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Chapter 1

Historical Precedents

1.1 Historical Precedents

1.1.1 Interferometry

1.1.2 Charged Particle Atomic Physics

1.1.3 Charged Particle Interferometry

1.1.4 Cavendish and the history of laboratory-based electromagnetic tests

1

$$1/r^2$$

Chapter 2

Ion Interferometer Guided Tour

2.1 Trapping of Neutral Strontium and LVIS

87

+

87

2.2 Ionization of Strontium

2.3 Actual Interferometry

2.4 Scope of this work

Chapter 3

The Atoms

3.1 Overview of relevant atomic transitions

2

$1/2$

$5s$

$$F = 4$$

$$F = 5$$

$3/2$

$5p$

$\vec{J}$

$$\vec{F}$$

$$\Omega_{eff} = \frac{\Omega_{2i}\Omega_{i1}}{2\Delta} \tag{3.1}$$

$$\Omega_{2i}$$

$$\Omega_{i1}$$

2

$1/2$

2

$3/2$

$$\Omega = \frac{\mu E}{h} \tag{3.2}$$

μ

μ^2

3.2 Calculation of ideal intensities

Chapter 4

Generation of Seed Light

4.1 Stabilization of Master Laser

4.1.1 Master Laser Layout

1

○

2

4.1.2 Master Laser Temperature and Current Selection

4.1.3 Placement of the Grating

4.1.4 Calculation of Maximum Safe Intensity

λ

4.2 Spectrum Analyzer

4.3 Adjustment of Light Amounts

4.3.1 A review of the principles of operation of a waveplate:

4

$$(2m + 1) * \pi$$

n

$$\Delta\phi = \frac{2\pi n x}{\lambda} \tag{4.1}$$

n_1

$$n_2$$

$$\Delta\phi = \frac{2\pi n_1 x}{\lambda} - \frac{2\pi n_2 x}{\lambda}. \tag{4.2}$$

$$\Delta\phi = (2m + 1)\pi \tag{4.3}$$

m

x

$$x = \frac{(2m+1)\lambda}{2(n_1 - n_2)}. \tag{4.4}$$

x

n_1

n_2

m

π

λ_s

λ'

λ_s

λ'

$$\Delta\phi = \frac{2\pi(n_1 - n_2)x}{\lambda'} \tag{4.5}$$

$$x \to ((2m+1)\lambda_s)/(2(n_1 - n_2))$$

$$\Delta\phi = \frac{2\pi(n_1 - n_2)(2m + 1)\lambda_s}{2(n_1 - n_2)\lambda'} \tag{4.6}$$

$$\Delta\phi = \frac{\pi(2m + 1)\lambda_s}{\lambda'} \tag{4.7}$$

m

$$\Delta\phi = (m_2 + .3656)(2\pi)$$

$$m = 55$$

7

8

$$\begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{4.8}$$

$$\begin{pmatrix}\cos\theta & -\sin\theta \\ \sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}\xi & 0 \\ 0 & 1\end{pmatrix}\begin{pmatrix}\cos\theta & \sin\theta \\ -\sin\theta & \cos\theta\end{pmatrix}$$
$$= \begin{pmatrix}\cos^2\theta + \xi\sin^2\theta & \cos\theta\sin\theta - \xi\cos\theta\sin\theta \\ \cos\theta\sin\theta - \xi\cos\theta\sin\theta & \xi\cos^2\theta + \sin^2\theta\end{pmatrix} \quad (4.9)$$

θ

$$\xi \approx e^{.366(2\pi)}$$

θ_1

θ_2

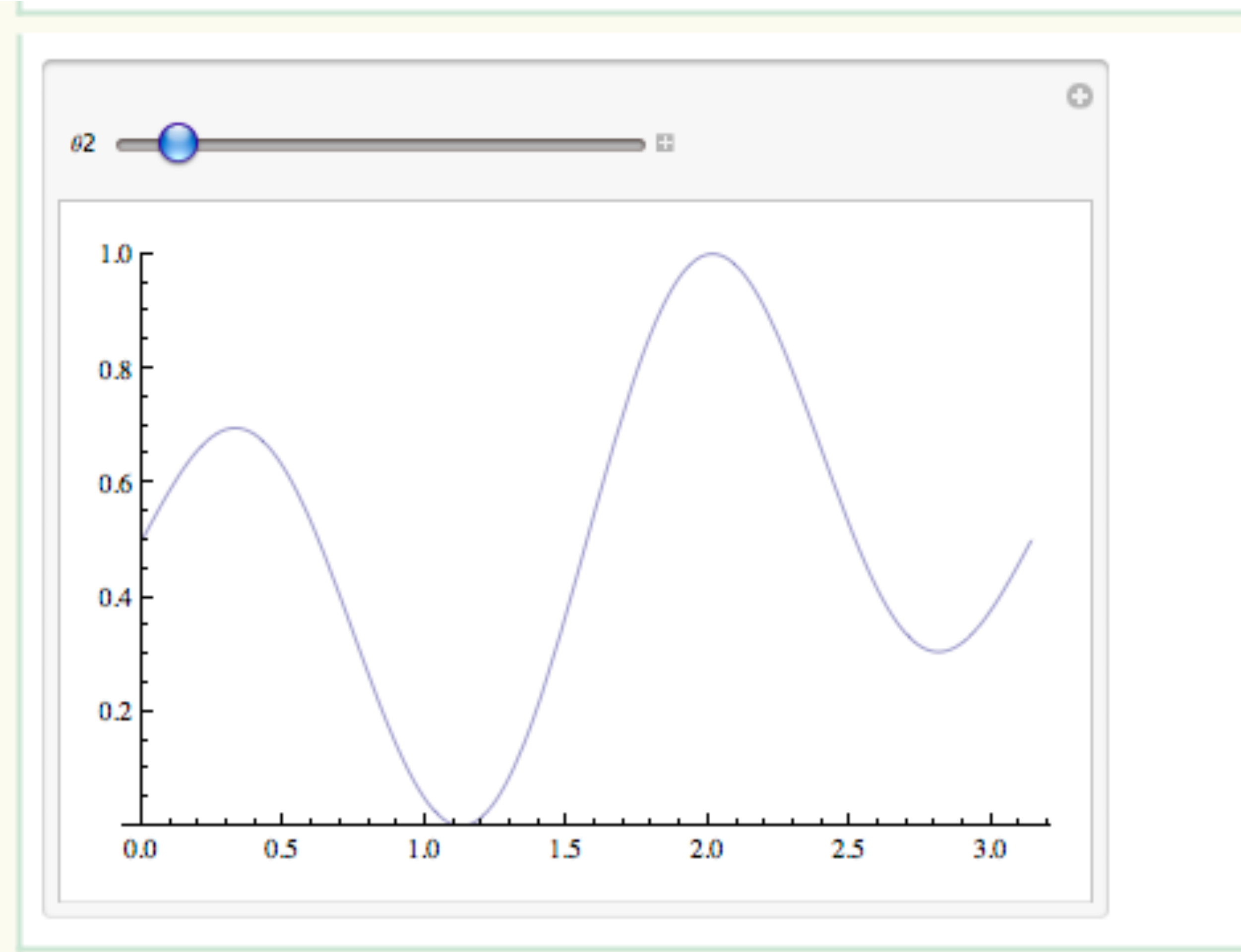

Figure 4.1 Just plot the magnitude of the vertically polarized component as a function of θ_1. I used the slider to control θ_2. Obviously, I'll illustrate this better at some point.

θ_2

θ_1

θ_2

ϕ

$-\phi$

ϕ

ϕ

4.4 Installation of AOM

9

m^2

$$M^2$$

$$M^2 = 1$$

$$\sigma_x^2 = \frac{\int_{-\infty}^{\infty} (x - x_0)^2 I(x, y)\, dx\, dy}{\int_{-\infty}^{\infty} I(x, y)\, dx\, dy} \tag{4.10}$$

$$\sigma_x^2 = \sigma_{0x}^2 + \left(\frac{M_x^2 \, \lambda}{\pi \, \sigma_{0x}} \right)^2 (z - z_{0x})^2 \tag{4.11}$$

$$I(x, y)$$

Z

$$\left(z - z_0\right) \to \infty$$

$$\frac{\sigma_x}{z - z_0} = M_x^2 \frac{\lambda \pi}{\sigma_{0x}} \tag{4.12}$$

$$M^2 = 1$$

$$M^2 = 1$$

$$w_{x0} = 2\sigma_{x0}$$

$$w_{y0} = 2\sigma_{y0}$$

10

$$I(x, y) = (\text{constants}) \exp\left(-2\left(\frac{x}{W_{0x}}\right)^2 - 2\left(\frac{y}{W_{0y}}\right)^2\right). \tag{4.13}$$

$$\text{Total Power} = P = \int_{-\infty}^{\infty} I(x,y)\,dx\,dy \tag{4.14}$$

$$= \frac{\pi}{2}(\text{constants})W_{0x}W_{0y} \tag{4.15}$$

P

W_{0x}

W_{0y}

$$I(x,y) = \frac{2P}{\pi W_{0x} W_{0y}} \exp\left(-2\left(\frac{x}{W_{0x}}\right)^2 - 2\left(\frac{y}{W_{0y}}\right)^2\right). \tag{4.16}$$

$$2P/\pi W_{0x}W_{0y}$$

$$\text{Power incident on photodiode} = \frac{1}{2}P\left(\operatorname{erf}\left(\frac{\sqrt{2}x}{W_{0x}}\right)\right) \tag{4.17}$$

4.4.1 Ray Transfer Matrix Analysis of System

M^2

$$M^2 = 1$$

A

B

C

D

$$z' - iz'_0 = \frac{A(z - iz_0) + B}{C(z - iz_0) + D} \tag{4.18}$$

$$z_0' = \frac{z_0(BC - AD)}{C^2 z^2 + C^2 z_0^2 + 2CDz + D^2} \tag{4.19}$$

$$z' = \frac{ACz^2 + ACz_0^2 + ADz + BCz + BD}{C^2 z^2 + C^2 z_0^2 + 2CDz + D^2} \tag{4.20}$$

x

y

12

$$\begin{bmatrix} 1 & 0 \\ -1/f_f & 1 \end{bmatrix} \begin{bmatrix} 1 & d_2 - d_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_a & 1 \end{bmatrix} \begin{bmatrix} 1 & d_1 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \tag{4.21}$$

$$z_0'$$

z'

$$d_1$$

d_2

Chapter 5

Data that shows it worked

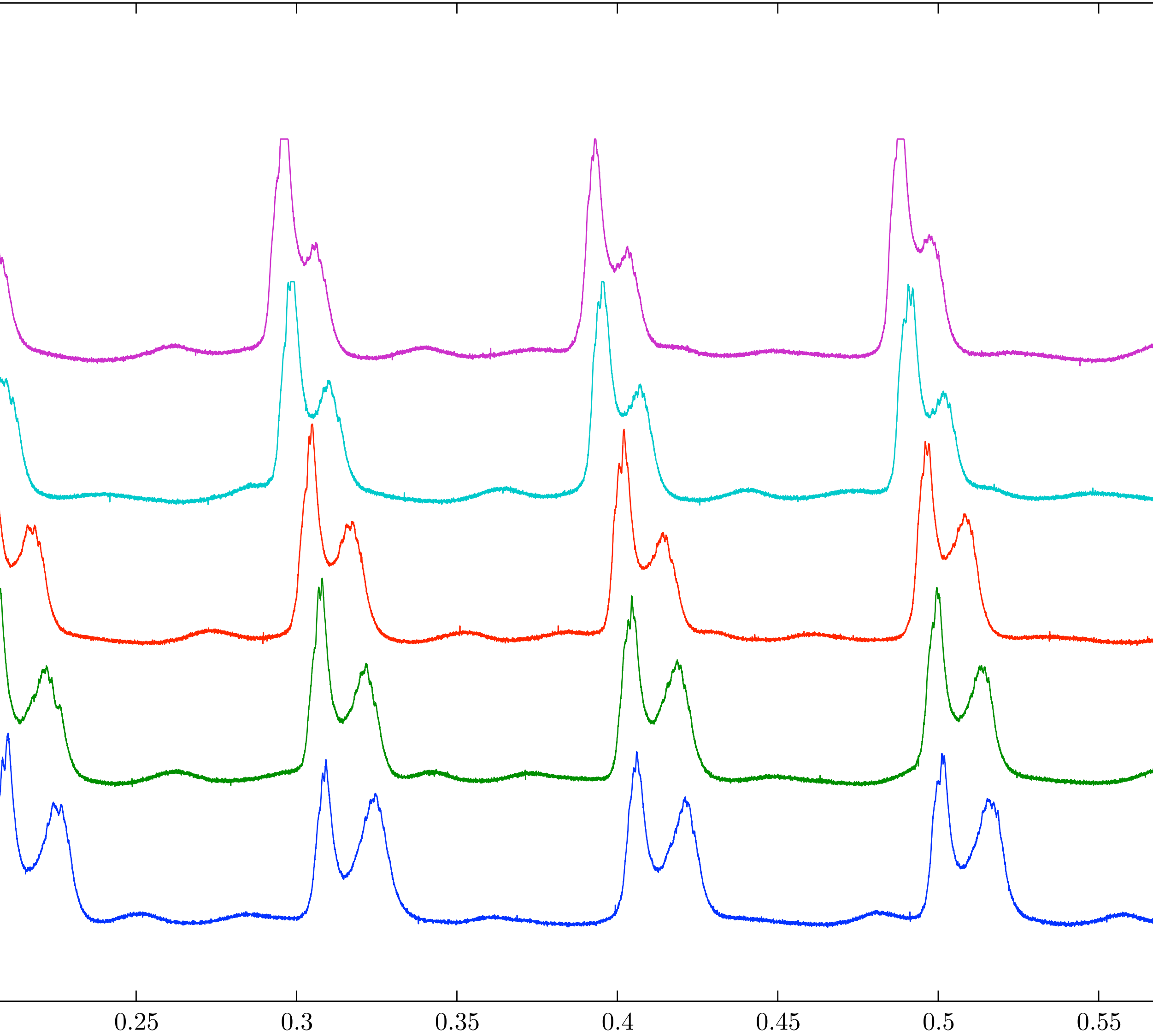

Figure 5.1 We changed the detuning on our frequency generator in something like 10 MHz increments. These are some of the data that we have that show the spacing between our peaks changing in a predictable way.

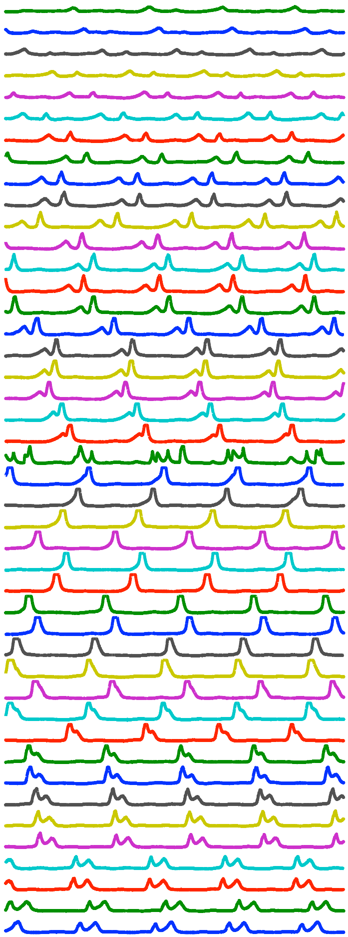

Figure 5.2 This is the complete set of data from which the previous graphic was culled. Some of it is clipped uglily. The peaks are on top of each other, but it may have drifted to a higher power between when I set it up and when I took the data. I'm not sure why this looks so much worse than the data I normally take.

Appendix A

Measuring Beam Waist

1

$$I(r, z) = I_0 \left(\frac{w_0}{w(z)} \right)^2 \exp \left(\frac{-2r^2}{w^2(z)} \right) \tag{A.1}$$

$$I(r, z) = (\text{constants}) \exp\left(-2\frac{x^2}{w_x^2(z)} - 2\frac{y^2}{w_y^2(z)}\right). \tag{A.2}$$

P

$$P = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} (\text{constants}) \exp\left(-2\frac{x^2}{w_x^2(z)} - 2\frac{y^2}{w_y^2(z)}\right) dxdy \tag{A.3}$$

$$P = \frac{\pi}{2} (\text{constants}) w_x(z) w_y(z) \tag{A.4}$$

$$\text{(constants)} = \frac{2P}{\pi w_x(z) w_y(z)}. \tag{A.5}$$

$$x = y = z = 0$$

$$x = -\infty$$

x_0

x_0

x

$$P(x_0) = \int_{\infty}^{\infty} \int_{-\infty}^{x_0} \frac{2P}{\pi w_x(z) w_y(z)} \exp\left(-2\frac{x^2}{w_x^2(z)} - 2\frac{y^2}{w_y^2(z)}\right) dxdy \tag{A.6}$$

$$P(x_0) = \frac{P}{2}\left(\operatorname{erf}\frac{\sqrt{2}x}{W_x} + 1\right) \tag{A.7}$$

σ

$$f(x) = a_1 \operatorname{erf}\left(\frac{x - a_3}{a_2}\right) + a_4. \tag{A.8}$$

$$(a_1 a_2 a_3 a_4)$$

a_2

$$\sqrt{2}$$

$$W_x^2(z) = W_{0x}^2 + M_x^4 \left(\frac{\lambda}{\pi W_{0x}} \right)^2 (z - z_{0x})^2. \tag{A.9}$$

$$M_x^2 \to 1$$

$$W_x = a_1 \sqrt{1 + \left(\frac{(x - a_2)\lambda}{\pi a_1^2} \right)^2} \tag{A.10}$$

$$W_x = a_1 \sqrt{1 + (1 + a_3^2) \left(\frac{(x - a_2)\lambda}{\pi a_1^2} \right)^2}. \tag{A.11}$$

$$M^2$$

$$M^2$$

A.1 Using the Camera

$$M^2$$

A.1.1 The Camera is discovered to be quite non-linear

2

$$(214, 442)$$

$$(214, 442)$$

$$(214, 442)$$

$$119.70/85.350 = 1.4025$$

$$M_{ij}$$

j

i

3

$f(p)$

$f(p)$

$$\text{Figure of merit} = \sum_{M_{ij} \neq 0} \left(\frac{f(M_{ij})/P_j}{\text{average of all nonzero } f(M_{ij})/P_j \text{ for the ith pixels}} - 1 \right)^2 \quad \text{(A.12)}$$

P_j

$$P_1$$

P_3

$$f(M_{ij})/P_j$$

$$M_{ij} = 0$$

$$M_{ij} = 0$$

$$f(M_{ij})$$