

absorb light at different frequencies, it has proved possible to separate isotopes by irradiating an isotopic mixture at a (laser) frequency at which only one of the isotopes absorbs the light appreciably; the energetically excited isotopic molecule may then decompose or otherwise chemically react to a form readily separable from the other isotopic species. A number of such isotopic separations have been found, though none is yet sufficiently efficient to displace existing methods. Finally, it has been proposed that lasers can be instrumental in achieving controlled thermonuclear fusion, and there is hope that laser-assisted fusion will become feasible in one or two decades.

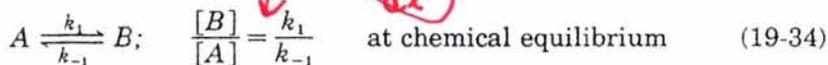
### 19.B.3. Saturation Phenomena and Spectral Lifetimes

In the preceding Section, we calculated the effect of monochromatic radiation on the relative populations of a system of *isolated* particles characterized by two energy-levels,  $E_m$  and  $E_n$ . The principal result of that calculation appeared as Eq. 19-32 showing that externally applied radiation at a frequency of  $(E_n - E_m)/\hbar$  causes any initial population difference,  $(N_n - N_m)$ , to decrease exponentially to zero while the irradiation is applied. However, for an actual system in *thermal equilibrium* with its surroundings, it is found that in the absence of externally applied radiation, the two populations are not the same, but obey the Boltzmann ratio of Eq. 19-4a. We are therefore led to conclude that there must be some "coupling" or connection between the system and its surroundings that makes "downward" transitions more likely than "upward" transitions by the Boltzmann factor that describes the two populations at *thermal equilibrium*:

$$\frac{N_n}{N_m} = \frac{W_{\downarrow}}{W_{\uparrow}} = e^{-(E_n - E_m)/kT} \quad \text{at thermal equilibrium} \quad (19-33)$$

(no radiation applied)

Equation 19-33 is conceptually identical to the usual relation between an equilibrium constant and the component rate constants in an ordinary *chemical equilibrium*



$$\frac{d[A]}{dt} = -k_1[A] + k_{-1}[B] \approx 0 \text{ at equilibrium}$$

in which  $W_{\uparrow}$  and  $W_{\downarrow}$  represent the "rate constants" for transitions upward or downward (see Fig. 19-8).

In the *absence* of applied radiation, we can write equations for the rate of change of energy-level populations,  $dN_n/dt$  and  $dN_m/dt$ , where the rate constants  $W_{\uparrow}$  and  $W_{\downarrow}$  for (radiationless) transitions between levels reflect some sort of interaction between the system and its surroundings (this interaction is discussed more precisely in Chapter 21.A and 21.B):

$$dN_m/dt = -W_{\downarrow} N_m + W_{\uparrow} N_n \quad (19-35a)$$

$$dN_n/dt = -W_{\uparrow}N_n + W_{\downarrow}N_m \tag{19-35b}$$

or just

~~$$\frac{d(N_n - N_m)}{dt} = (N_m + N_n)(W_{\downarrow} - W_{\uparrow}) - (N_n - N_m)(W_{\downarrow} + W_{\uparrow}) \tag{19-36}$$~~

It is convenient to rewrite Eq. 19-36 in the form

$$\boxed{\frac{d(N_n - N_m)}{dt} = \frac{(N_n - N_m)_{eq} - (N_n - N_m)}{T_1}} \tag{19-37}$$

where

~~$$(N_n - N_m)_{eq} = (N_n + N_m) \frac{(W_{\downarrow} - W_{\uparrow})}{(W_{\downarrow} + W_{\uparrow})} \tag{19-37a}$$~~

*MANIFOLD Eigen*  
 $A \begin{matrix} k_1 \\ \rightleftharpoons \\ B \\ k_{-1} \end{matrix} \xrightarrow{[A]} \frac{1}{0} \neq \frac{1}{0} \neq \frac{1}{0} \neq 1 - e^{-t/\tau}$   
 $\frac{1}{\tau} = k_1 + k_{-1}$

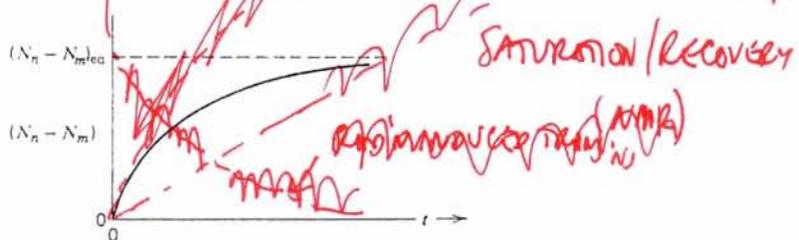
$$\boxed{\frac{1}{T_1} = (W_{\downarrow} + W_{\uparrow})} \tag{19-38}$$

For example, starting from a situation in which  $N_n = N_m$  at time zero (i.e., both levels equally populated initially), Eq. 19-37 is quickly solved to give

$$(N_n - N_m) = (N_n - N_m)_{eq} (1 - e^{-t/T_1}) \tag{19-39}$$

from which it is clear that  $(N_n - N_m)_{eq}$  represents the equilibrium population difference between the two levels. Equation 19-39 describes, for example, the exponential increase in magnetic moment for a system of spin one-half nuclei suddenly placed in a constant magnetic field at time zero (see Fig. 19-17).

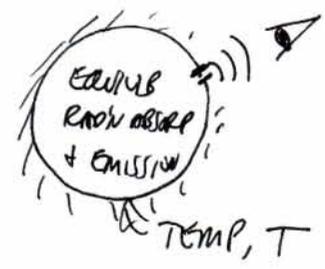
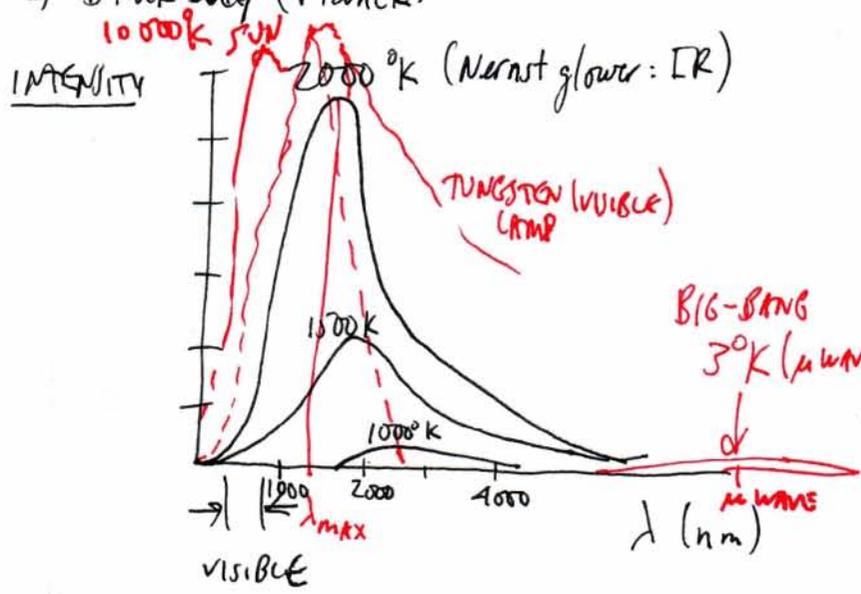
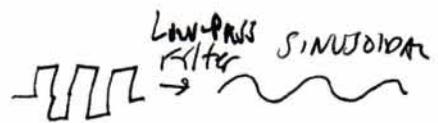
We may now combine Equations 19-31 and 19-37 to find the behavior of a two-level system subject both to externally applied radiation at fre-



**FIGURE 19-17** Plot of population difference versus time, for a two-level system with initial population difference equal to zero at time zero. At infinite time later (i.e., thermal equilibrium) the population difference approaches its thermal equilibrium value  $(N_n - N_m)_{eq}$  (see Eq. 19-37a).

RADIATION SOURCES ~~(CHAPTER 5)~~ ~~CHAPTER 8~~

- Monochromator: 1) LASER / RF,  $\mu$ WAVE OSCILLATORS (FREQ. SYNTHESIZERS)  
 2) Black body (Planck)



"BLACK BODY" (Absorption)  
 ("WHITE BODY") (Emission)

COMPOSITION DOESN'T MATTER  
 Planck: ENERGY QUANTIZED IN PACKETS OF  $h\nu$

Classical, but don't explain shape of curve

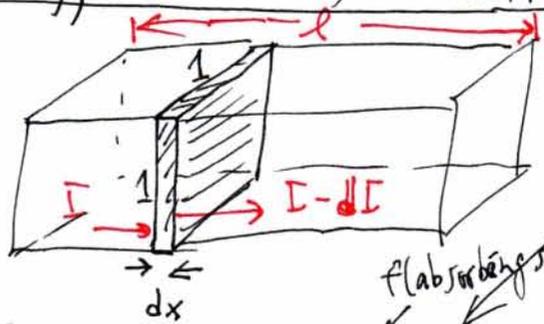
$\nu_{max} \propto T$   
 $TOTAL ENERGY \propto T^4$   
 (Note:  $\int \frac{1}{e^{h\nu/kT} - 1} d\nu$ )  
 INTEGRATE OVER  $\nu$

PLANCK: ENERGY DENSITY  $\propto \frac{\nu^3}{e^{h\nu/kT} - 1}$

ABSORPTION, TRANSMISSION, (FOCUSING), REFLECTION, OF LIGHT

REFRACTION, DETECTION ~~CHAPTER 11~~

ABSORPTION



more incident intensity  $\rightarrow$  more absorption by sample

PATH LENGTH

$$I_{final} - I_{initial} = (I - dI) - (I) = -dI = -I \cdot \text{AREA} \cdot \text{conc} \cdot N \cdot dx$$

ONLY TRUE FOR VERY THIN SLAB

USUALLY LET AREA =  $1 \text{ cm}^2$

$$-dI = \text{const} \cdot c \cdot I \cdot dx$$

$$\frac{dI}{I} = - \text{const} \cdot c \cdot dx$$

$$\int_{I_{in}}^{I_{out}} \frac{dI}{I} = - \text{const} \cdot c \int_0^l dx$$

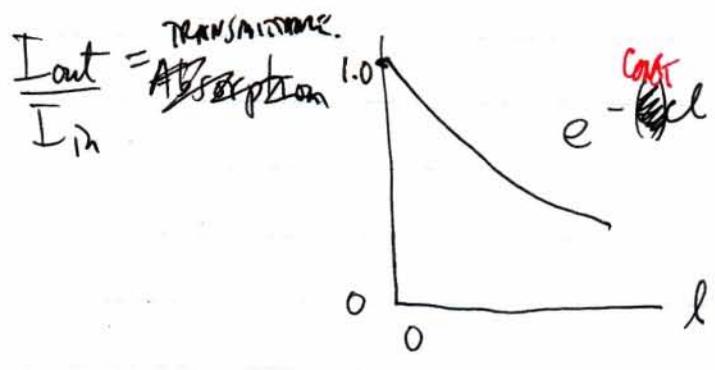
$$\ln I_{out} - \ln I_{in} = - \text{const} \cdot c \cdot (l - 0)$$

$$\ln \frac{I_{out}}{I_{in}} = - \text{const} \cdot c \cdot l$$

~~$$\ln \frac{I_{out}}{I_{in}} = - \text{const} \cdot c \cdot l$$~~

Beer-Lambert Law

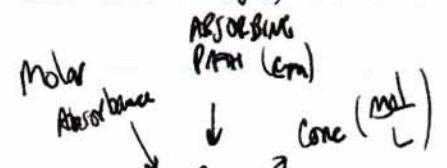
$$\frac{I_{out}}{I_{in}} = e^{-\text{const} \cdot c \cdot l}$$

~~$$10^{-A} = \frac{1}{10^A}$$
  
$$\frac{I_{out}}{I_{in}} = \frac{1}{10^A}$$
  
$$10^{-A} = e^{-\text{const} \cdot c \cdot l}$$~~

OK FOR ABSORP'N VS DISTANCE.

WHAT ABOUT ABSORP'N VS. FREQUENCY? (SPECTROSCOPY)

$$T = \text{TRANSMITTANCE} = \frac{I_{out}}{I_{in}}$$



$$A = \text{ABSORBANCE} = \log_{10} \left( \frac{I_{in}}{I_{out}} \right) = \log_{10} \left( \frac{1}{T} \right) = -\log_{10} T = \epsilon \cdot l \cdot c$$

SO THAT ABSORBANCE IS A POSITIVE #

# Lens Primer

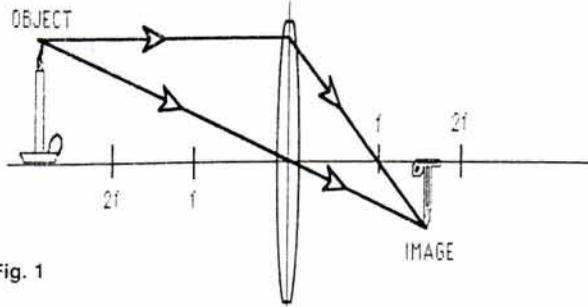


Fig. 1

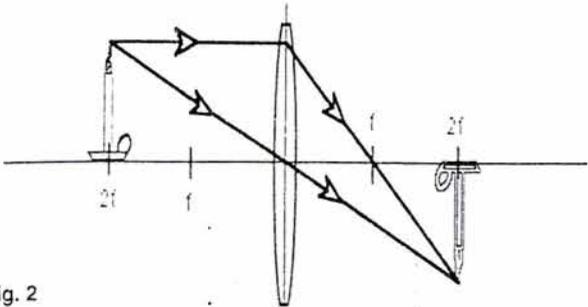


Fig. 2

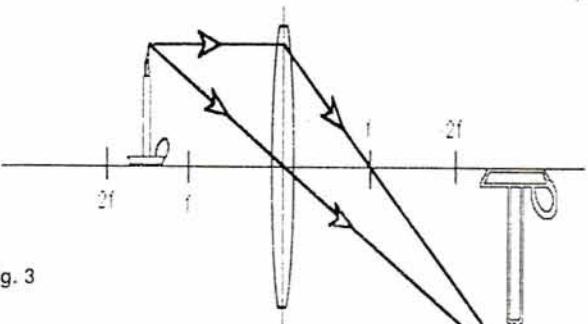


Fig. 3

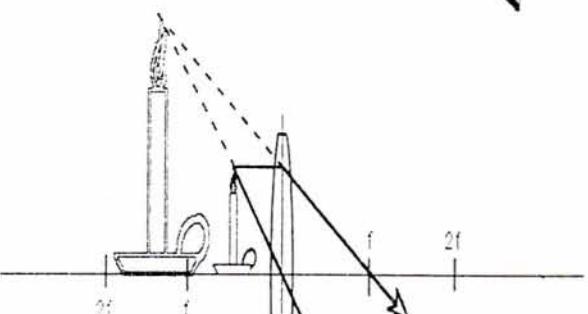


Fig. 4

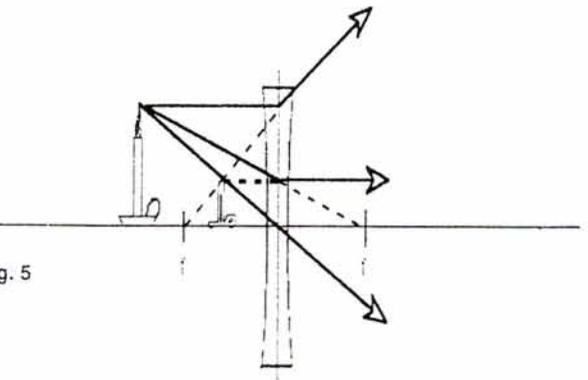


Fig. 5

The drawings show how simple lenses form images. The first four drawings represent positive lenses (plano-convex, double convex, positive meniscus and positive achromats), and the last drawing represents negative lenses (plano-concave, double-concave, negative meniscus and negative achromats). From these drawings one can infer where an image will be formed and its size relative to the focal length (f), and two times the focal length (2f). It can also be inferred that if the image is formed on the right side of the lens it is **real** and can be projected onto a screen. If the image is to the left of the lens it is **virtual** and cannot be projected on a screen. Fig. 4 shows the most common case of a virtual image, the hand held magnifier. From the drawing one can see the image is virtual and enlarged, and as we all know can be seen with the eye. This is an important point to remember, as virtual images can only be viewed or projected with the aid of another lens, in this case the eye. The final point to infer from the drawings are image orientations. For real images the orientation will be inverted and for virtual images the orientation will remain the same. The following chart summarizes object and image locations.

Positive Lens				
Object Location	Type	Image Location	Orientation	Relative Size
$\infty > O > 2f$	Real	$f < I < 2f$	Inverted	Reduced
$O = 2f$	Real	$I = 2f$	Inverted	Same size
$f < O < 2f$	Real	$\infty > I > 2f$	Inverted	Magnified
$O = f$	$\pm\infty$			
$I < f$	Virtual	$I > O$	Erect	Magnified

Negative Lens				
Object Location	Type	Image Location	Orientation	Relative Size
Anywhere	Virtual	$ I  <  f $ $O >  I $	Erect	Reduced

\*O = Object Distance    I = Image Distance

To further determine object and image location it is possible to use the following approximation.

$$\frac{1}{\text{focal length}} - \frac{1}{\text{object distance}} = \frac{1}{\text{image distance}}$$

The object and image distance should be measured from the center of the lens to their respective distances away from the lens.

To find the approximate projected magnification of a lens the following is used.

$$\text{projected magnification} = - \frac{\text{focal length}}{\text{object distance} - \text{focal length}}$$

If the equation works out to be negative the image will be inverted and if positive the orientation will remain the same. One should not confuse the magnification above with that of a magnifier used to aid the eye. In the case of the eye the magnification is dictated by a two lens combination and is not as easily approximated.

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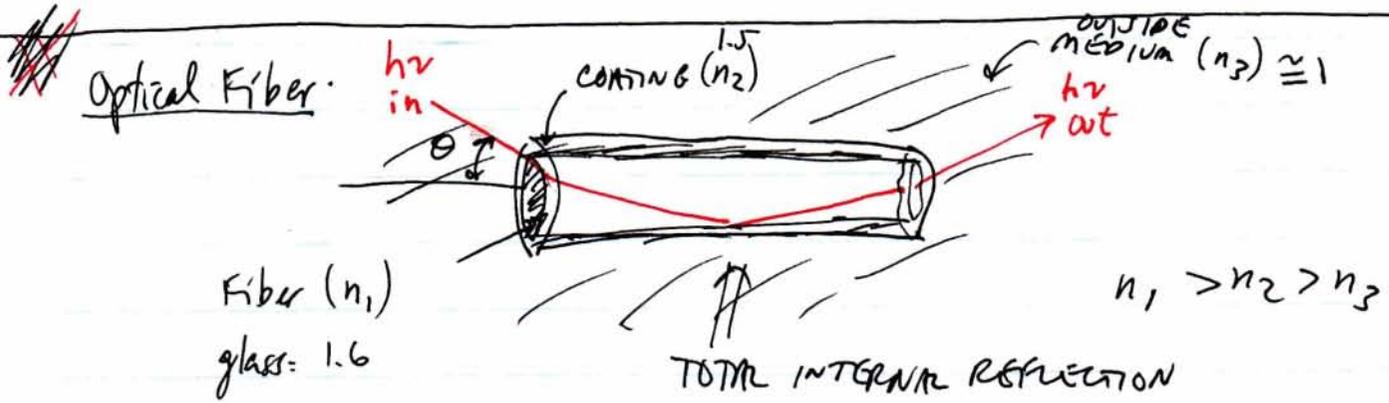
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Flexible, Transmit light from <sup>source to</sup> sensor to detector

$$\theta \leq \text{MAX } \theta: \quad \sin \theta_{\text{MAX}} = \frac{\sqrt{n_1^2 + n_2^2}}{n_3}$$

$\uparrow$   
 For TOTAL INTERNAL REFLECTION