Atom-surface interactions in optical dipole mirror

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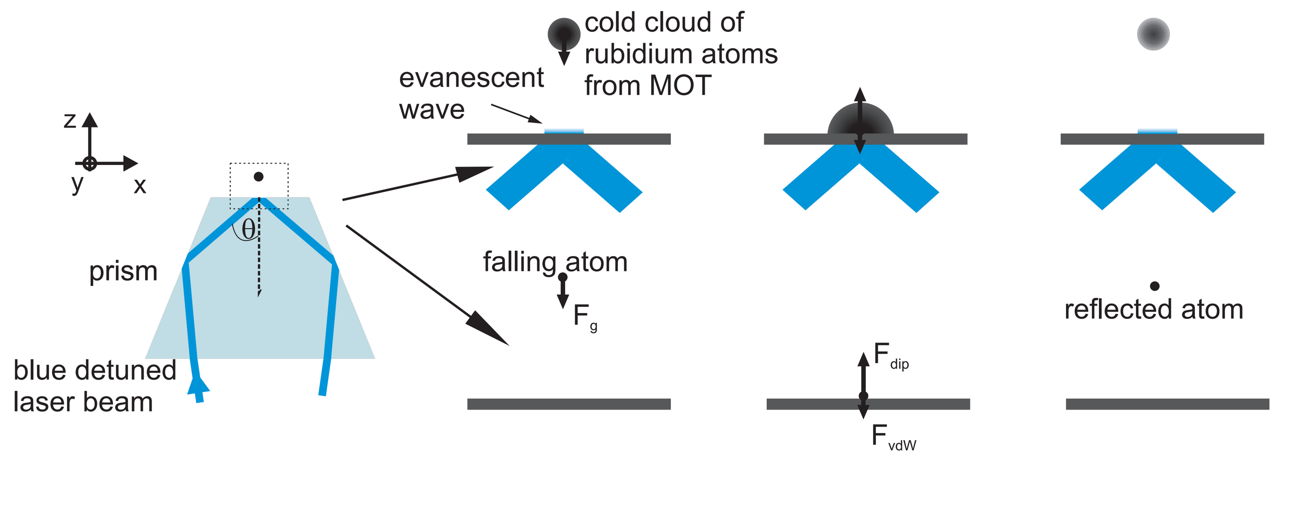
ABSTRACT

An evanescent wave dipole mirror for cold rubidium atoms from the magnetooptical trap (MOT) is described. Its flexibility [1] provides promising perspectives in atom-surface interaction measurments. The setup is being optimized for investigation of the radiation pressure exerted by evanescent wave on bouncing atoms (for glass prism [2] and prism coated with thin gold film) as well as for measurments of changes in populations of Zeeman sublevels during the bounce (with the use of Stern-Gerlach effect). Also further applications, like observation of the quantum reflection [3] or probing of the QED corrections to the van der Waals potential [4,5], are briefly presented.

INTRODUCTION

principle of the optical dipole mirror

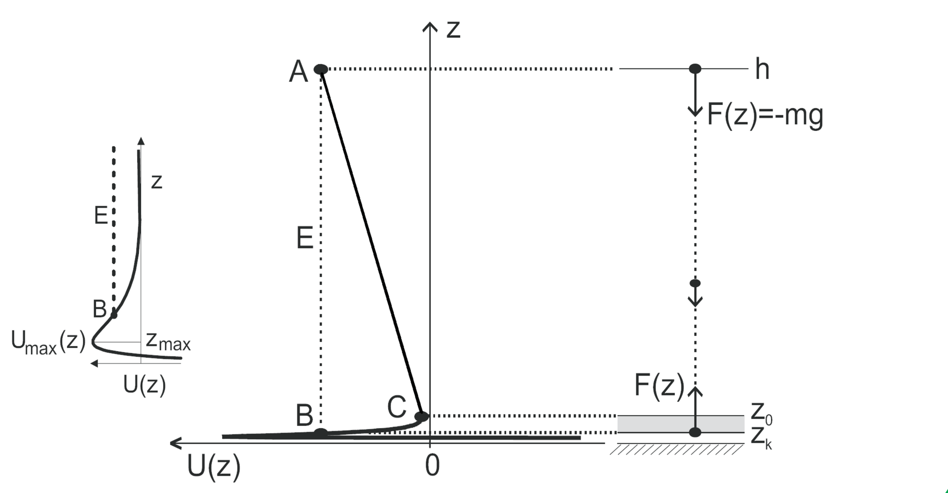


evanescent wave intensity:

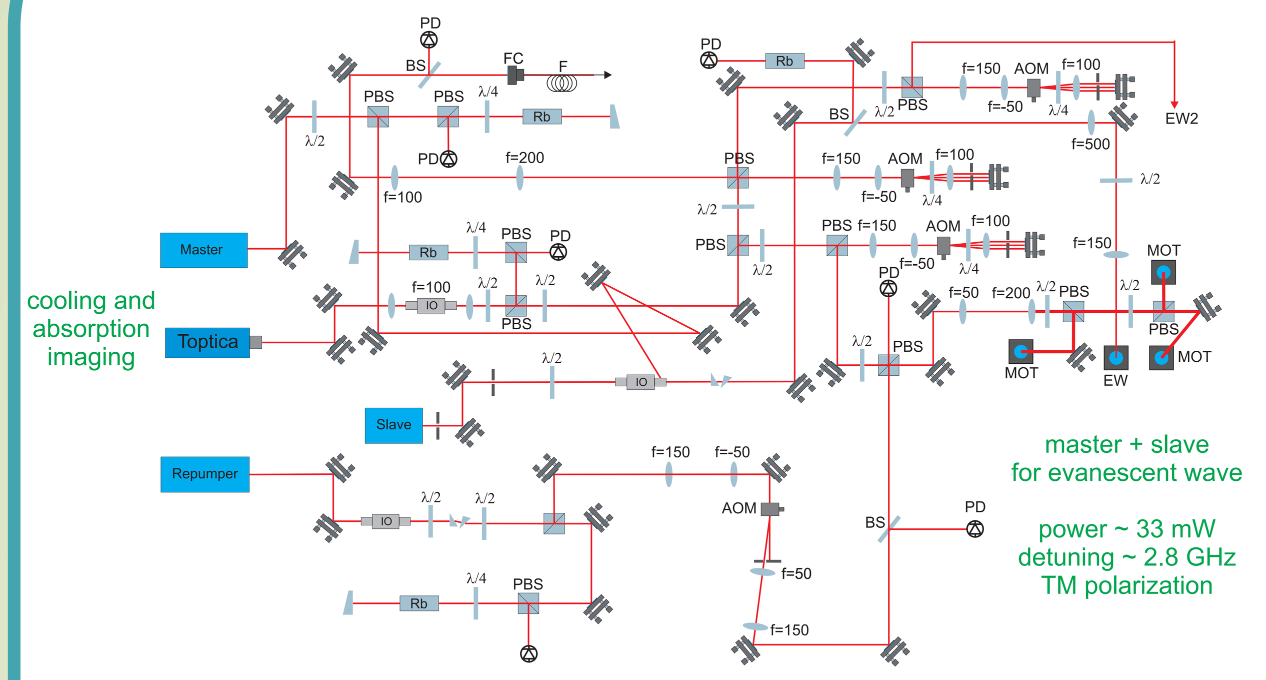
$$I(\vec{r}) = I_0 \exp\left(-\frac{x^2}{w^2\cos^2\theta}\right)\exp\left(-\frac{y^2}{w^2}\right)\exp\left(-\frac{2z}{d}\right) \xrightarrow{\text{dipole potential for two level atom}} U^{dip}(\vec{r}) = \frac{3\pi c^2}{2\omega_0^3}\frac{\Gamma}{\delta} I(\vec{r})$$

potentials of dipole mirror

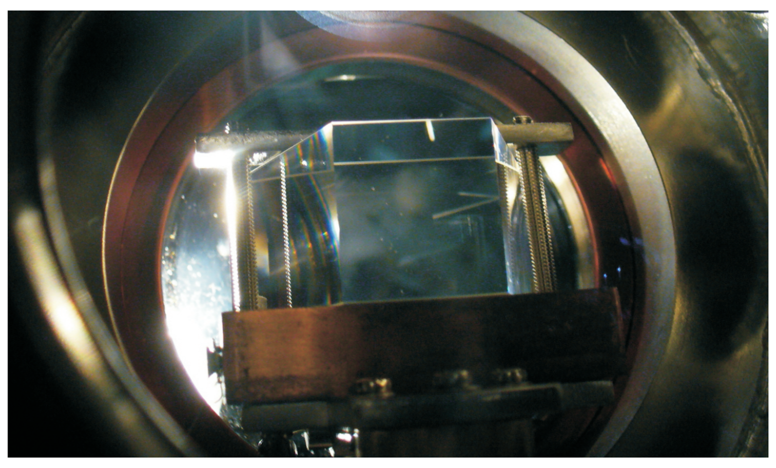
$$U(z) = U_{dip}(z) + U_g(z) + U_{vdW}(z)$$
$$= U_0 e^{-\frac{2z}{d}} + mgz - \frac{q}{z^3}$$



EXPERIMENTAL SETUP

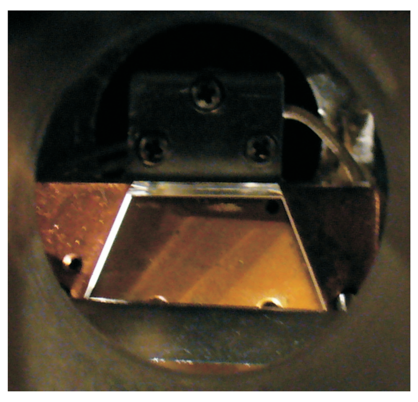


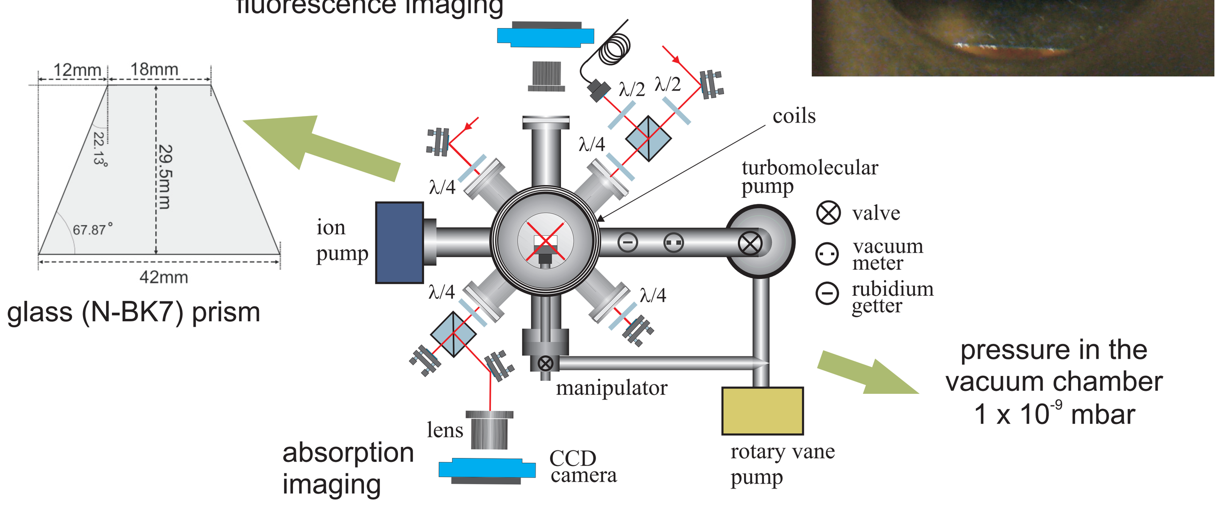
IO - optical isolator, Rb - rubidium cell, PBS - polarization beam splitter, f - lens, PD - photodiode, BS - beam splitter, AOM - acousto-optic modulator, F - fiber, λ/2, λ/4 - half- and quarter-wave plate



prism in the vacuum chamber - top view

prism in the vacuum chamber - side view





pressure in the vacuum chamber 1×10^{-9} mbar

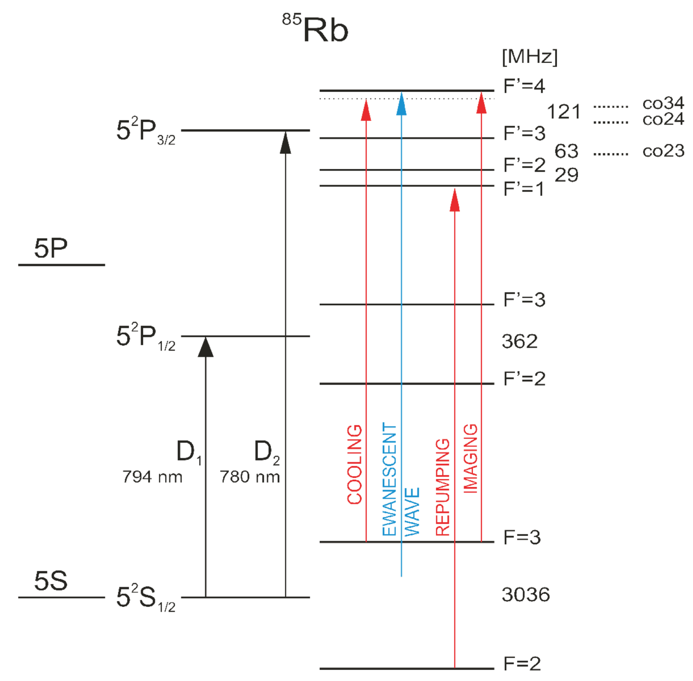
DIAGNOSTICS

temporal dark MOT
molasses cooling
falling in repumping beam

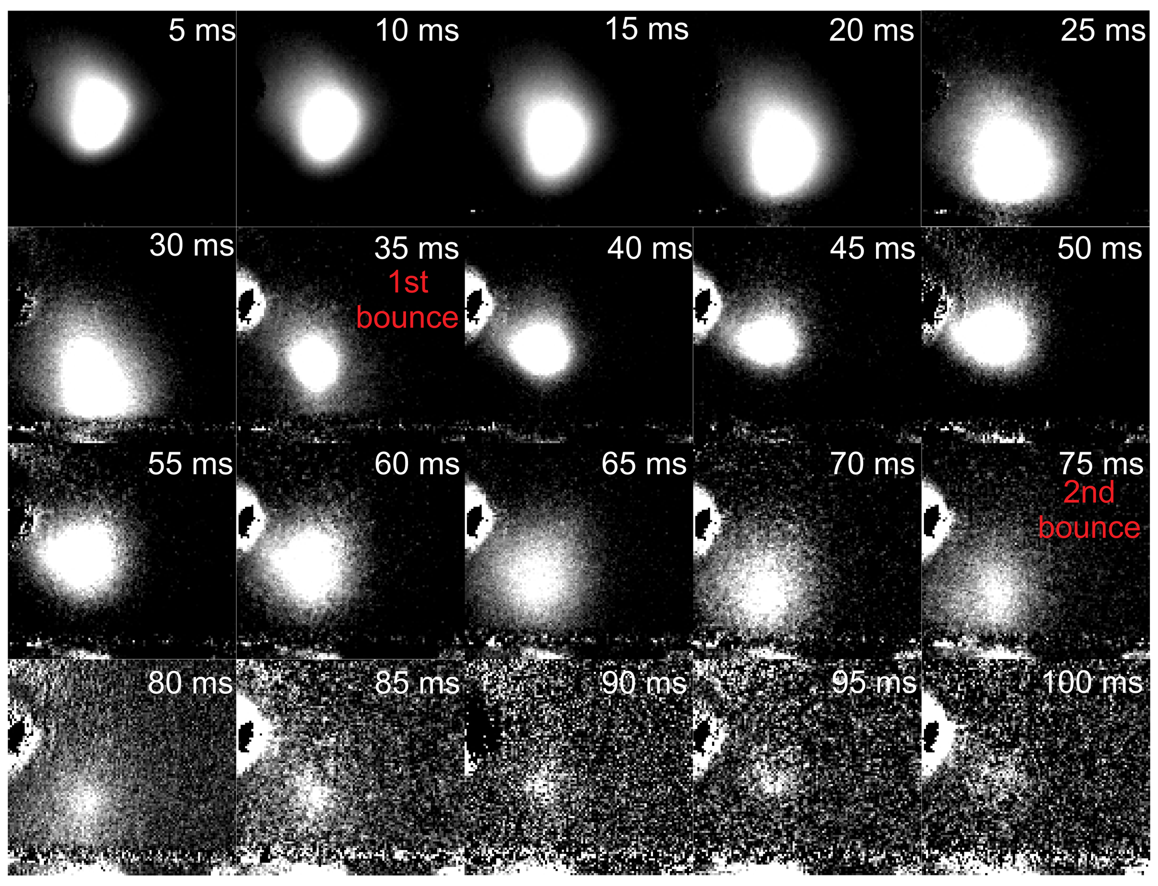
temperature 12 μK

number of atoms 8×10^6

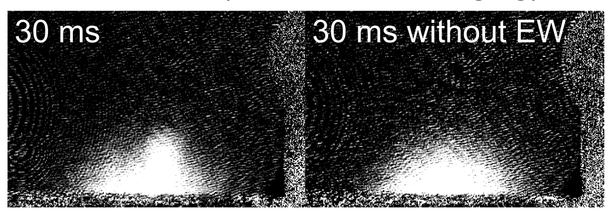
energy levels of ^{85}Rb



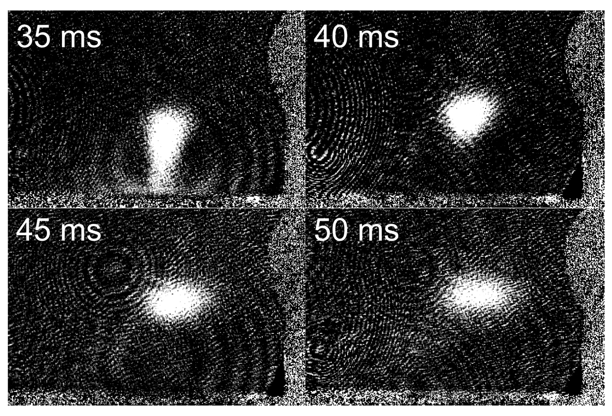
falling cloud of cold atoms - 2 bounces in fluorescence imaging



the bounce (in absorbtion imaging)

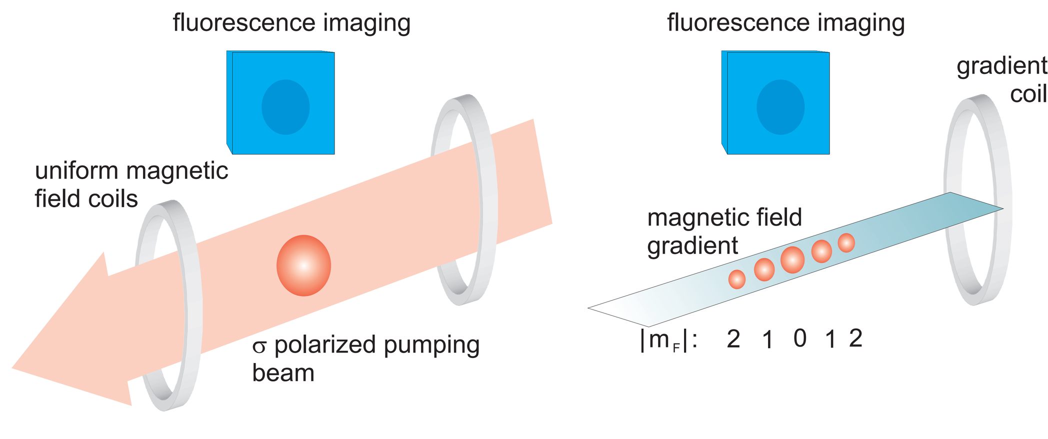


characteristic tail and vertical compression due to reflection and movement in gravitational field



STERN GERLACH EFFECT OF MAGNETIC SUBLEVELS

test of decoherence with and without metallic layer



falling cloud of cold atoms pumping beam and uniform magnetic field coils are switched on for a few ms

reflected cloud of cold atoms gradient coil is switched on

RADIATION PRESSURE

propagating component of the wave vector of EW along the surface

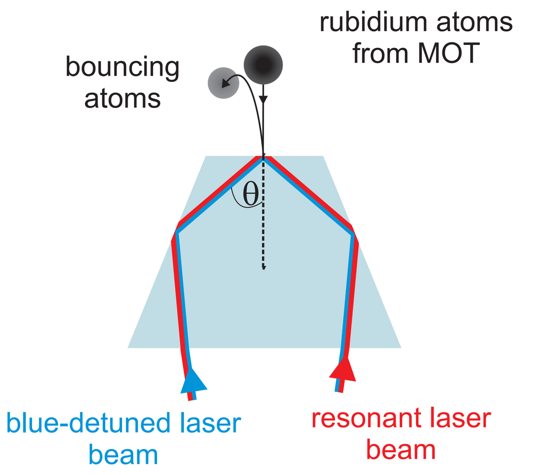
$$k_x = k_0 n \sin\theta$$

→ recoil momentum of the atom

$$p_{rec} = \hbar k_x$$

additional EW with controlled intensity, polarization, detuning and decay length

→ investigation of photon scattering in dependence on the additional EW polarization state



OPTICAL DIPOLE MIRROR WITH METALLIC LAYER

thin gold layer on the prism surface

↓

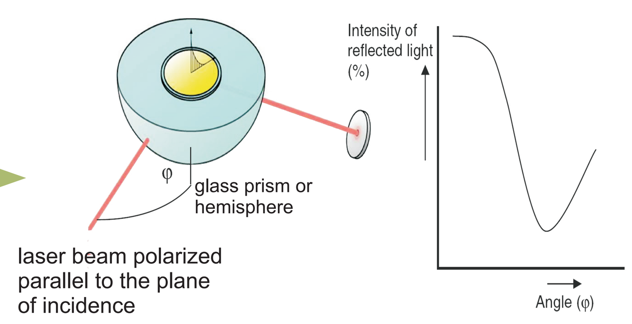
surface plasmon polaritons

↓

enhancement of the intensity of EW

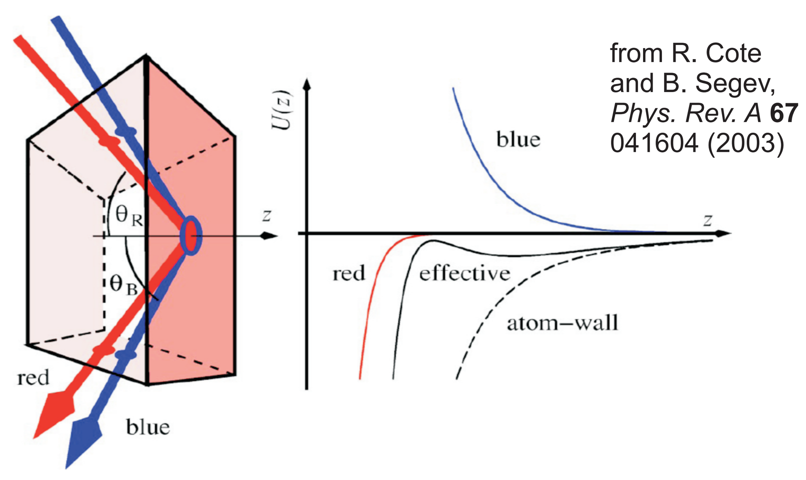
↓

observation of radiation pressure



cooperation with Syddansk Universitet (Odense and Sønderborg, Denmark)

QUANTUM REFLECTION



from R. Cote and B. Segev, *Phys. Rev. A* **67** 041604 (2003)

effective attractive potential created by two laser beams (red-detuned and weaker blue-detuned from atomic transition) [3]:

$$U(z) = C_B e^{-2\kappa_B z} - C_R e^{-2\kappa_R z} - \frac{C_3}{z^3},$$

where $\kappa_{B/R} = k_{B/R}\sqrt{n^2 \sin^2\theta_{B/R} - 1}$ and $C_{B/R} \simeq \frac{I_{B/R} d^2}{8\hbar\epsilon_0\delta_{B/R}}$

CASIMIR-POLDER POTENTIAL

precise mesurement of number of atoms reflected by optical dipole mirror for various intensities and detunings of EW (shape of potential)

$$V_{\text{noret}}(z) = C_0 \exp(-2\kappa z) - \frac{C_3}{z^3},$$

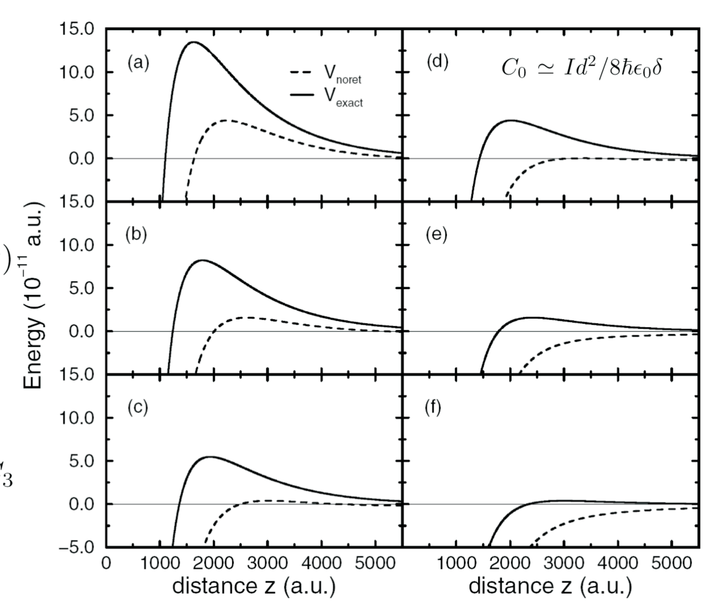
$$V_{\text{exact}}(z) = C_0 \exp(-2\kappa z) + V_{\text{QED}}(z),$$

$$V_{\text{QED}}(z) = -f(z)\frac{C_3}{z^4}$$

$f(z) \to z$ for small z and $f(z) \to K_4/C_3$

calculated potentials with and without retardation as a function of z for various values of C_0 for sodium

C_0 from 9.877×10^{-10} a.u. (a) to 2.119×10^{-10} a.u. (f)



from S.Kallush, B.Segev and R.Côte, Eur. Phys. J. D **35**, 3-14 (2005)

REFERENCES

[1] T. Kawalec, K. Kiersnowski, J. Fiutowski, T. Dohnalik, *Acta Phys. Pol. A* **114** 721 (2008).
[2] D. Voigt, B.T. Wolschrijn, R. Jansen, N. Bhattacharya, R.J.C. Spreeuw, and H. van Linden van den Heuvell, *Phys. Rev. A* **61** 063412 (2000).
[3] R. Cote and B. Segev, *Phys. Rev. A* **67** 041604 (2003).
[4] R. Cote, B. Segev, and M.G. Raizen, *Phys. Rev. A* **58** 3999 (1998).
[5] A. Landragin, J.Y. Courtois, G. Labeyrie, N. Vansteenkiste, C. Westbrook, and A. Aspect, *Phys. Rev. Lett.* **77** 1464 (1996).
[6] S. Kallush, B. Segev, R. Côte, *Eur. Phys. J. D* 35, 3-14 (2005)
[7] A. Tudos, R. Schasfoort, *Handbook of Surface Plasmon Resonance*, RSC Publishing (2008)