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1. A Zeeman Slower

(a)

The maximum deceleration is achieved when the scattering rate is maximized. Since the maximum population when pumping with a laser in such a two level system is 50% the maximum scattering rate is $\frac{\gamma}{2}$. Maximum deceleration

$$\begin{aligned} a_{max} =& \frac{\gamma}{2}\frac{p_{rec}}{m} \\ =& \frac{h\gamma}{2m\lambda} \\ =& 9.3 \cdot 10^5 \mathrm{m} \cdot \mathrm{s}^{-2} \end{aligned}$$

(b)

Assuming the atom flux (and therefore the optical depth of the slower) is small so that the intensity of light is almost constant in the slower.
Length of the slower,

$$\begin{aligned} L =& \frac{v_{max}^2}{2a} \\ =& \frac{v_{max}^2}{2fa_{max}} \\ =& \frac{1}{f}\frac{k_B T\lambda}{h\gamma} \\ =& \frac{0.12}{f}\mathrm{m} \end{aligned}$$

Maximum velocity in the slower

$$v = \sqrt{2fa_{max}(L-x)}$$

Doppler shift

$$\begin{aligned} \delta_{doppler} =& \frac{v}{\lambda} \\ =& \frac{\sqrt{2fa_{max}(L-x)}}{\lambda} \end{aligned}$$

This should be canceled by the Zeeman shift

$$B = \frac{\sqrt{2fa_{max}(L-x)}}{g\mu_B\lambda}$$

(c)

Variance of Δx for each emission for three situations

$$\begin{aligned}
\left\langle\Delta p^2\right\rangle_0 =& p_{rec}^2 \begin{cases} 1 & \text{i} \\ \displaystyle\int_{-1}^{1} x^2\mathrm{d}x & \text{ii} \\ \displaystyle\int_{-1}^{1} x^4\mathrm{d}x & \text{iii} \end{cases} \\
=& p_{rec}^2 \begin{cases} 1 & \text{i} \\ \frac{1}{3} & \text{ii} \\ \frac{1}{5} & \text{iii} \end{cases}
\end{aligned}$$

$$\begin{aligned}
\mathcal{D} =& \frac{\mathrm{d}\left\langle\Delta p^2\right\rangle}{\mathrm{d}t} \\
=& \left\langle\Delta p^2\right\rangle_0 \Gamma_s \\
=& \Gamma_s p_{rec}^2 \begin{cases} 1 & \text{i} \\ \frac{1}{3} & \text{ii} \\ \frac{1}{5} & \text{iii} \end{cases}
\end{aligned}$$

2. Slowing an atom with off-resonant light

(a)

(b)

(c)

3. Density Limit in a MOT

(a)

(b)

(c)

(d)

(e)