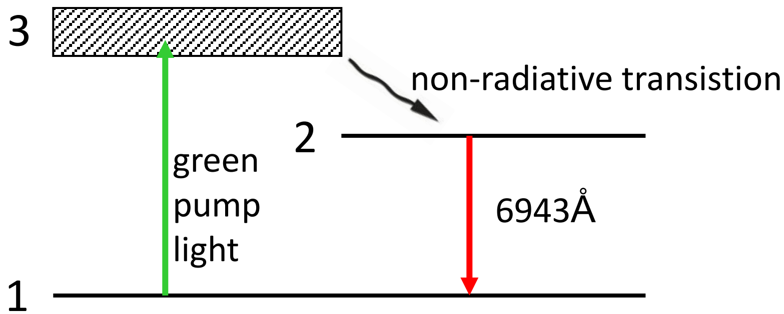
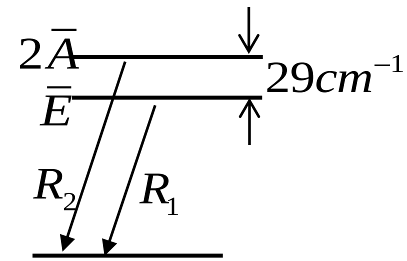
Ruby Laser

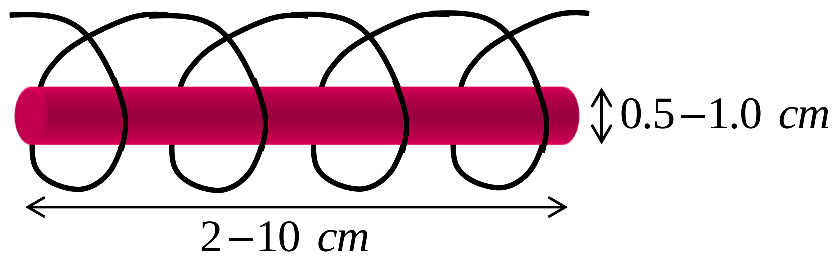
First operable three-level system

Ruby: crystal of sapphire (Al_2O_3) with a small amount of Al replaced by chromium (0.05% Cr_2O_3)

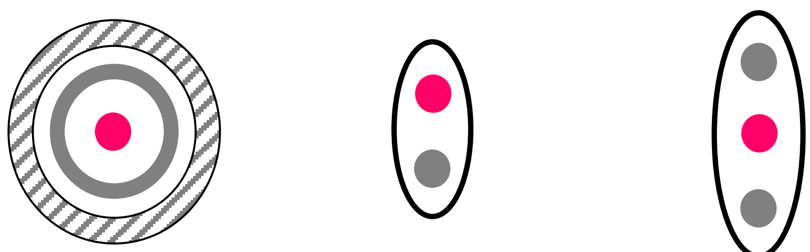




pink ruby



Three common flash lamp geometries



helical

elliptical linear

dual elliptical

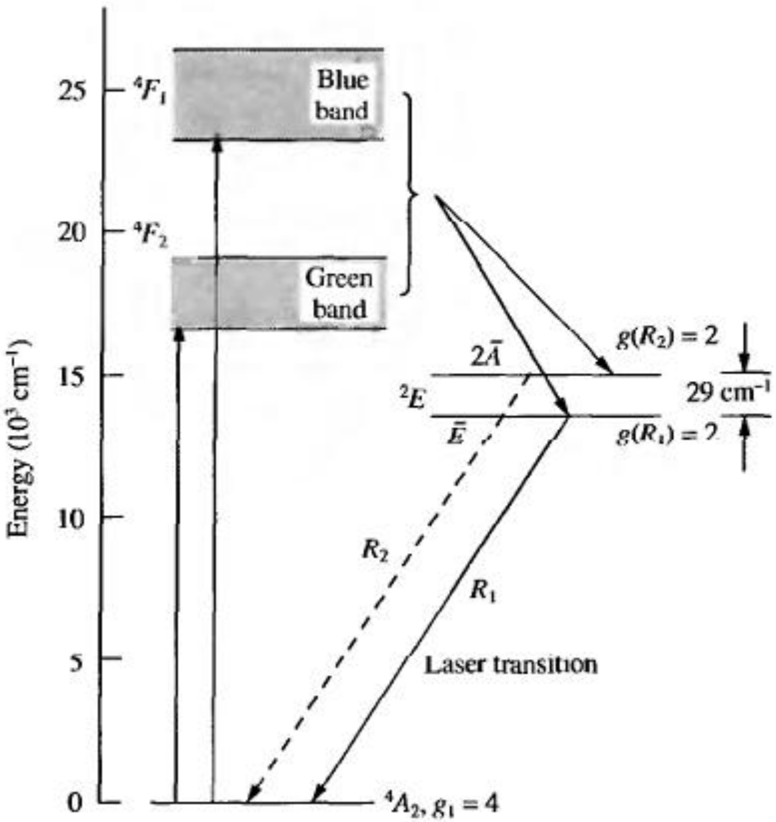


FIGURE 10.2. Energy level diagram for Cr^{3+} ion in Al_2O_3.

Low-level signal (not much depletion of the ground state)

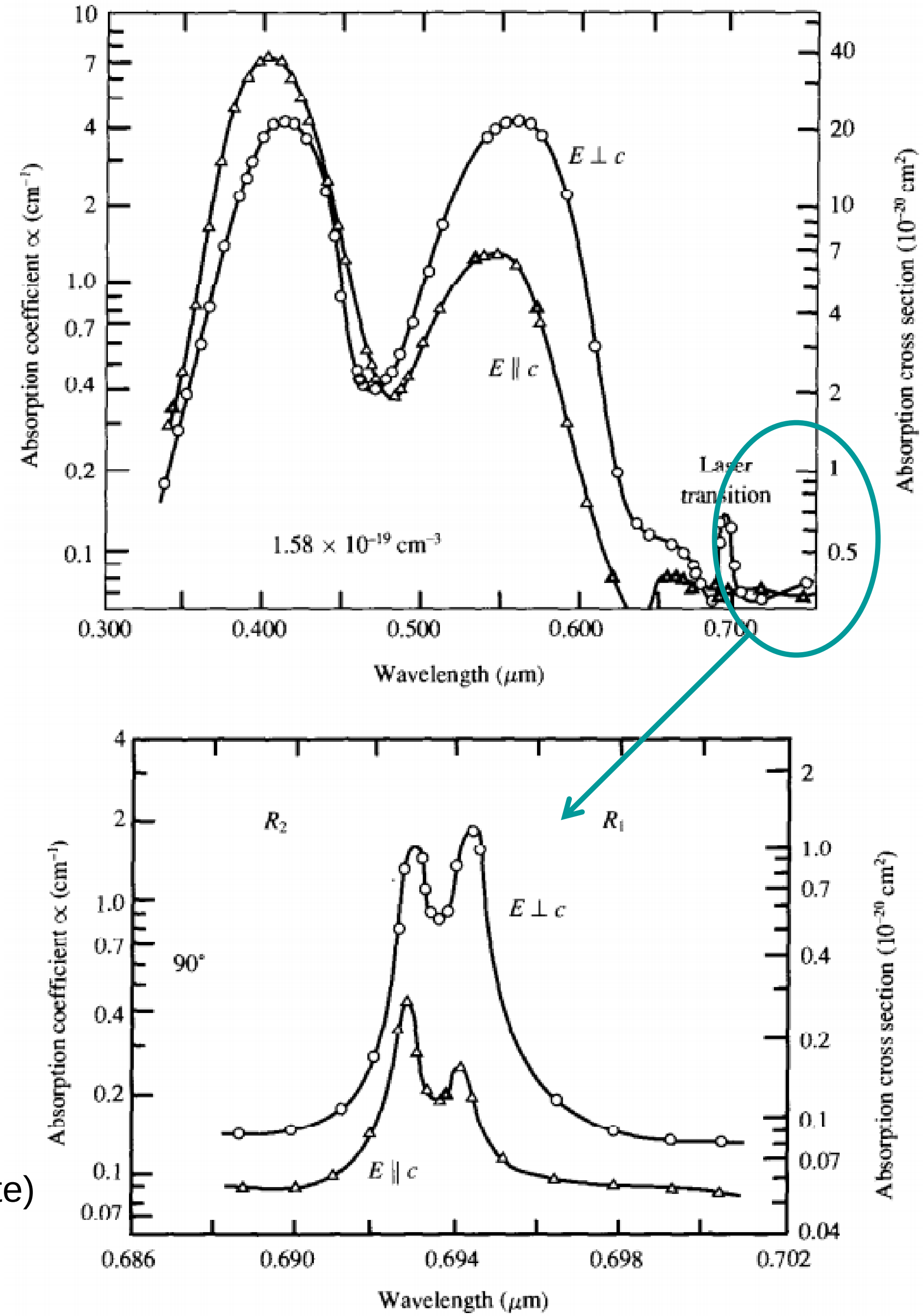


FIGURE 10.3. Absorption coefficient and cross section for ruby with $Cr^{3+} = 1.58 \times 10^{19}$ cm^{-3}.

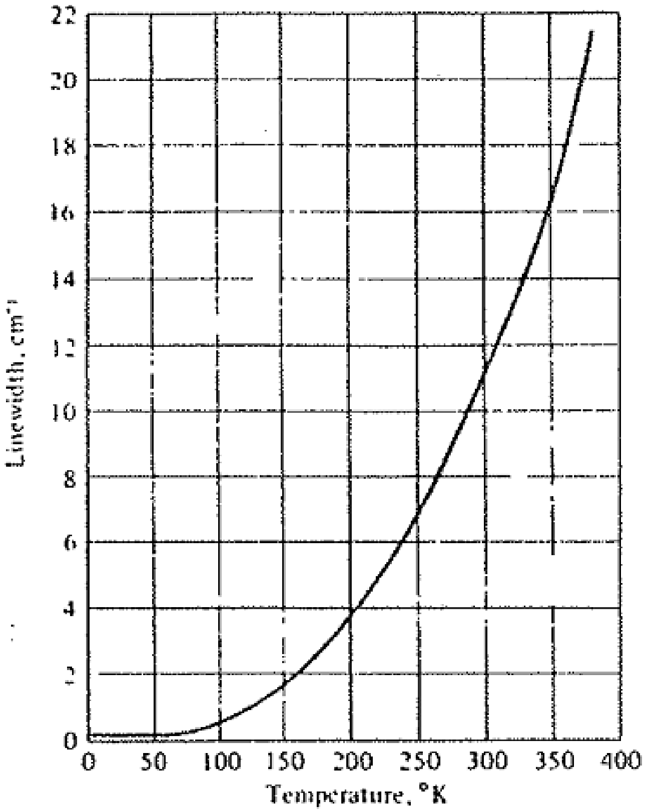


Figure 7-5 Linewidth of the R_1 line of ruby as a function of temperature.

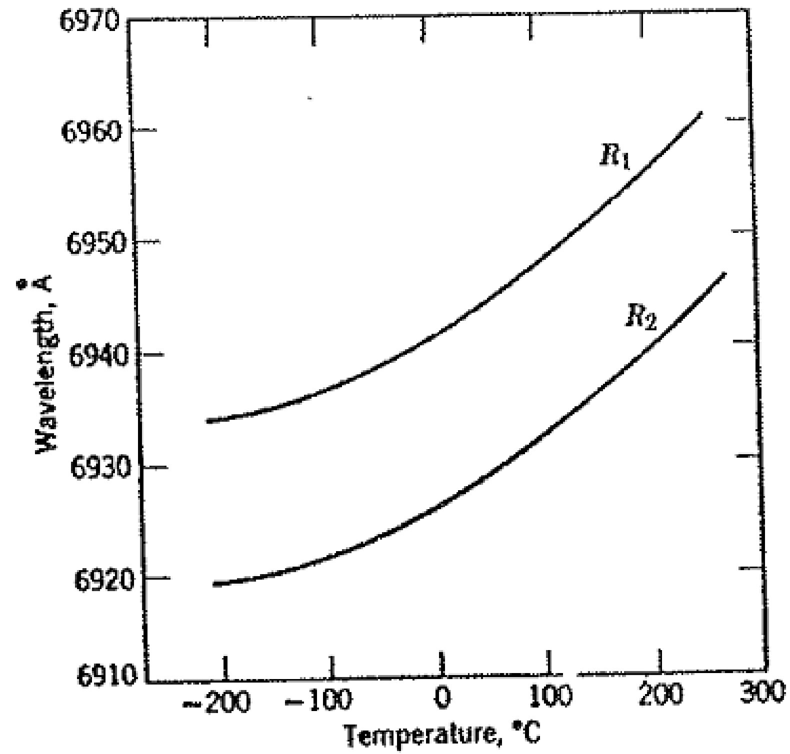
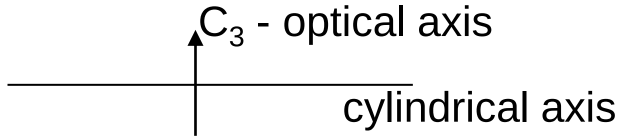


FIG. 4.7 Wavelengths of the R_1 and R_2 fluorescent lines of ruby as functions of temperature.



ordinary ray $(E \perp c)$ $\eta_0 = 1.764$

extraordinary ray $(E \parallel c)$ $\eta_e = 1.756$

at $\lambda = 6942 \mathring{A}$

$N_0 = 1.58 \times 10^{19} cm^{-3} \;\; Cr^{3+}$

$\tau_{32} = 50 \;\; ns$ $\sigma_{SE} = 1.27 \times 10^{-20} cm^2$

$\tau_{21} = 3 \;\; ms$ $t_{flash} = 100 - 500 \mu s$

lattice vibrations couple the $2\bar{A}$ and $\bar{E}$

$\left(< 1 \;\; ns\right.$ photon assisted transfer time $\left. 2\bar{A} \leftrightarrow \bar{E} \right)$

$\Delta E = 29 \;\; cm^{-1}$ $\mathrm{k}T = 208 \;\; cm^{-1} \; (300K)$

$$K = \frac{N(2\bar{A})}{N(\bar{E})} = \exp\left[\frac{\Delta E}{\mathrm{k}T}\right] = 0.87$$ (at room temp.)

Gain is larger for $\bar{E}$ as this level is depleted by the laser action, population from $2\bar{A}$ is coupled in

$(2) \Rightarrow \bar{E}$ $g_2 = 2$

$(1) \Rightarrow \text{ground}$ $g_1 = 4$

$$N_1 + N_2 + N_3 = N_0$$
$$N_3 \ll N_1, N_2$$
$$N_1 + N_2 \simeq N_0$$

$$N(2\bar{A}) + N(\bar{E}) = N_2$$

$$\frac{N(2\bar{A})}{N(\bar{E})} = 0.87 = K$$

$$N(2\bar{A}) = \frac{K}{1+K} N_2 \qquad N(\bar{E}) = \frac{1}{1+K} N_2$$

(1) Optical transparency

$$N_2 - \frac{g_2}{g_1} N_1 = 0$$

$$N(\bar{E}) - \frac{2}{4} N(^4A_2) = 0$$

$$\frac{N_2}{1+K} - \frac{1}{2} N_1 = 0 \qquad N_2 + N_1 = N_0$$

$$N_2 = \frac{1+K}{3+K} N_0 = 0.483 N_0$$

$$N_1 = \frac{2}{3+K} N_0 = 0.517 N_0$$

(2) Spontaneous fluorescence (at no gain)

$$P_{sp} = h\nu \frac{N_2}{\tau_{sp}} = \frac{1+K}{3+K} \frac{h\nu N_0}{\tau_{sp}} = 727 \ {W}/{cm^3}$$

$N_0 = 1.58\times10^{19}\, cm^{-3}$ $\quad \tau_{21} = 3\ ms$

$K = 0.87$ $\quad \lambda = 6943 Å$

(3) Needed absorbed power (at quantum efficiency of the pumping = 0.7)

$$P_{ab} = \frac{P_{sp}}{\eta} = 1.04 \ {kW}/{cm^3}$$

from the flash lamp in order to reach the condition of optical transparency.

(4) Needed input energy

If we assume a conversion efficiency of electrical energy stored in the capacitor to emitted radiation of the flash lamp into all λ of 55%, with 20% of that radiated energy being in the green pump light, and a time scale for the pumping of 3 ms, then we require a stored energy in the capacitor $\left(\frac{1}{2} CV^2\right)$ of:

$$W = \frac{1.04\times10^3\ {W}/{cm^3} \cdot 3\times10^{-3} s}{0.55\times0.20} = 28.3 \frac{Joules}{cm^3 \text{ of rod}}$$

(for lasing, more energy is needed)