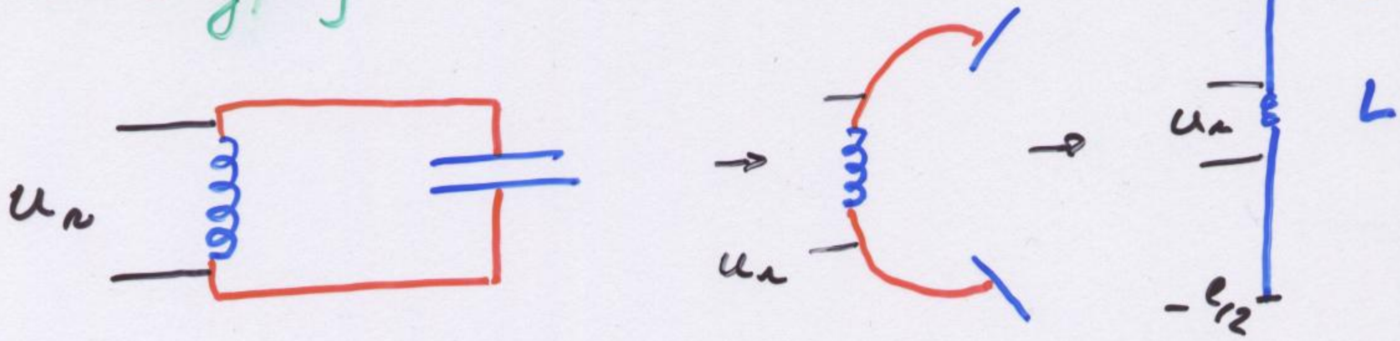
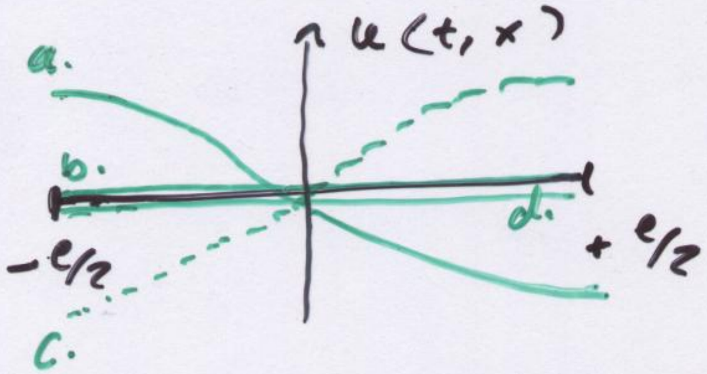
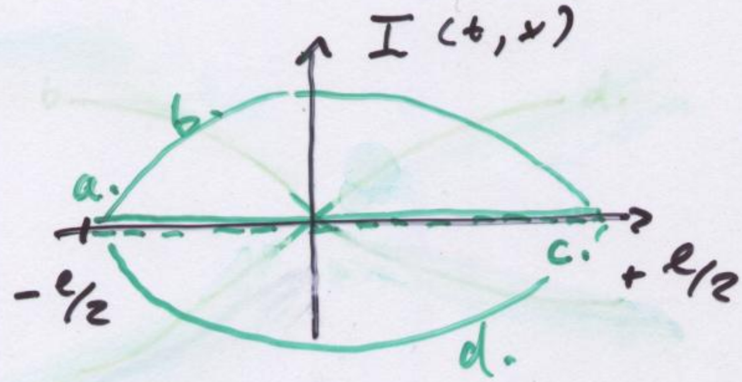
Erläuterungen zu EM Wellen

Erzeugung im Falle des Dipols

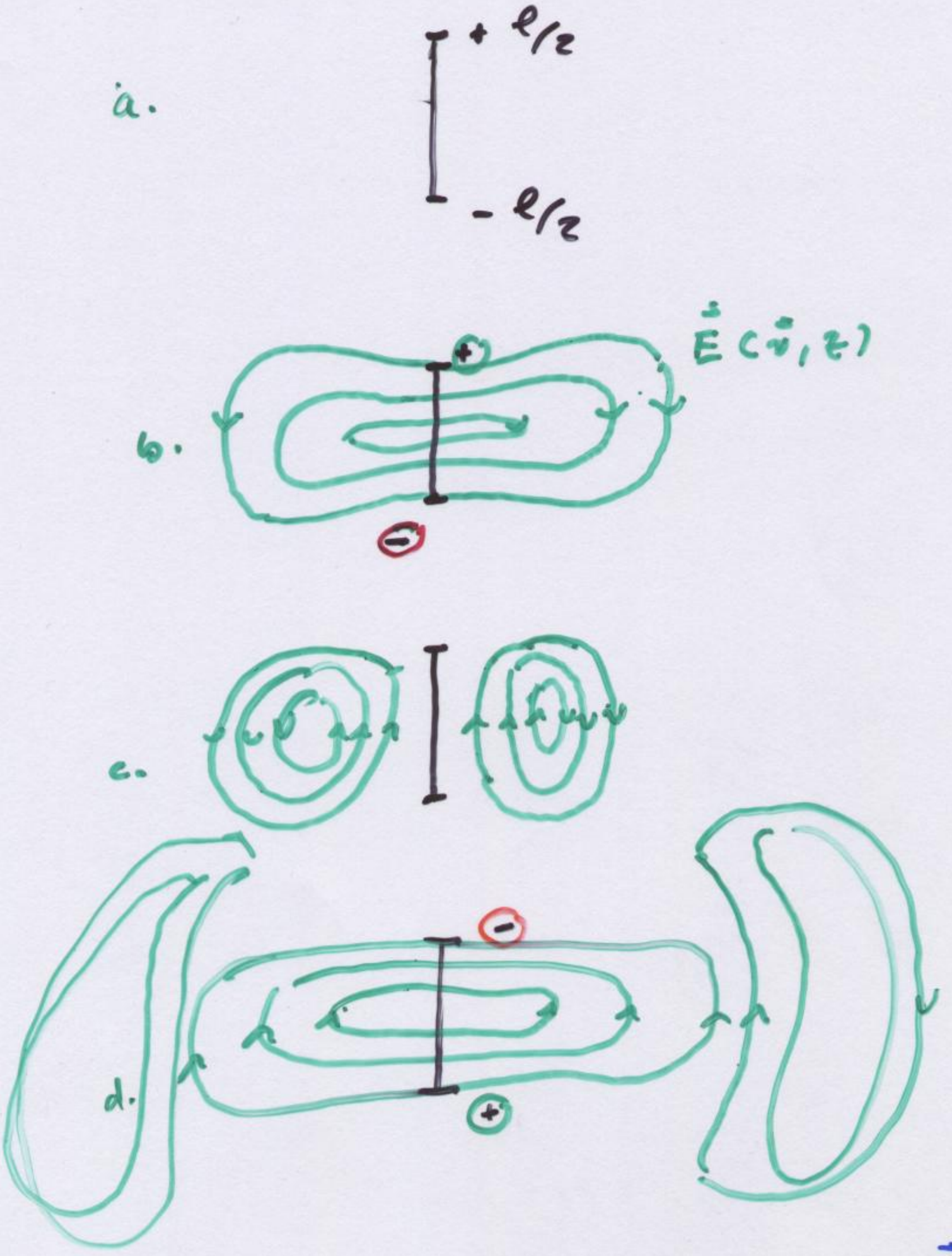


zeitl. Verlauf der Spannung längs dem Dipol:





Spannung und Strom phasenverschoben



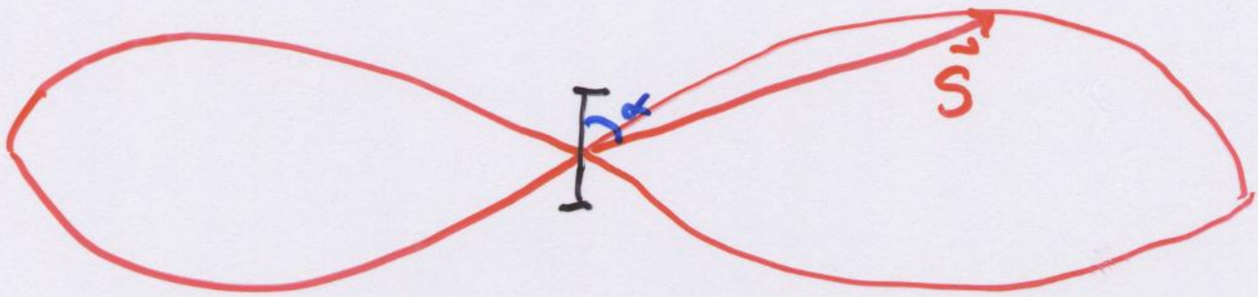
$\vec{B} \perp \vec{E}$

$\vec{B}$ ist in Phase mit $\vec{E}$

Nahbereich : $E, B \sim \frac{1}{r^3}$

Fernbereich $\sim \frac{1}{r}$

Abstrahlcharakteristik eines Dipols



$\vec{S}$: Poynting vektor
Energiefluß in Abstrahlrichtung

6.2. Elektromagnetische Wellen und Licht

a) Energiedichte

$\vec{E}$ - Feld $\quad w_e = \frac{1}{2} \varepsilon_0 E^2$

$\vec{B}$ - Feld $\quad w_b = \frac{1}{2\mu_0} B^2$

$$= \frac{1}{2} \varepsilon_0 E^2$$

$$= w_e$$

$$\sum w_i = \varepsilon_0 E^2$$
$$= \frac{1}{\mu_0} B^2$$
$$= \frac{|\vec{E}|\,|\vec{B}|}{\mu_0 c}$$

b) Intensität

$$[I] = \frac{\text{Energie}}{\text{Fläche Zeit}}$$

$$I = w \cdot c = \frac{|\vec{E}| \cdot |\vec{B}|}{\mu_0}$$

Spezielles Beispiel: 1d E/B Welle

$$I = \frac{E_0 B_0 \sin^2(kx - \omega t)}{\mu_0}$$

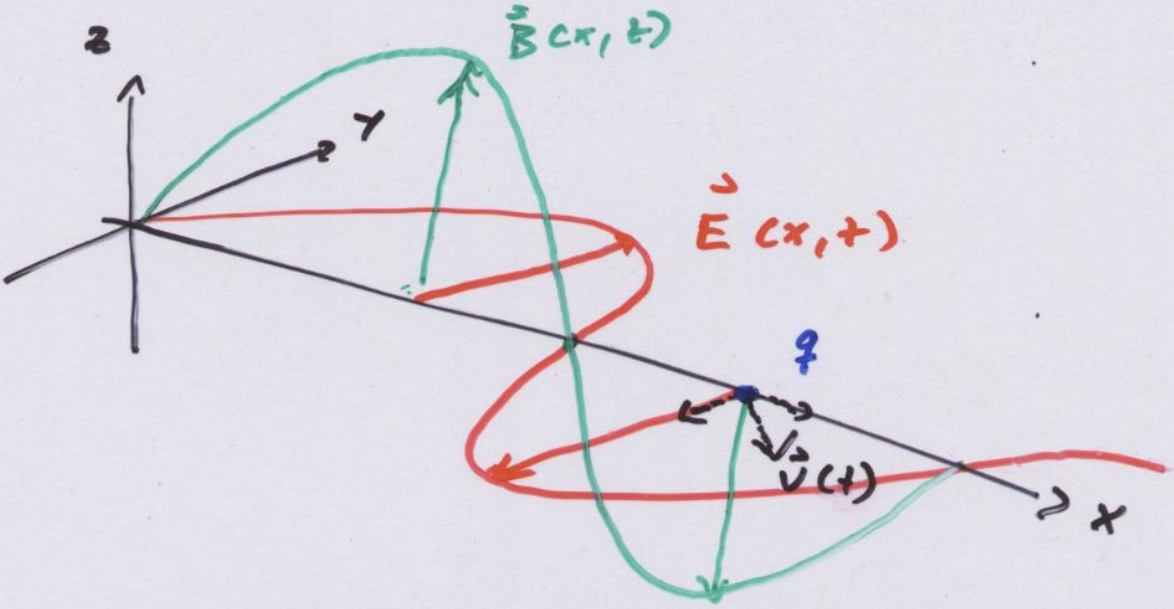
$$\langle I \rangle = \frac{E_0 B_0}{2\mu_0}$$

c) Energiefluss

$$\vec{S} \equiv \frac{\vec{E} \times \vec{B}}{\mu_0}$$ Poynting-Vektor

$\parallel \vec{k}$

6. 2. 2. Impuls einer EM Welle



a) Kräfte auf q

$$\vec{F}_E = q \cdot \vec{E}$$
$$\vec{F}_B = q \cdot \vec{v} \times \vec{B}$$

} Teilchen bekommt Impuls $\vec{p} = m\vec{v}$

b) Impuls der EM Welle

$$|\vec{P}| = \frac{W}{c}$$
$$= \frac{I}{c^2}$$

Konsequenz: Strahlung übt Druck aus.

Intensität : $\frac{\text{Energie}}{\text{Zeit} \cdot \text{Fläche}}$

$= \frac{\text{Impuls} \cdot c}{\text{Zeit} \cdot \text{Fläche}}$

$= \frac{\text{Kraft} \cdot c}{\text{Fläche}}$ =>

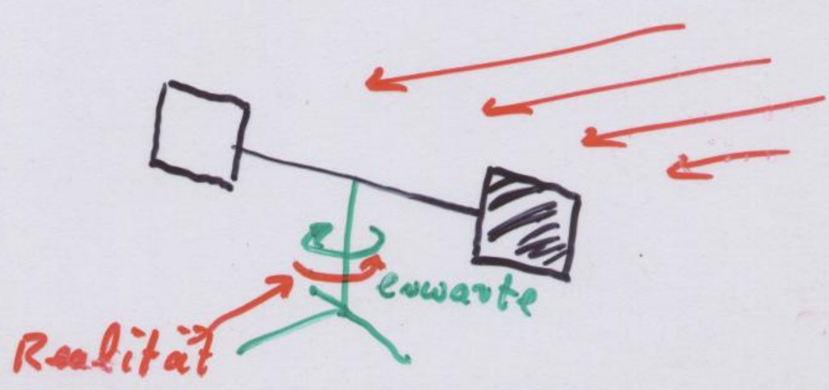
Druck : $P_s = \frac{I}{c}$

$= \frac{E_0 \cdot B_0}{2 \mu_0 c}$

- Absorption: Übertragung des Impulses
  $P_s = \frac{I}{C}$
- Reflektion: Welle nicht absorbiert
  $P_s = 2 \cdot \frac{I}{c}$

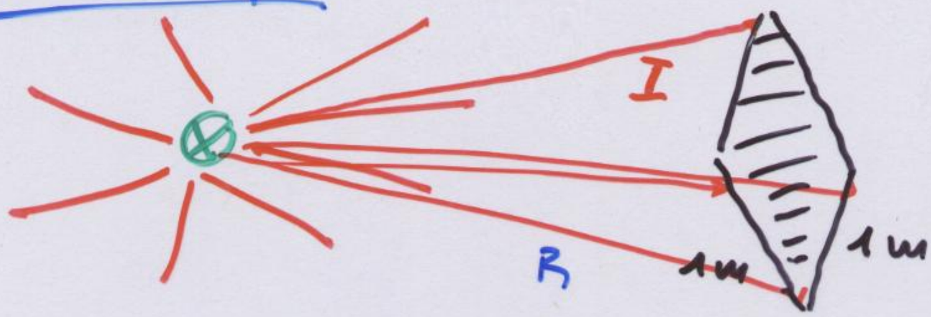
Demonstration:

Lichtmühle



Zahlenbeispiele:

a) Glühlampe



Leistung: 150 W Leistung
50 W Lichtleistung

- $I = \frac{I_{tot}}{4\pi R^2} = \frac{50\,W}{4\pi\,(3m)^2} = 0{,}44\ \frac{W}{m^2}$

z.B.

- $P_s = \frac{I}{c} = \frac{0{,}44\ W/m^2}{3\cdot 10^8\ m/s} = 1{,}5\cdot 10^{-9}\ \frac{N}{m^2}$

(vgl mit $P_{Atmosph} = 10^5\ \frac{N}{m^2}$)

- Magnetfeldstärke $B_0 = \sqrt{2\mu_0 P_s} = 6\cdot 10^{-8}\ T$

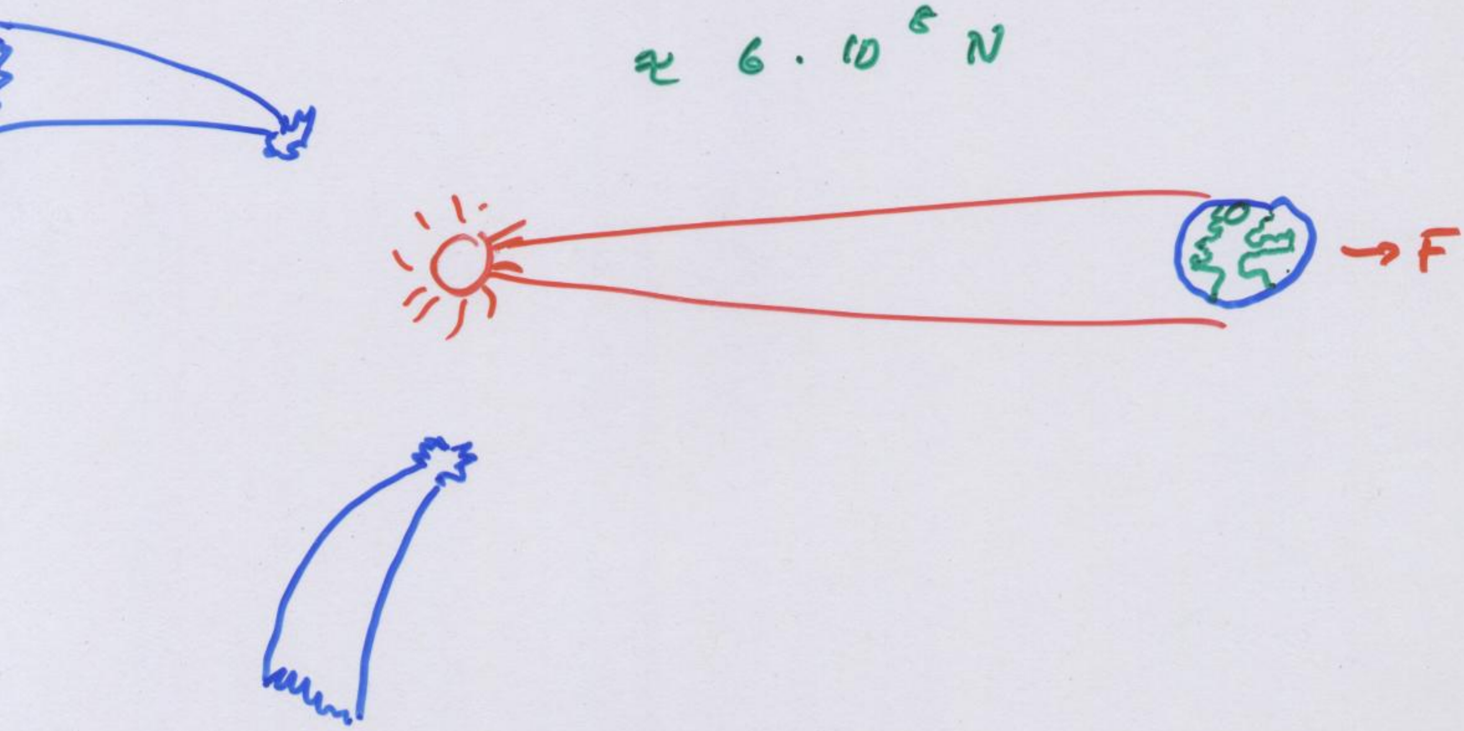
- Elektr. Feldstärke $E_0 = c\cdot B_0 = 18{,}2\ \frac{V}{m}$

b) Lichtdruck der Sonne auf die Erde

Solarkonstante : $1,4 \cdot 10^3 \frac{W}{m^2}$

Kraft : $F = \frac{1,4 \cdot 10^3 \, W/m^2 \cdot \pi \cdot (6,4 \cdot 10^6 \, m)^2}{3 \cdot 10^8 \, m/s}$

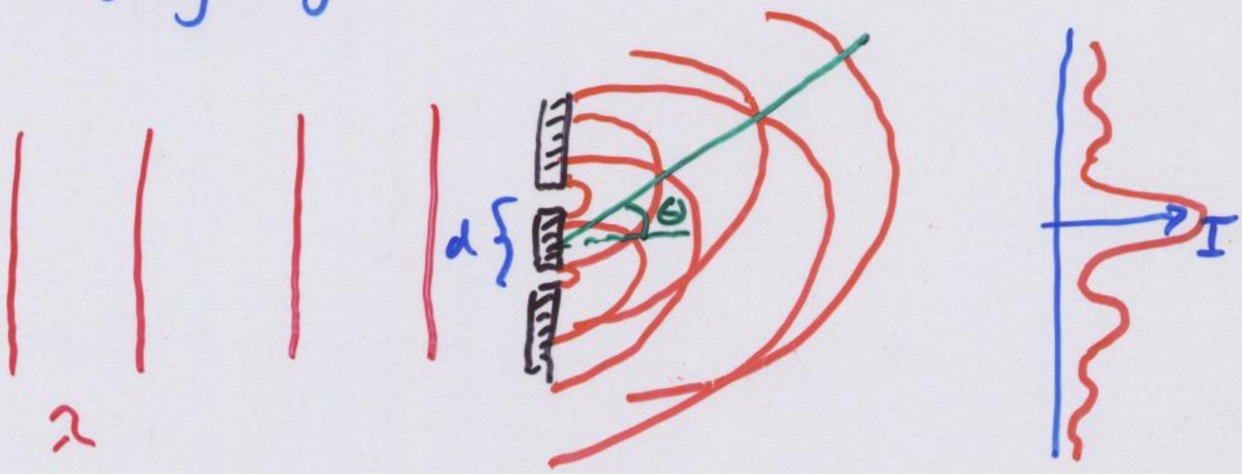
$\approx 6 \cdot 10^8 \, N$



6.3. Optische Vorgänge

Licht ist eine Welle

1] Beugung

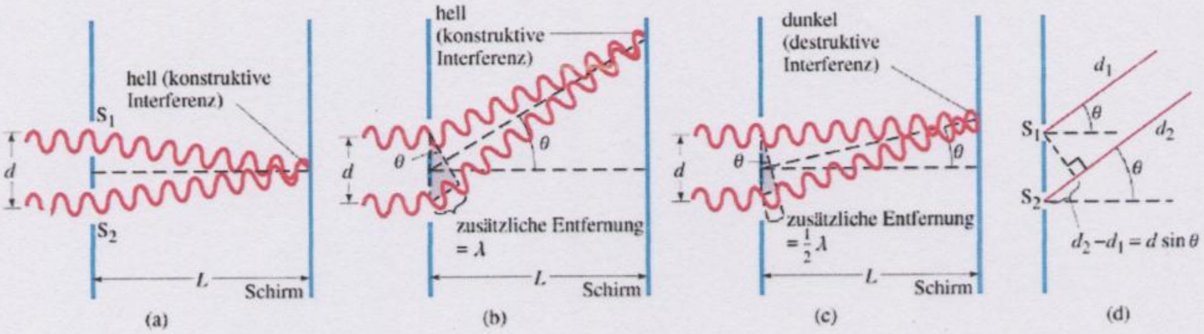


Interferenz:

Maxima bei $\sin\theta_{max} = \frac{\lambda}{d}\, m$

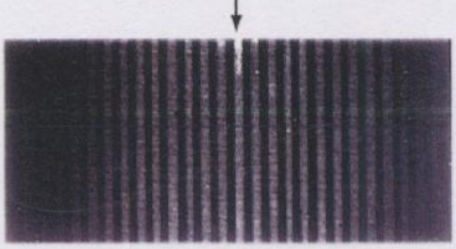
Minimum bei $\sin\theta_{min} = \frac{\lambda}{d}\cdot\left(m+\frac{1}{2}\right)$

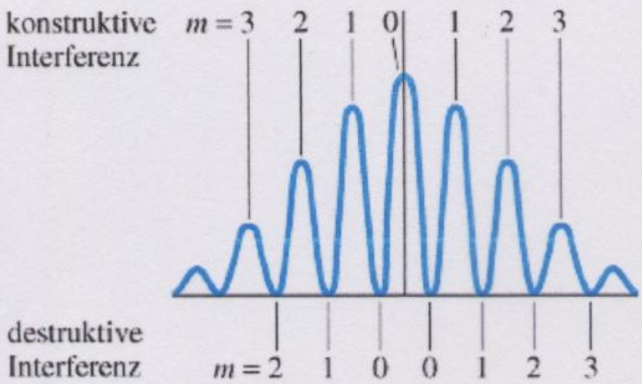
$m = 0, \pm 1, \pm 2 \ldots$



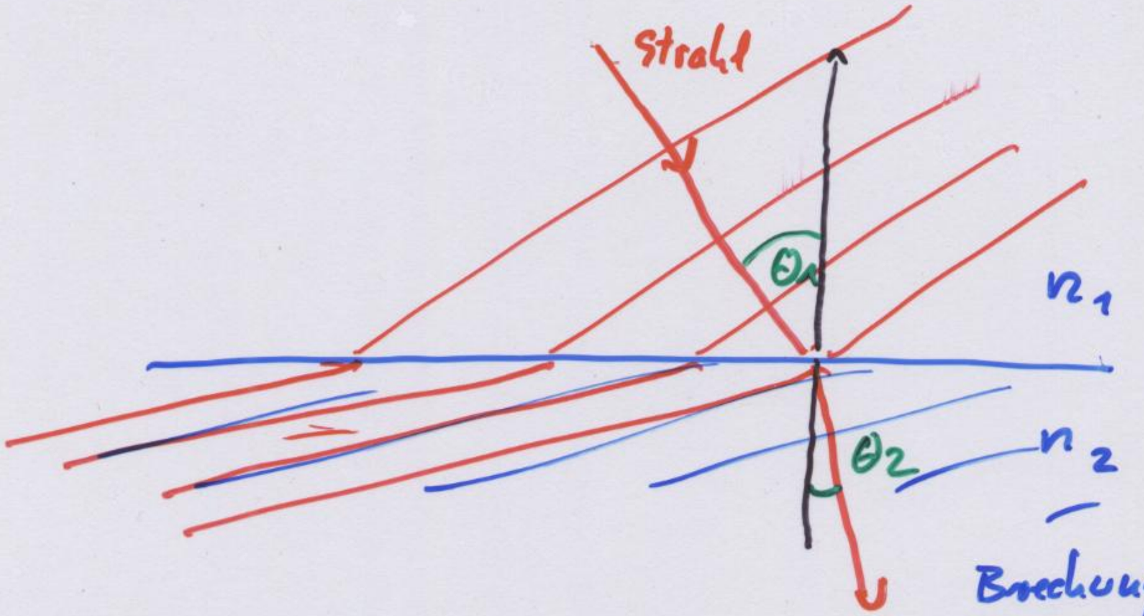
$$\sin\Theta = m\frac{\lambda}{d} \qquad \sin\Theta = \left(m+\frac{1}{2}\right)\frac{\lambda}{d} \qquad m = 0,1,2,...$$

Maxima Minima





2] Lichtbrechung



Im Medium 1: Lichtgeschwindigkeit v_1

$$v_1 = c/n_1 = \nu \cdot \lambda_1$$

Medium 2: $v_2 = c/n_2 = \nu \cdot \lambda_2$

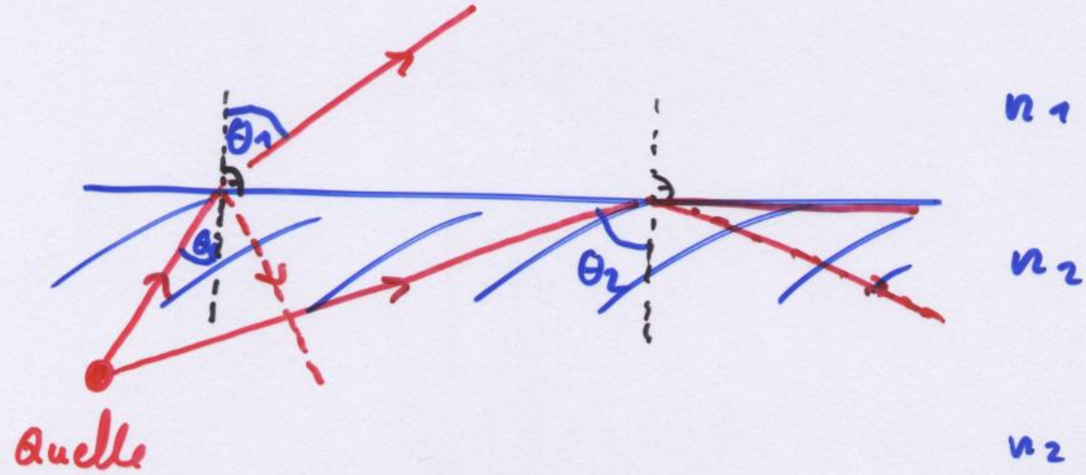
$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

Snelliusches
Brechungsgesetz

Bs:

Vakuum	: n =	1,000
Luft	:	1,0003
Wasser	:	1,33
Glas	:	1,5
Diamant	:	2,4

Anwendung: 1. Totalreflektion, Lichtfasern



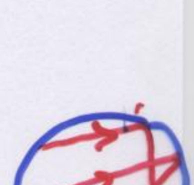
$n_2 > n_1$

Totalreflexion für $\Theta_1 = 90°$

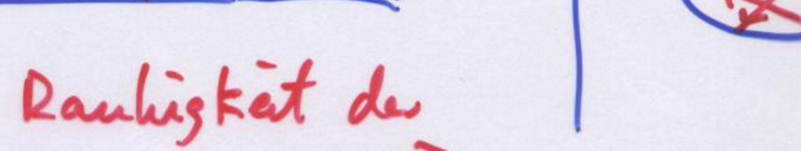
$$\sin\Theta_2 = \sin\Theta_T = \sin 90° \cdot \frac{n_2}{n_1}$$

Für $\Theta \geq \Theta_T$ Totalreflexion.

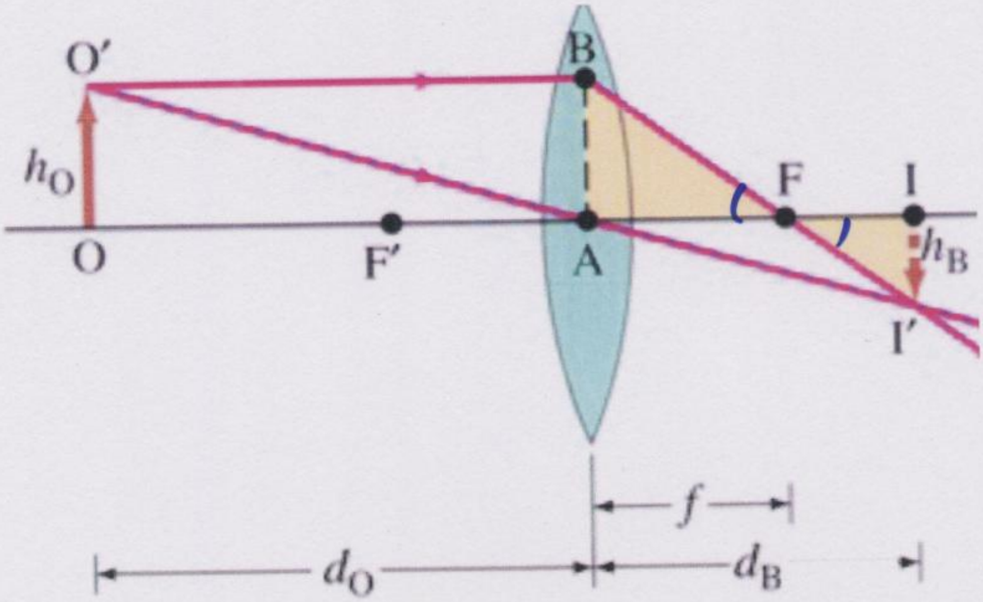
Lichtfasern



Verluste durch Rauhigkeit der Faserfläche



2. Refraktion



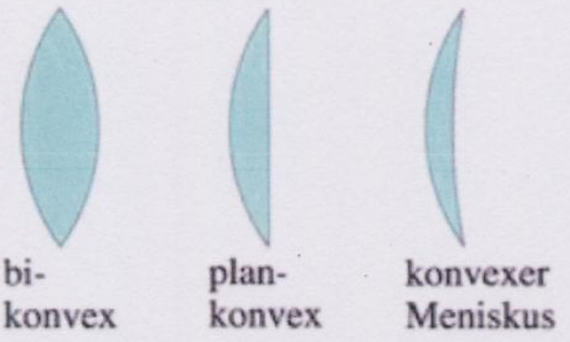
$\measuredangle AFB = \measuredangle IFI'$

$$\frac{h_B}{h_O} = \frac{d_B - f}{d_O}$$

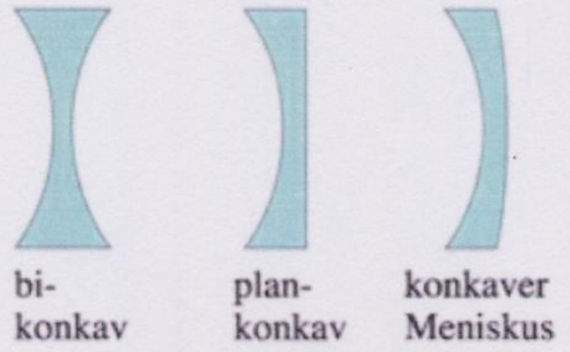
$$\frac{h_B}{h_O} = \frac{d_B}{d_O}$$

$$\Rightarrow \frac{d_B - f}{f} = \frac{d_B}{d_O} = \frac{d_B}{f} - 1$$

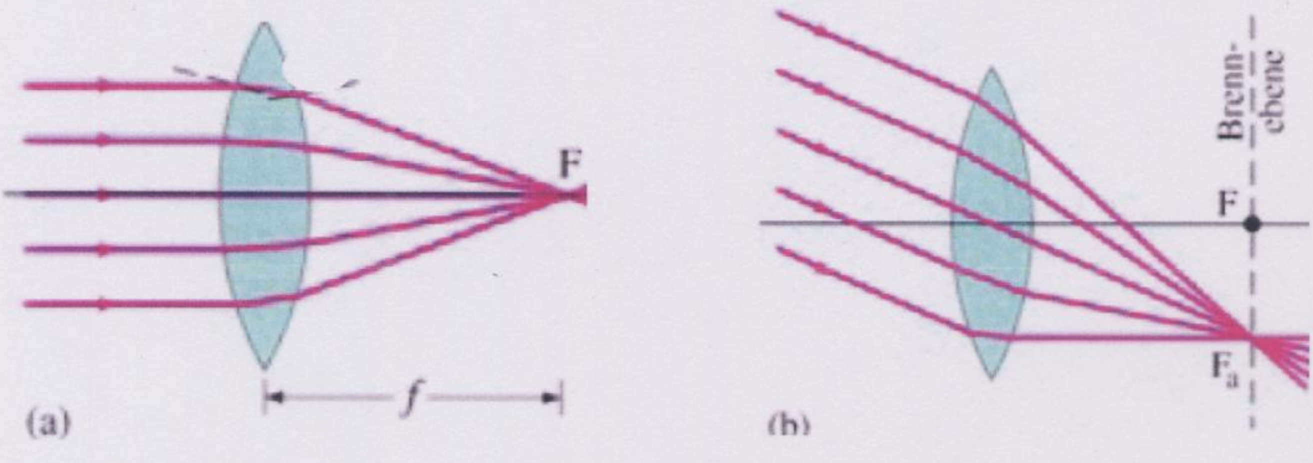
$$\Rightarrow \frac{1}{d_O} + \frac{1}{d_B} = \frac{1}{f}$$ Linsengleichung

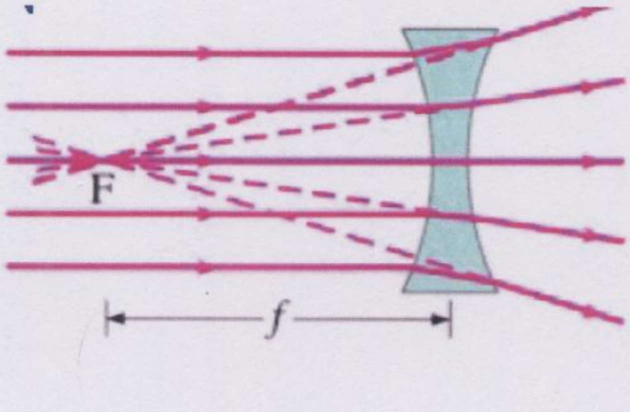


(a) Sammellinsen



(b) Zerstreuungslinsen



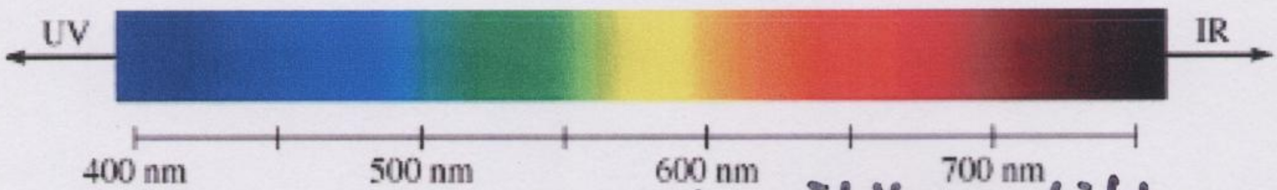


Brechkraft von Linsen:

$$B \equiv \frac{1}{f} \quad ; \quad [B] = 1 \text{ Dioptrie} = 1/m$$

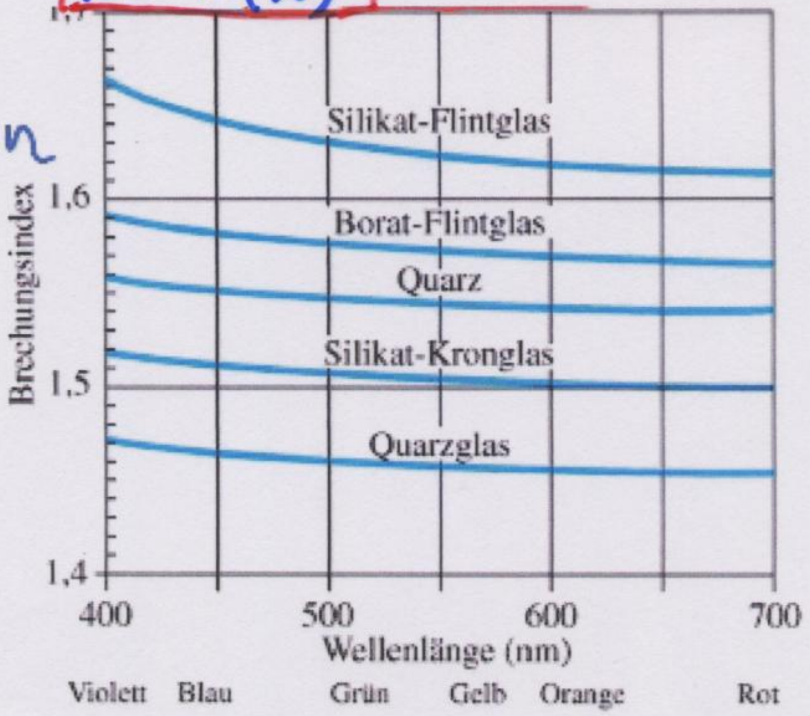
zB 20 cm Brennweite = 5 Dioptrien

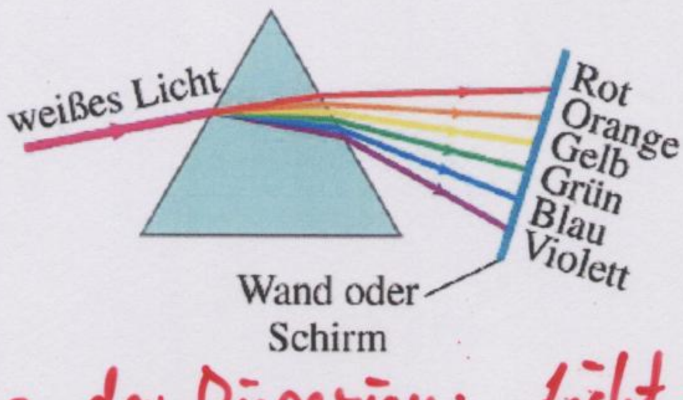
3. Dispersion



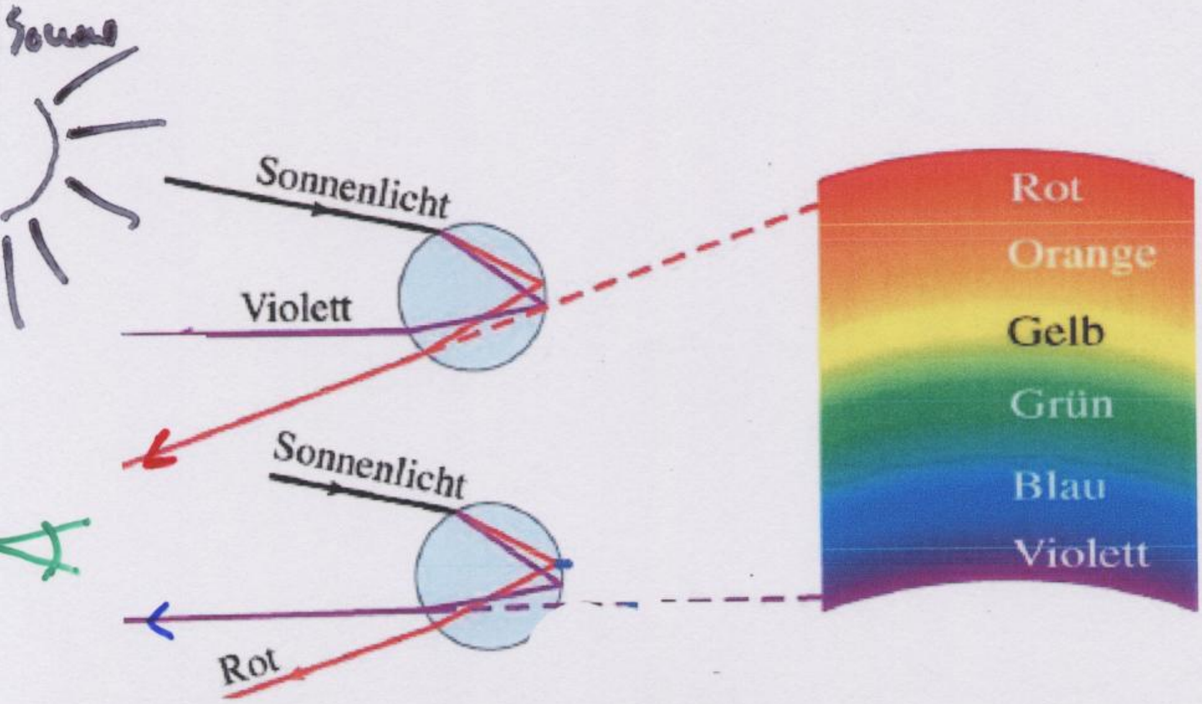
Spektrum des sichtbaren Lichtes

$$n = n(\lambda)$$





Konsequenz der Dispersion: Lichtzerlegung im Prisma



Sonne
Sonnenlicht
Violett
Sonnenlicht
Rot
Rot
Orange
Gelb
Grün
Blau
Violett

Regenbogen