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① $\lambda = 530$ nm

$$f = \frac{c}{\lambda} =$$

$V = 3\cdot10^{8}$ m/s

$$t = \frac{100\,\text{yd}\cdot\frac{\square\,\text{m}}{\square\,\text{yds}}}{V}$$

②

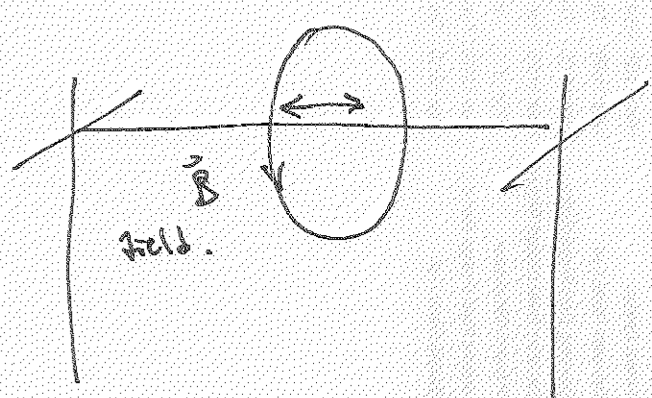
~1m	~10^{-3} m		~10^{-6} m		~10^{-9} m
Radio	Microwaves	Infrared		Ultraviolet	X-ray

~10^{-12} m

Gamma Ray

$$f = \frac{V}{\lambda} = \frac{3\cdot10^{8}}{\lambda}$$

③



Time changing current produces a time changing $\vec{B}$ field

$$\nabla\times B = \vec{J}(t) + \frac{\partial E}{\partial t}$$

If I assume the earth is a large dipole $\nabla\circ B = 0$.

(4) $\lambda = 1.06\,\mu m$

$$f = \frac{3 \cdot 10^{8}\ m/s}{1.06 \cdot 10^{-9}\ m} = \cancel{O(3\ Hz)}\ O(3 \cdot 10^{17}\ Hz)$$ ✓

$E = h \cdot f = (6.63 \cdot 10^{-34}\ J \cdot s)(3 \cdot 10^{17}\ 1/s)$ /* energy per photon */

$= \text{- -}\ J$

$1.87 \cdot 10^{-46}\ J$

$\therefore$ Total # of photons $= \dfrac{1J}{} = \text{- - -}\ 5 \cdot 10^{45}$ photons

① $\Omega = \dfrac{4\pi R^2}{R^2} = 4\pi$

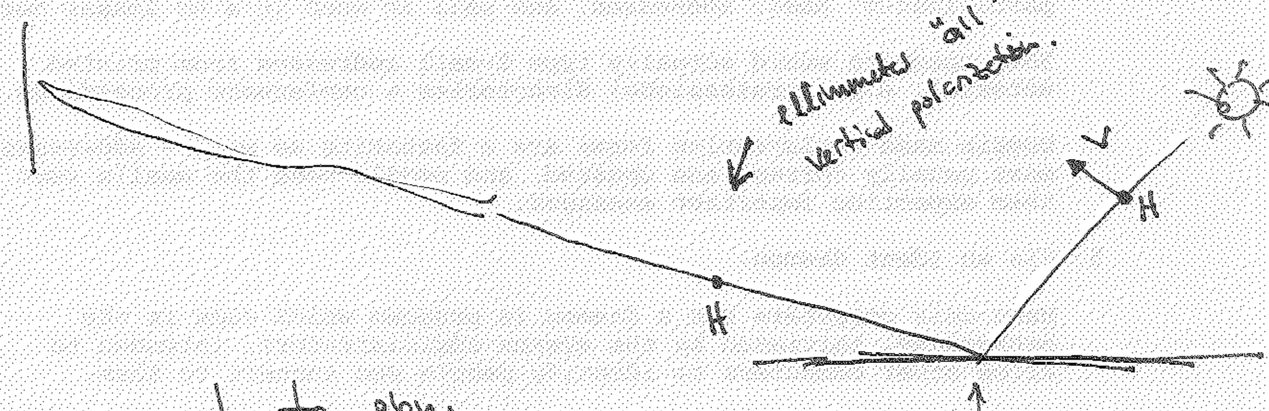
② (i) $B = \dfrac{P}{A\Omega} = \dfrac{1W}{\frac{\pi}{4}(1cm)^2(10^{-6})}$ $\qquad A = \pi r^2 = \frac{\pi}{4} d^2$

$= \dfrac{4 \cdot 10^6}{\pi} \dfrac{W}{cm^2}$

(ii) $\dfrac{P}{A\Omega} = \dfrac{1W}{\frac{\pi}{4}(1cm)^2(2 \cdot 10^{-6})} = \dfrac{2 \cdot 10^6}{\pi} \dfrac{W}{cm^2}$

(iii) $\dfrac{P}{A\Omega} = \dfrac{1W}{\frac{\pi}{4}(2cm)^2(10^{-6})} = \dfrac{10^6}{\pi} \dfrac{W}{cm^2}$

③



After reflection at an angle ≈ Brewster's angle

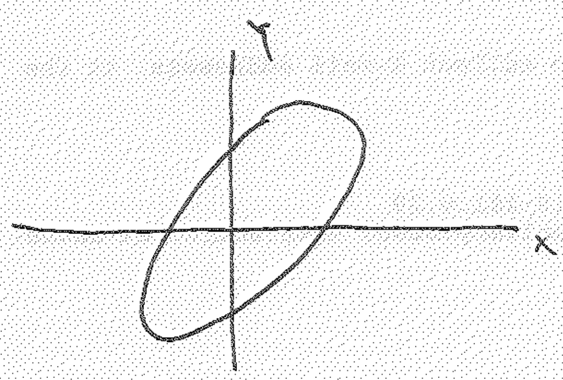
Horizontal polarization ⊥ to plane of figure

Vertical polarization ∥ to plane of figure

They should reject Horizontal polarization.

(4) None. Circularly polarized light? Not sure.

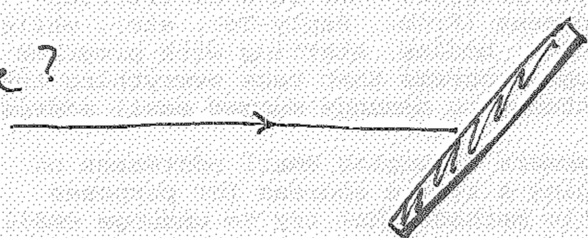
(5)



This would be produced by shifting one of the two E fields by an amount smaller than $\frac{\lambda}{4}$

Thus the phase relationship is an amount $< \frac{2\pi}{4} = \frac{\pi}{2}$

(6) Not sure?



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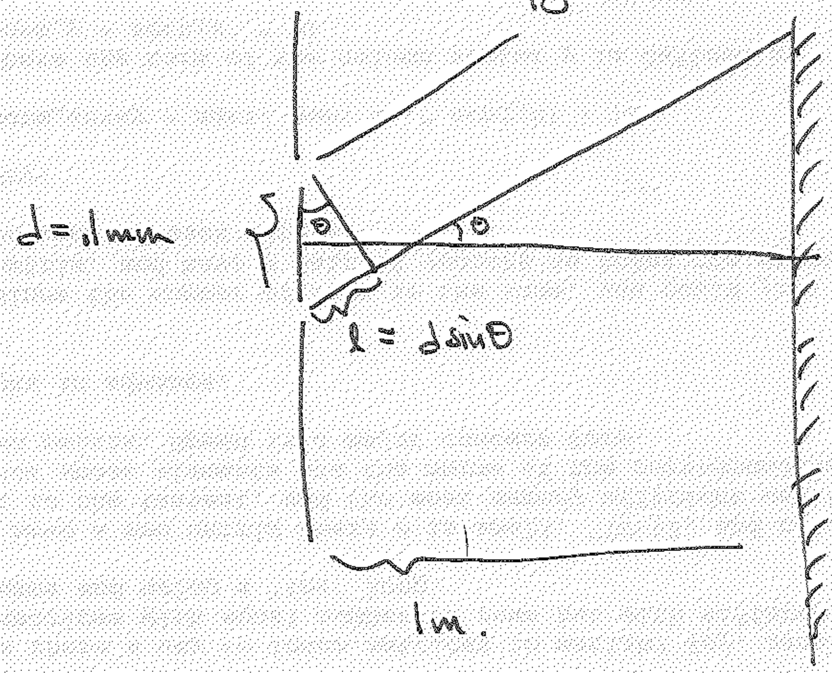


constructive interference when $n\lambda = d\sin\theta$ $\lambda = 632.8$ nm.

$n=1,2,3,\dots$

$n=1 \rightarrow \theta = ?$ $\theta = \sin^{-1}\left(\frac{n\lambda}{d}\right) = \sin^{-1}\left(\frac{1\cdot 632.8\cdot 10^{-9}\,m}{.1\cdot 10^{-3}\,m}\right)$

$= .0063$

Then location of 2nd constructive interference line is

$$y_1 = L\tan\theta = 1\cdot\tan(.0063) \cong .0063\ m$$

$$\Delta y \cong .0063\ m = 6.3\ mm$$

(2) $\lambda_1 = 488$ nm $\quad l = 1$cm

$\lambda_2 = 532$ nm

$$\Delta f_1 = \frac{c}{2l} = \frac{3 \cdot 10^8 \text{ m/s}}{2(10^{-2} \text{ m})} = 1.5 \cdot 10^{10} \text{ 1/s} = 1.5 \text{ Hz}.$$

Same separation independent of incident frequency.

(3) $\lambda = 1.064$ um $\quad l = 1$ cm

$$\frac{n\lambda}{2} = l \qquad \lambda = \frac{c}{f}$$

$$\frac{nc}{2f} = l \Rightarrow f = \frac{nc}{2l} = \frac{n}{\lambda_0 \, 2}$$

$$\lambda_n = \frac{2l}{n}$$ resonances at these wavelengths.

require n ∋ $\frac{2l}{n} \cong \lambda_0 = 1.064$ um

$$\Rightarrow n \cong \frac{2l}{\lambda_0} = \frac{2 \text{ cm}}{1.064 \text{ um}} = \frac{2 \cdot 10^{-2} \text{ m}}{1.064 \cdot 10^{-6} \text{ m}} = \ldots$$

round to nearest integer, produces the closest wavelength.

n = the # of half wave lengths between the mirrors.

reducing λ to fit one more ~~half~~ half wave length $\Rightarrow n' = n+1$

Then the new wavelength between the mirrors

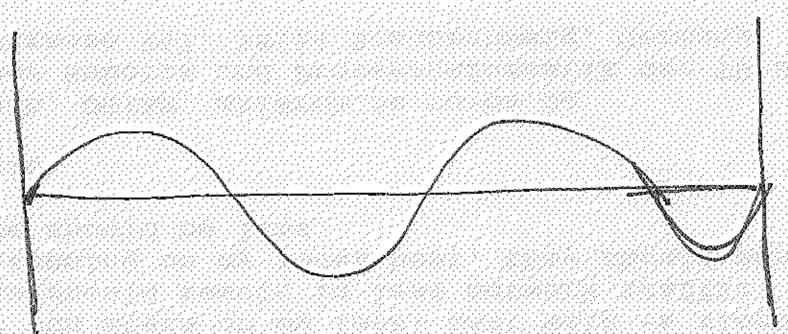
is $\lambda' = \frac{2l}{n+1} = \dots$

~~$\Delta f = \frac{c}{2l}$ for both cases the freq~~

$$\Delta f = f' - f = \frac{c}{\lambda'} - \frac{c}{\lambda} = c\left(\frac{1}{\lambda'} - \frac{1}{\lambda}\right) = \dots c\left(\frac{n+1}{2l} - \frac{n}{2l}\right)$$

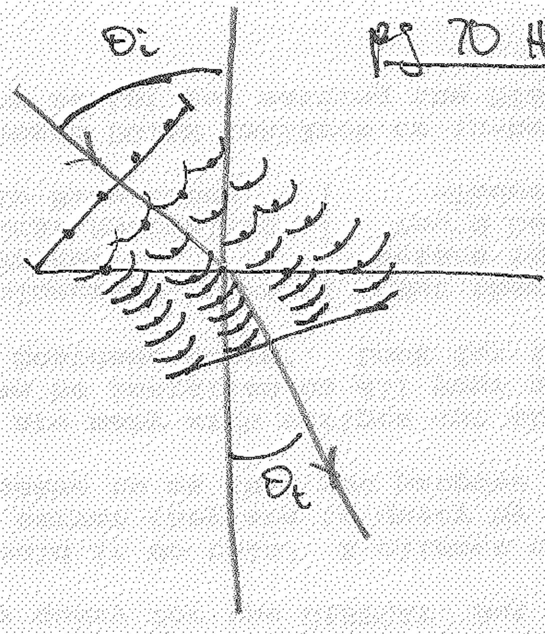
$$= \frac{c}{2l}$$

(4)



Don't understand the question?

(1)



(2) $r = 1\text{ mm}$ $\quad \theta = 1.27 \dfrac{\lambda}{D} = \dfrac{1.27 \cdot (1.06\text{ nm})}{2(10^{-3}\text{ m})} = \cdots$

$\lambda_{HeNe} \overset{?}{\cong} 1.06\text{ nm}$

(3) Nd:YAG $\lambda \cong 1.06\text{ nm}$ $\quad \theta = 1.27 \cdot \dfrac{\lambda}{D} = \dfrac{1.27(1.06\text{ nm})}{10^{-3}\text{ m}} = \cdots$

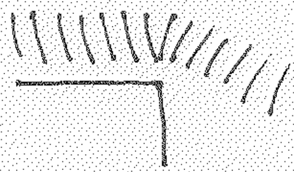
Then arc-length of radius = 240,000 miles

$S = \theta \cdot R$

Either (1) decrease the wavelength of the laser light

(2) The diameter of the beam

(4) Diffraction

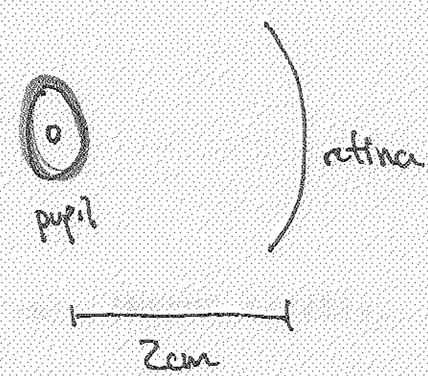


(5) Monochromaticity $\Rightarrow$ wavelength is all the same

+ temporal coherence $\Rightarrow$ in time two ^produced wavelengths are the same

(6) $P = .5 \cdot 10^{-3}\,W$

$\theta_{divergence} = .5 \cdot 10^{-3}\ rad$



$$\theta = \frac{S}{f} \Rightarrow S = \theta f$$

$f = 2\,cm$

$$I = \frac{P}{S} = \frac{\frac{1}{2}\cdot 10^{-3}\,W}{(.5\cdot 10^{-3})^2(2\cdot 10^{-3})^2\,m^2} =$$

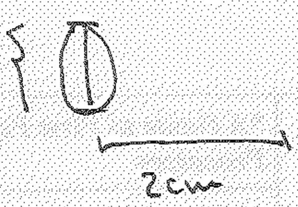
$$= \cancel{.86 \cdot 10^{-3}\,W/m}$$

$$= \frac{\cancel{\tfrac{1}{2}\cdot 10^{-3}}\,W}{(\cancel{\tfrac{1}{2}\cdot 10^{-3}})(\tfrac{1}{2}\cdot 10^{-3})(2\cdot 10^{-3})^2\,m^2} = \frac{W}{\frac{1}{2}\cdot 4\cdot 10^{-9}\,m^2}$$

$$= .5 \cdot 10^{9}\ W/m^2 \ !$$

$$I \cong \frac{P}{\pi ?}$$ How compute Intensity outside of ones eye?

7 $\lambda = 514\ \text{nm}$ $D \cong 7\text{mm}$



$\Theta_{div} = 5 \cdot 10^{-3}\ \text{rad}$

$d = 100\text{m}$ $f = 2\text{cm}$

$$I = \frac{5W}{(\Theta \cdot d)^2} = \frac{5W}{5^2 \cdot 10^{-6} \cdot 10^4\ m^2} = \frac{5W}{25 \cdot 10^{-2}\ m^2} = \frac{1}{5} \cdot 10^2\ W/m^2$$

$$= .2 \cdot 10^2\ W/m^2 = 20\ W/m^2 \equiv I_0$$

Power "intercepted by the retina after focusing due to the eye's lens is

Not sure how to do the remaining calculation...

If

$$\Theta = 2.44 \frac{\lambda}{D} \quad \ldots$$ for the divergence affected by a small apperture

so the divergence entering the eye is

$$\Theta = 2.44 \cdot \frac{514\ \text{nm}}{7\text{mm}} = 2.44 \cdot \frac{514 \cdot 10^{-9}}{7 \cdot 10^{-2}} = \frac{2.44 \cdot 514 \cdot 10^{-7}}{7} =$$

$$S = \Theta \cdot f = \left(\frac{2.44 \cdot 514 \cdot 10^{-7}}{7}\right)(2 \cdot 10^{-2}\ m)$$

Then Intensity on pupil =

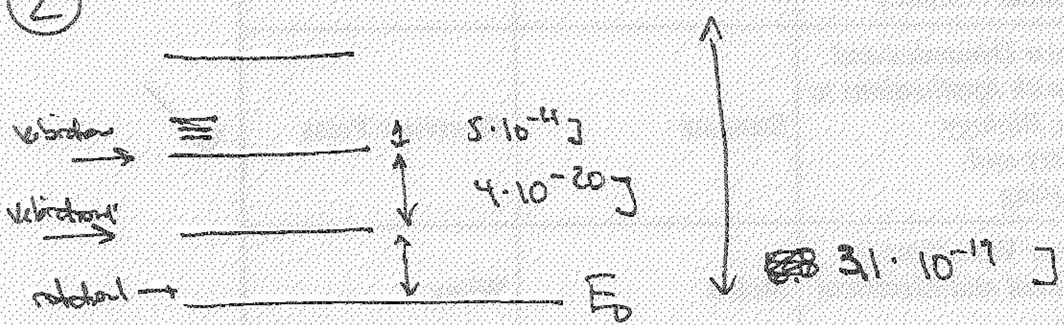
$$I = \frac{I_0 \left(\frac{\pi D^2}{4}\right)}{S} = \ldots$$

① $1\,eV =$

$\lambda = 1.2\,\mu m$

$E = hf = \frac{hc}{\lambda} =$

②



$\lambda = \underline{\Delta E}$ $\Delta E = h\nu = \frac{hc}{\lambda} \rightarrow \lambda = \frac{hc}{\Delta E}$

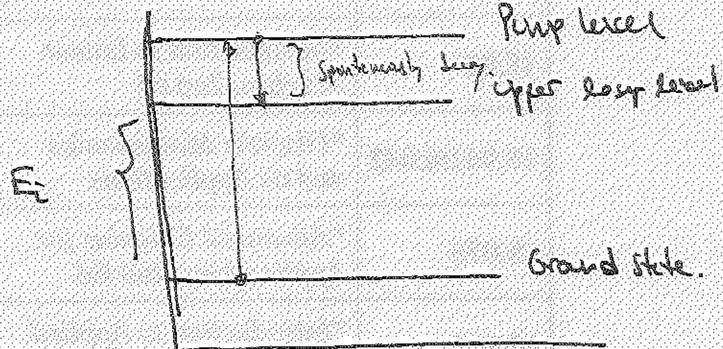
(1) $\cancel{\Delta E = 5\cdot10^{-21}\,J}$ $\Delta E = (3.1\cdot10^{-19} + 5\cdot10^{-21})\,J$

(2) $\Delta E = (2\cdot3.1\cdot10^{-19} + 4\cdot10^{-20} + 5\cdot10^{-21})\,J$

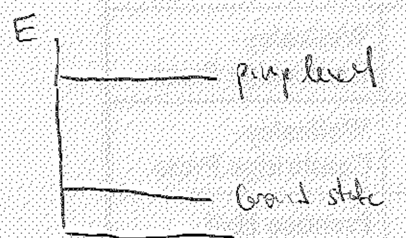
(3) $\Delta E = [(3.1\cdot10^{-19} + 2\cdot5\cdot10^{-21}) - (4\cdot10^{-20} + 5\cdot10^{-21})]\,J$

(1) $N_i = N_0 e^{-\frac{E_i}{kT}}$ $\qquad k = 1.38 \cdot 10^{-23}\ J/K$

$E_i = \frac{hc}{\lambda} = \frac{h \cdot c}{\lambda}$ ✓



$N_i =$



(2) Because the ~~pump atoms would~~ pumping would excite

[redacted] The atoms falling back to the ground state, due to stimulated emission.

(3) Any heating or cooling process?

(1) $1J \cong 10^{19}$ photons

1 visible photon $\cong 10^{-19}$ J

$$3^n = 10^{19}$$

$$n = \frac{19 \ln(10)}{\ln(3)} = 39.8$$

(2) $P_{circ} = 10$ W $\qquad P_{circ} = ?$

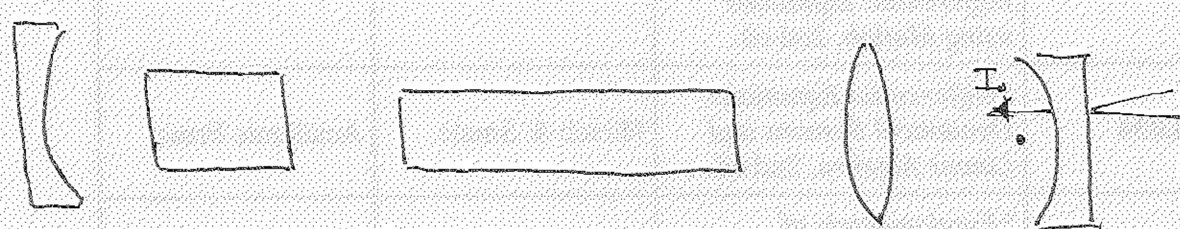
$\tau_{OM} = .06 \qquad \tau = .01$

$P_{out} = (.06)(10)$ W $\qquad P_{out} = 2 \cdot 10^{-3}$ W

$= \frac{6}{100} \cdot 10$ W $\qquad P_{circ} = \frac{P_{out}}{\tau} = .2$ W.

$= .6$ W

(3) $\tau = .03$



$\tau_1 = .005 \quad s = .0025 \quad s = .0025 \quad s = .0025 \quad \tau_2 = .03$

Total round trip loss

$$I_0(.9975)^3(.995)(.9975)^3(.97) = I_0(.9507)$$

$\Rightarrow \simeq$ 5% < 5% loss Adding 5% will produce a saturated laser

(4) $g = \dfrac{g_0}{1+\beta P_c}$ $\qquad P_{out} = \tau P_{circ}$

$$g = \frac{g_0}{1+\frac{\beta}{\tau}P_{out}} \Rightarrow \frac{g_0}{g} = 1 + \frac{\beta}{\tau}P_{out}$$

$$\Rightarrow P_{out} = \left(1-\frac{g_0}{g}\right)\left(-\frac{\tau}{\beta}\right)$$

$$= \frac{\tau}{\beta}\left(\frac{g_0}{g}-1\right)$$

$g_0 = .05$

$\beta = .018\ W^{-1}$

$g = \frac{1}{2}(.05)$

$$P_{out} = \left(\frac{.03}{.018}\right)\left(\frac{.05}{.025}-1\right) = \cdots$$

$$= \frac{.04}{''}\left('' - 1\right)$$

$$= \frac{.05}{''}\left('' - 1\right)$$

(1) $\lambda = 694.3\,nm$

$W_0 = 1mm$ (radius)

1mile = 1600 m

$$W = (1mm)\left[1 + \left(\frac{(694.3\cdot10^{-9})(800\cdot1600m)}{\pi\,(10^{-6})}\right)^2\right]^{1/2}$$

(2) $W_0 = 1m$

$$W = 1m\left[1 + \left(\frac{1.06\cdot10^{-6}\cdot(3.84\cdot10^{8})}{\pi}\right)^2\right]^{1/2}$$

$= 129.56\,m$ much improvement to original

$2.5\cdot10^5\ m$!!

(3) $$w = w_0\left[1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]^{1/2}$$

$z =$

$$w_0 = 2.5\cdot 10^{-4}\ m$$
$$\lambda = 5.14\cdot 10^{-7}\ m$$
$$z = .5\cdot 10^{0}\ m$$

$$w = (2.5\cdot 10^{-4})\left[1+\left(\frac{(5.14\cdot 10^{-7})(.5)}{\pi(2.5\cdot 10^{-4})^2}\right)^2\right]^{1/2}$$

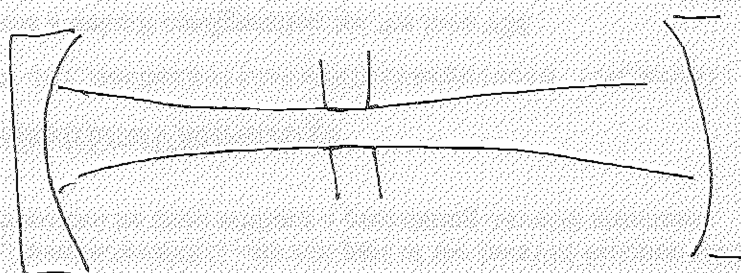
$= \cdots$

$\infty = 0$

$$w = w_0\left[1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]^{1/2} \quad w/\ z = 25\ m$$

(4) HeNe

$$w_0 = .25\cdot 10^{-3}$$
$$\lambda \cong 1.06\cdot 10^{-6}\ m$$
$$z = 15\cdot 10^{-2}\ m$$



$$R = z\left[1+\left(\frac{\pi w_0^2}{\lambda z}\right)^2\right]$$

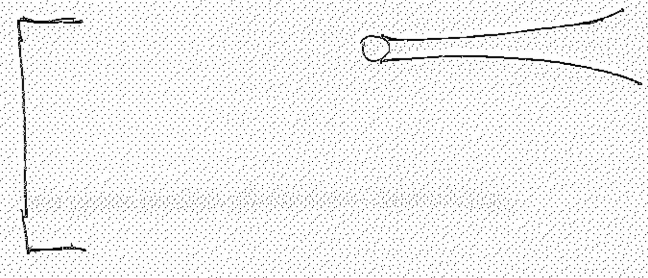
$$= (15\cdot 10^{-2})\left[1+\left(\frac{\pi(.25\cdot 10^{-3})^2}{(1.06\cdot 10^{-6})(15\cdot 10^{-2})}\right)\right] = \cdots$$

Radius of curvature of two end cap mirrors

$$+\ w = w_0\left[1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]^{1/2} = \cdots$$

waist of laser at end caps → min size of mirrors

(5) TEM_{00}



$$W = W_1\left[1+\left(\frac{\lambda z}{\pi W_1}\right)^2\right]$$

set equal

$$W = W_2\left[1+\left(\frac{\lambda z}{\pi W_2}\right)^2\right]$$

$$= \frac{W_1}{W_2}\left[1+\left(\frac{\lambda z}{\pi W_1}\right)^2\right] = 1+\left(\frac{\lambda z}{\pi W_2}\right)^2$$

$$\frac{W_1}{W_2} - 1 = \frac{\lambda^2}{\pi^2 W_2^2} z^2 - \frac{W_1}{W_2}\frac{\lambda^2}{\pi^2 W_1^2} z^2 = \frac{\lambda^2}{\pi^2} z^2\left(\frac{1}{W_2^2} - \frac{1}{W_1 W_2}\right)$$

$$\Rightarrow \quad z^2 = \frac{\frac{\pi^2}{\lambda^2}\left(\frac{W_1}{W_2} - 1\right)}{\left(\frac{1}{W_2}\right)\left(\frac{1}{W_2} - \frac{1}{W_1}\right)} = \frac{\pi^2}{\lambda^2}\frac{(W_1 - W_2)}{\left(\frac{1}{W_2} - \frac{1}{W_1}\right)} \cdot \frac{W_2 W_1}{W_2 W_1}$$

$$= \frac{\pi^2}{\lambda^2} W_1 W_2 \frac{\cancel{(W_1 - W_2)}}{\cancel{(W_1 - W_2)}} = \frac{\pi^2 W_1 W_2}{\lambda^2}$$

$$z = \pm \frac{\pi}{\lambda}\sqrt{W_1 W_2}$$

$$\begin{array}{r}15\\5\overline{)75}\\50\\\hline\end{array}$$

(6) $g_1 = 1 - \frac{l}{R_1}$ $\quad g_2 = 1 - \frac{l}{R_2}$

$= 1 - \frac{75}{200}$ $\quad g = 1 + \frac{75}{500}$

$= 1 - \frac{15}{40}$ $\quad 1 + \frac{15}{100}$

$=$

$0 < g_1 g_2 \leq 1$ for stability

$g_1 = 1 - \frac{30}{75}$ $\quad g_2 = 1 - \frac{30}{75}$

$0 \leq g_1 g_2 \leq 1$ for stability.

(7) From

$$\Delta f \equiv f_{n+1} - f_n = \frac{c}{2l} = \frac{3 \cdot 10^8 \text{ m/s}}{2(1\text{m})} = 1.5 \cdot 10^8 \text{ 1/s}$$

(8) Changing l by increasing it would decrease the spacing between spikes in the frequency spectrum.

① $\lambda = 514.5$ nm translate horizontally to the left.

$$f = \frac{c}{\lambda} = \cdots$$

$.4\ {}^{1}/_{cm} = \Delta({}^{1}/_{\lambda})$

$$\Delta f = c\,\Delta({}^{1}/_{\lambda}) = c \cdot (.4\ {}^{1}/_{cm})$$

$$\cancel{\Delta\lambda = -\frac{\Delta}{\lambda^2}} \qquad 1 = \lambda({}^{1}/_{\lambda})$$

$$0 = \Delta\lambda({}^{1}/_{\lambda}) + \lambda\Delta({}^{1}/_{\lambda}) \Rightarrow \Delta\lambda = \lambda^2\Delta({}^{1}/_{\lambda}) = \cdots$$

$\lambda = 488$ nm

$\Delta({}^{1}/_{\lambda}) = .4\ \mathrm{cm}^{-1}$

② $$\frac{1\,W}{1\,Å} = 1\ W/Å$$

$$\frac{.5\,W}{{}^{3}/_{10}\,Å} = \frac{5}{3}\,\frac{W}{Å}$$

$$SI = \frac{.17\,W}{\frac{1}{10}\,Å} = 1.7\,\frac{W}{Å}$$

$$SI = \frac{.45\,W}{\frac{1}{10}\,Å} = 4.5\,\frac{W}{Å}$$

Don't know what the difference is?

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(3) Yes but spacing between mirrors would be on the order of the wave length.

?

(4) $\lambda \cong 600$ nm ?

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(1) $P = 1W$

$\underbrace{10(100 \cdot 10^{-9})}$ $P_{peak\ pulse} = 1$

$P_{peak\ pulse} = 10^9 \cdot 10^{-4} = 10^5$

(2) $\lambda_{Nd:YAG} = ?$ How calculate the energy stored in the resonator?

(3) $$\frac{.5 \cdot 10^{-3}\ m}{6 \cdot 10^3\ m/s} = \frac{\text{diameter of laser beam}}{\text{sound speed in medium}}$$

$= \frac{1}{2}\frac{1}{6} 10^{-6}$ s $= \frac{1}{12}$ μs

4 $(2\cdot 10^{19})\cdot 7\cdot E_\nu = 1\,J$

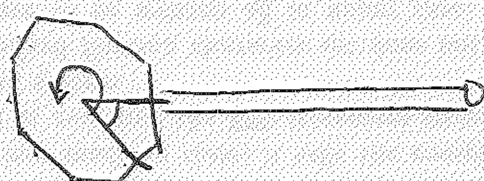
N_1 upper laser level

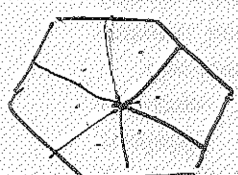
N_0 lower laser level

$$E_\nu = h\nu = \frac{hc}{\lambda}$$

$$N_0\cdot 7\cdot \frac{hc}{\lambda} = 1\,J$$

5 a





$$\frac{360}{6} = 60^\circ = \frac{\pi}{3}$$

~~Hz~~ one pulse every time mirror rotates 60°

$$3200\cdot 2\pi\,\frac{rad}{\cancel{60s}\ min}\ \frac{1\,min}{60\,s}$$

$$= \frac{320\cdot 2\pi}{6}\,\frac{rad}{s}$$

$$PRF = \frac{\frac{320 \cdot 2\pi}{6}}{\frac{\pi}{3}} = \frac{320 \cdot 2\pi}{2 \cdot 6}\left(\frac{3}{\pi}\right) = 320 \text{ Hz}$$

(6) ?

(7) (i) longer the resonator length the longer it would take to empty the optical cavity, more time is spent travelling back + forth

(ii) less transparent the mirror is the longer it takes to fully empty all photon energy in the beam.

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(1) ?

(2) ?

(3) $P_{AVG} = 800 \text{ mW} =$

?

(4) ?

① $\lambda_{Nd:YAG} = 106$ nm

$$\frac{\cancel{hc}}{\lambda_p} + \frac{hc}{\lambda_1} = \frac{hc}{\lambda}$$

How compute second-harmonic + third harmonic wavelength?

② Place a beam splitter at an angle to split the back reflected beams.

③ $$P_{SH} = \frac{\ell^2 P_f^2}{A}\left[\frac{\sin^2(\Delta\phi)}{(\Delta\phi)^2}\right]$$

$$P_{SH}' = 9\,P_{SH} = 9\text{ nW}$$

④ $P_f = 1\text{ W}$ $\quad P_{SH} = 10\text{ mW}$ $\quad P_{SH} = \alpha P_f^2$

$P_f = ?$ $\quad P_{SH} = 15\text{ mW}$

$$\cancel{P_f} \quad \alpha = \frac{P_{SH}}{P_f^2} = \frac{10\cdot 10^{-3}\,\text{W}}{\text{W}^2} = 10^{-2}\ {}^1\!/\!_W.$$

$$\therefore\ P_f = \left(\frac{P_{SH}}{\alpha}\right)^{1/2} = \left(\frac{15\cdot 10^{-3}\,\text{W}}{10^{-2}\ {}^1\!/\!_W}\right)^{1/2} = (1.5)^{1/2}\,\text{W}$$

$$= 1.2247\text{ W}$$

$\Delta P =$

$E = P \cdot \tau = P'\tau'$

$\Delta(P\tau = P'\tau')$

$0 = \Delta P'\tau' + P'\Delta\tau' \Rightarrow \dfrac{\Delta\tau'}{\tau'} = -\dfrac{\Delta P'}{P'} = \dfrac{-(1.2247-1.0)W}{1.2247\,W} = \ldots$

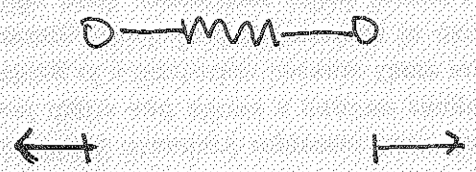
5. $\lambda_2 = \dfrac{\lambda_1 \lambda_3}{\lambda_3 - \lambda_1} = \dfrac{(106\,\text{nm})\,\lambda_3}{(\lambda_3 - 106)\,\text{nm}}$

what is λ_3?

6. Don't understand?

(1) $\varepsilon = \dfrac{2 \cdot 10^{-2}\ W}{(5 \cdot 10^{-3})(1600)} = \ldots$

(2)



Only 1 mode of vibration is possible

(3) Desire the polarization effect ...?

(4) It equal to the dye hence all absorption?

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(1) ?