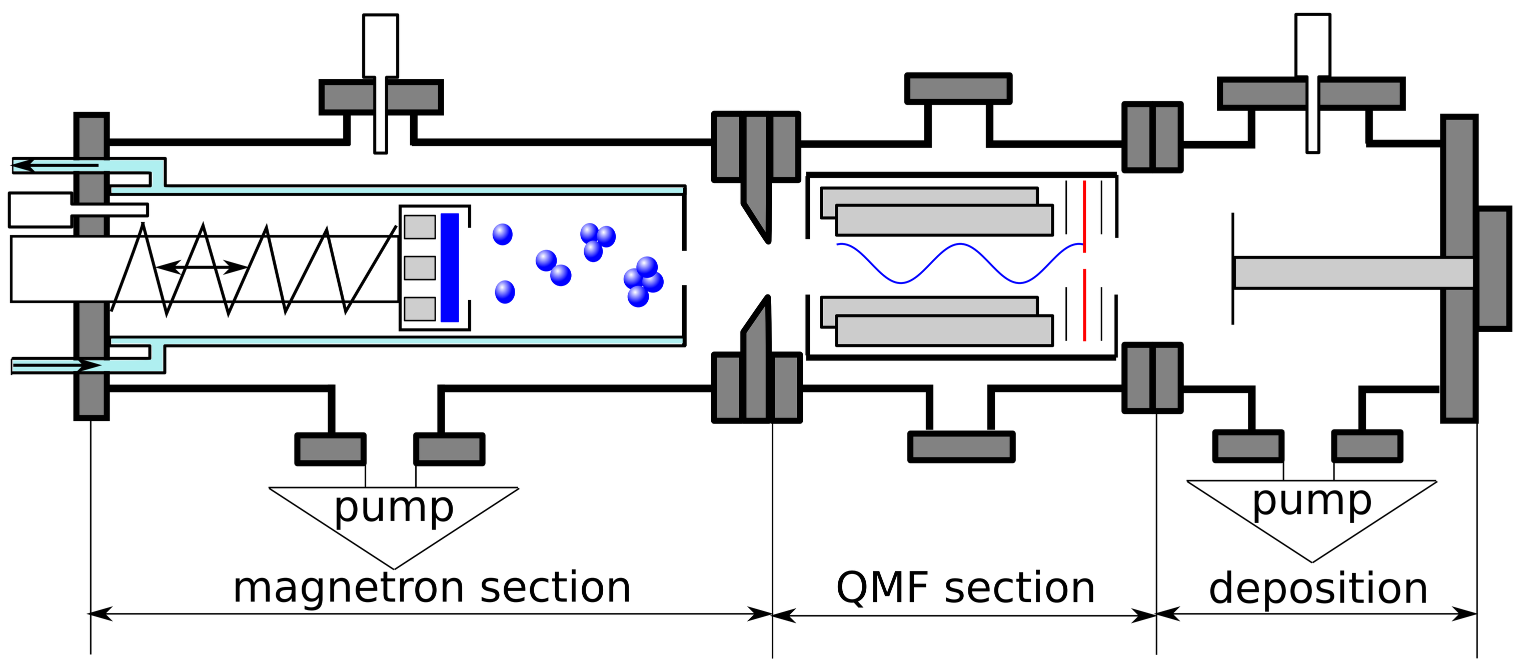
Nanocluster Source

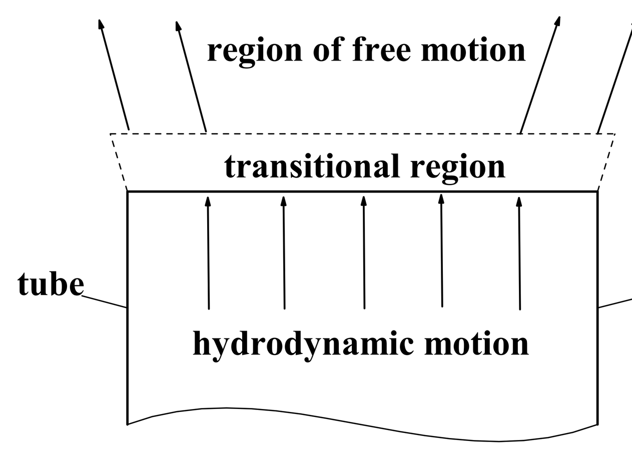
Cu nano-size cluster beam is produced using the DC magnetron-based gas aggregation source [1].



Nano-size clusters form by aggregation in a buffer gas and are extracted as a beam together with the flowing gas. The gas containing clusters effuses through an orifice in an aggregation chamber into vacuum or into a diluted gas. After the orifice the gas expands and transforms into a beam.

Theoretical model

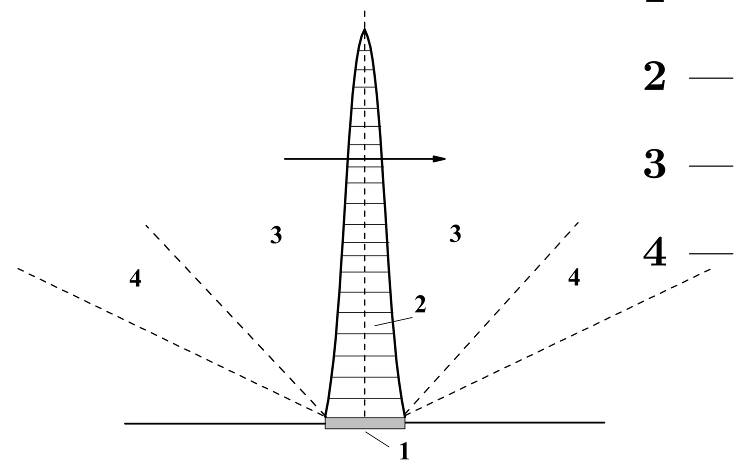
The present work analyzes the cluster relaxation in the gas beam in the framework of the small transition region model. First, we consider change of the flow regime for a gas flowing through an orifice. Then we analyze cluster motion.



$$M\frac{d\mathbf{w}}{dt} = \mathbf{F}$$

$$\mathbf{F} = \frac{M(\mathbf{v}-\mathbf{w})}{\tau_{\rm rel}}$$

$$\tau_{\rm rel} = \frac{3M}{8\sqrt{2\pi m k T}N_a a^2}$$

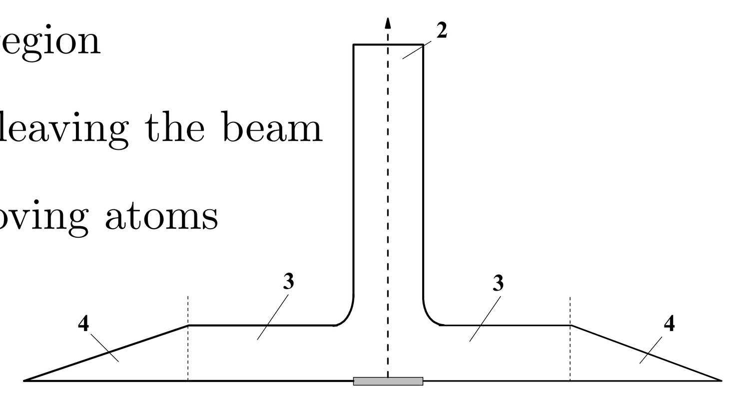


1 — orifice

2 — beam region

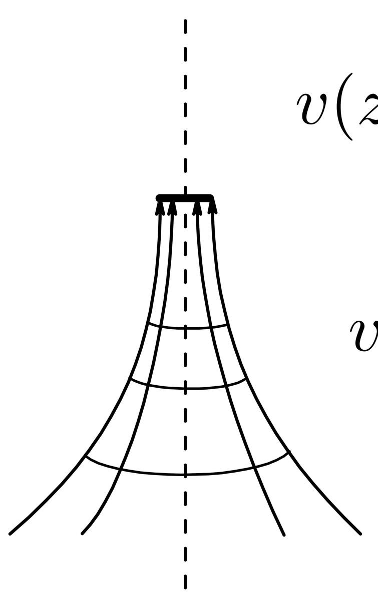
3 — atoms leaving the beam

4 — fast moving atoms



Results and Discussion

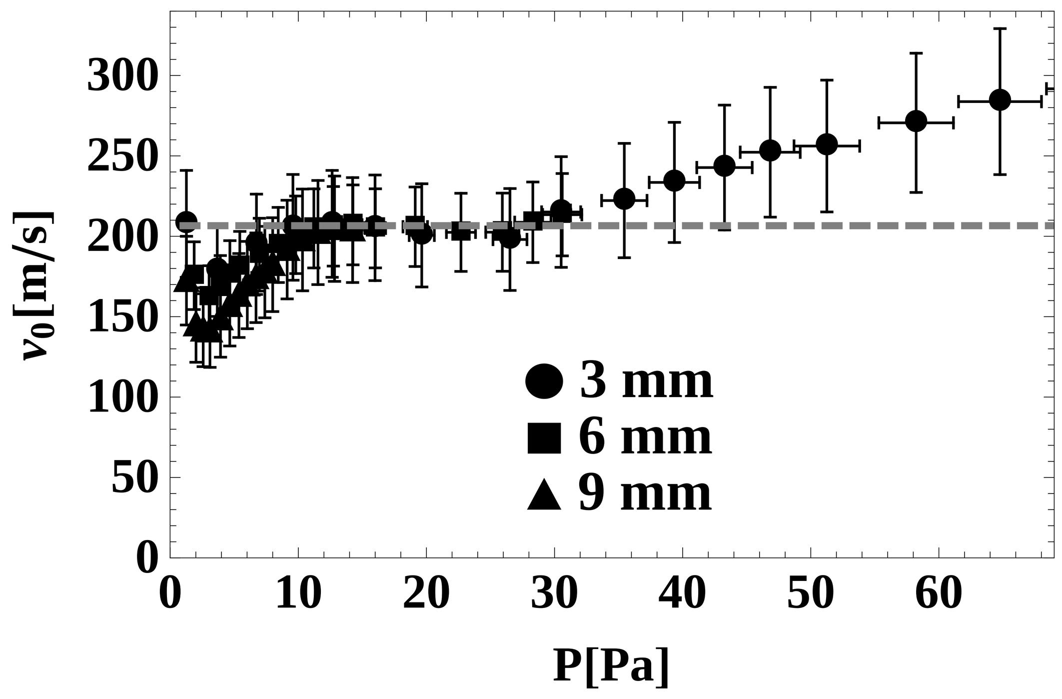
Gas flow velocity



$$v(z) = \frac{v_0 r^2}{(r + z\tan\alpha)^2}$$

$$v_0 \approx c_s = \sqrt{\frac{\gamma k T}{m}}$$

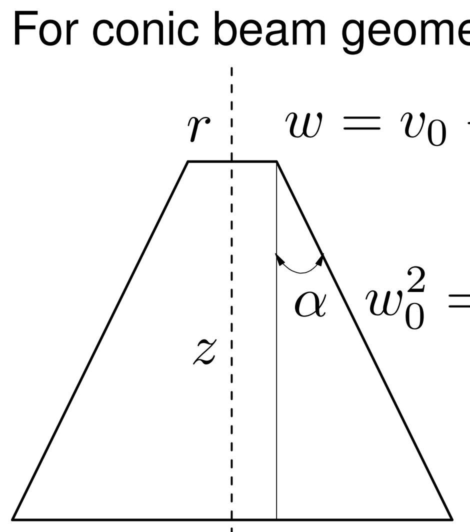
$$v_0 \approx 200 \text{ m/s}$$



Experimentally evaluated v_0 is in a fair agreement with theoretically estimated.

Cluster velocity

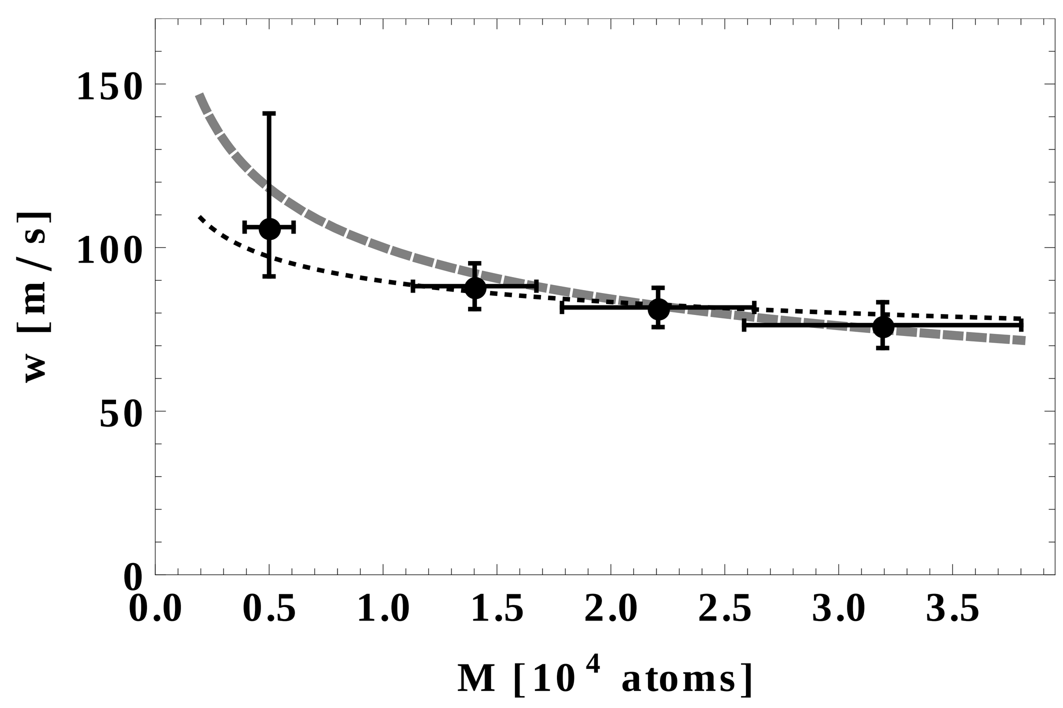
For conic beam geometry near the orifice:



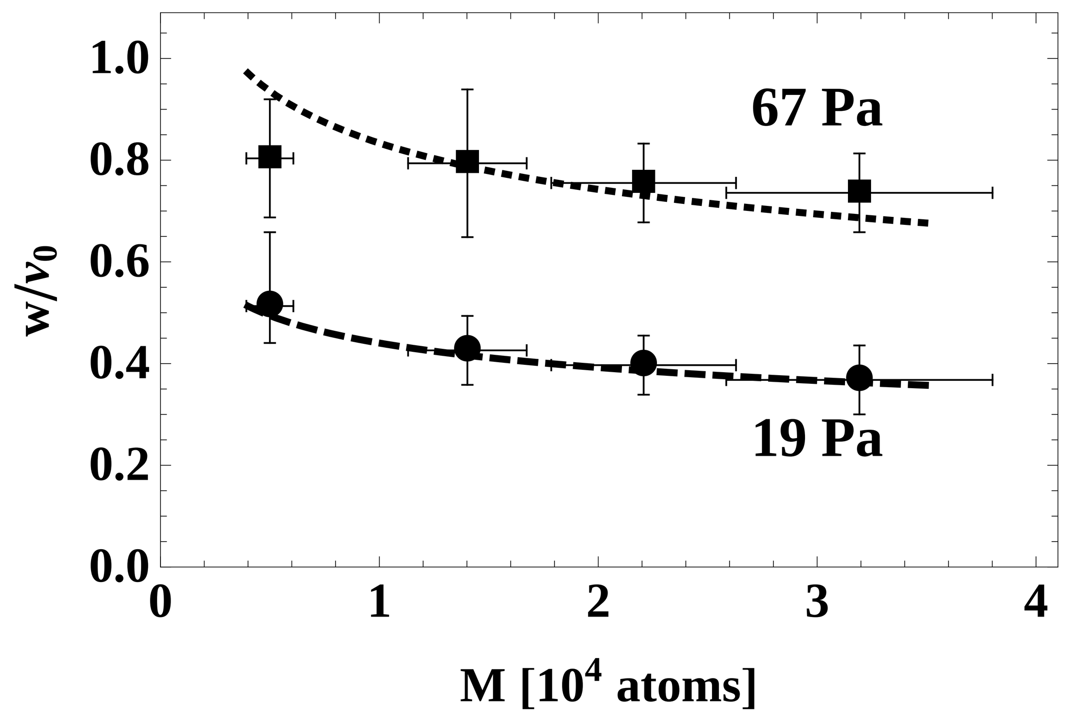
$$w = v_0 - (v_0 - w_0)\exp\left(-\frac{\tau_b}{\tau_{\rm rel}}\right)$$

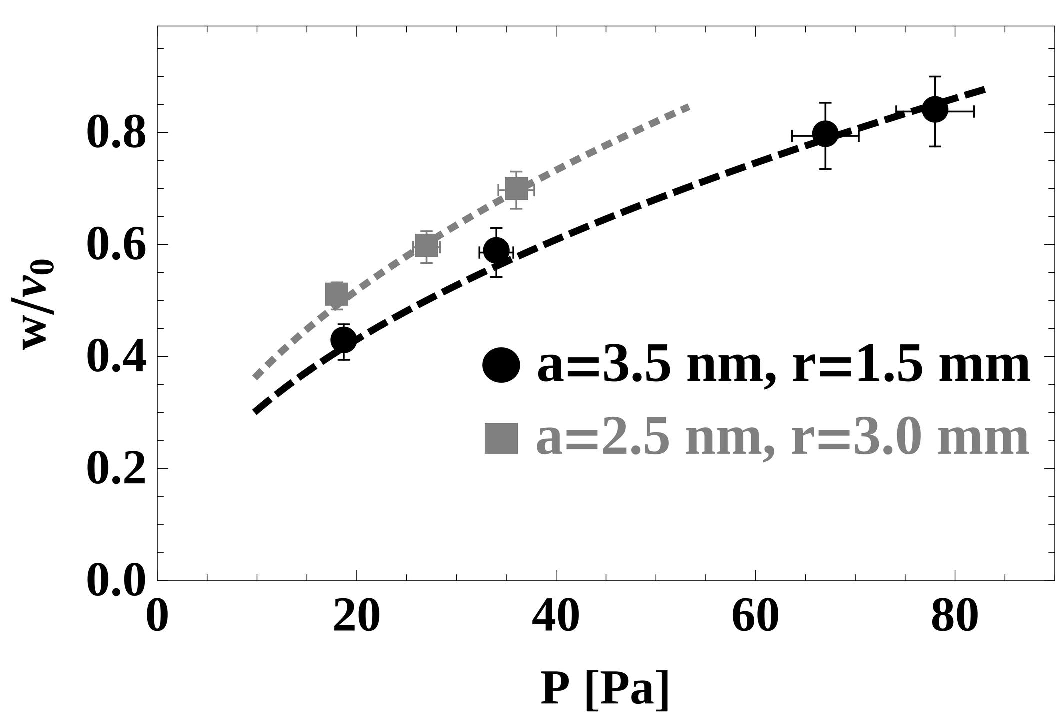
$$w_0^2 = \int \frac{2v(z)dz}{\tau_{\rm rel}} = \frac{2v_0 r}{\tau_{\rm rel}\tan\alpha}$$

$$\tau_b = \frac{r\delta}{v_T}$$



Comparison to experimental w allows to find α.





We obtain $\alpha = 24^\circ \pm 2^\circ$ for orifice radius $r = 1.5$ mm and $\alpha = 32^\circ \pm 3^\circ$ for $r = 3$ mm.

Conclusion

Both, velocity of the forming atomic gas beam and velocity distributions of mass-selected Cu nanoclusters, are investigated theoretically and experimentally. Model neglects edge effects near the orifice and can be applied only for orifice diameters $2r \gg \lambda$. The fit of the measured cluster velocity with derived in the framework of the present model equation allows for an estimation of the conic angle α which the flow forms near the orifice. Charged clusters are thus used as a tool to analyze the gas beam geometry.

Acknowledgement

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References

[1] M. Ganeva, A. V. Pipa, R. Hippler, *Surf. Coat. Technol.* **213** (2012) 41–47
[2] M. Ganeva, et. al., *Plasma Sources Sci. Technol.* **22** (2013) 045011
[3] Boris Smirnov *Nanoclusters and Microparticles in Gases and Vapors*, Germany: De Gruyter, 2012
[4] B. M. Smirnov, I. Shyjumon, R. Hippler, *Phys. Rev. E* **75** (2007) 066402
[5] J. Kousal et. al., *Vacuum* **96** (2013) 32–38

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