Acousto-optic effect

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Nonlinear polarisation

☐ Constitutive relations

$$\mathbf{D} = \varepsilon\mathbf{E} = \varepsilon_o\mathbf{E} + \mathbf{P},$$

$$\mathbf{P} = \varepsilon_o\chi\mathbf{E}$$

☐ Origin of nonlinear response

Related to anharmonic motion of bound electrons under the influence of an applied field.

$$\mathbf{P} = \varepsilon_o\chi\mathbf{E} = \varepsilon_o\left(\chi^{(1)}\mathbf{E} + \chi^{(2)}\mathbf{E}\mathbf{E} + \chi^{(3)}\mathbf{E}\mathbf{E}\mathbf{E} + \cdots\right)$$

Note: $\chi^{(2)}$ is non-zero only for media that lack an inversion symmetry (centrosymmetry).

Acousto-optic effect

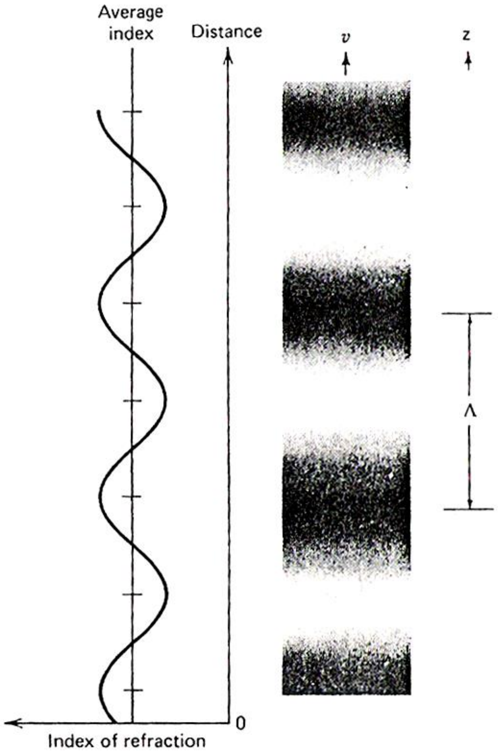
The interaction of optical waves with the acoustic wave in materials, i.e. $\Delta n \propto Strain_{sound}$.

Predicted by Brillouin in 1922

Experimentally verified by Debye and Sears &
Lucas and Biguard in 1932.

Traveling sound waves

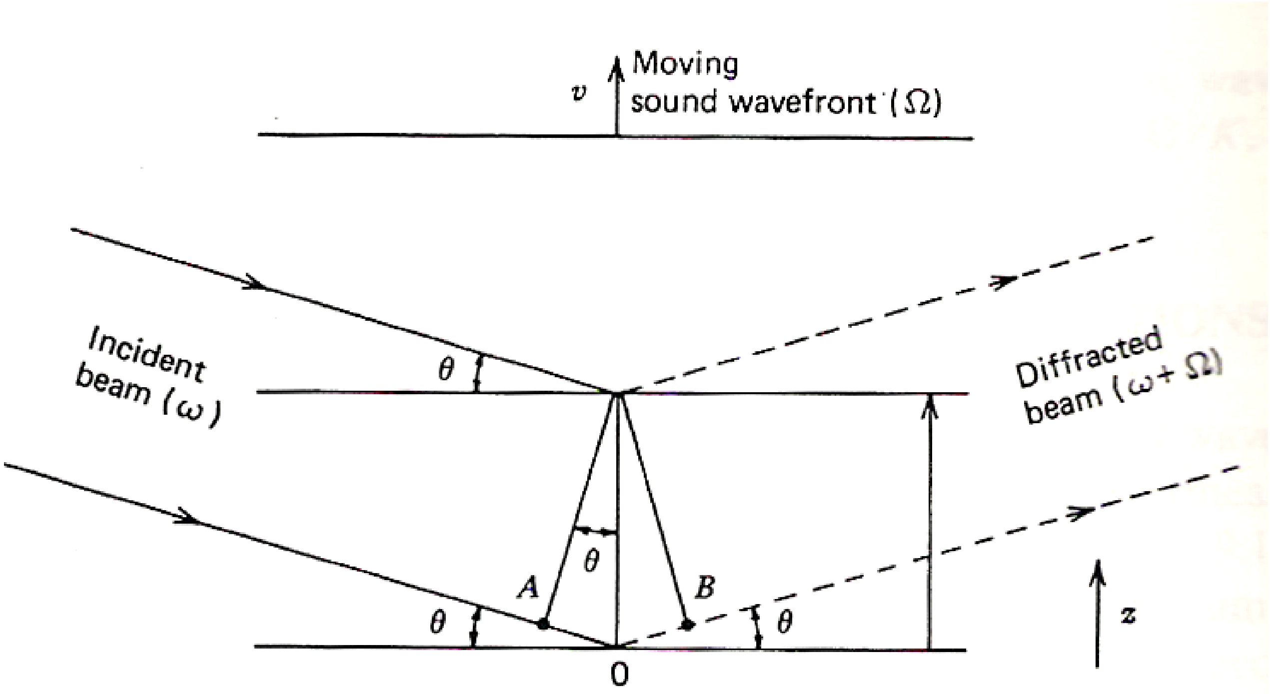
The traveling sound wave leads to compression and rarefaction of the medium: $\Delta n \propto S_{Sound}$.



$$\Delta n \propto S \sin(\Omega t - Kz).$$

Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

Interaction of optical waves with sound



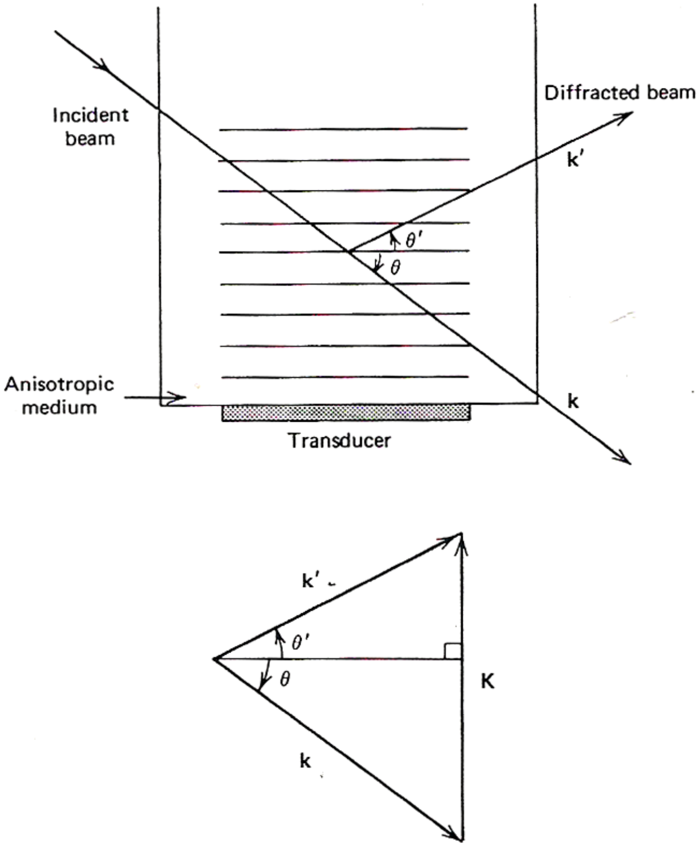
Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

The momentum and energy must be conserved:

$$\boldsymbol{k}' = \boldsymbol{k} + \boldsymbol{K}$$

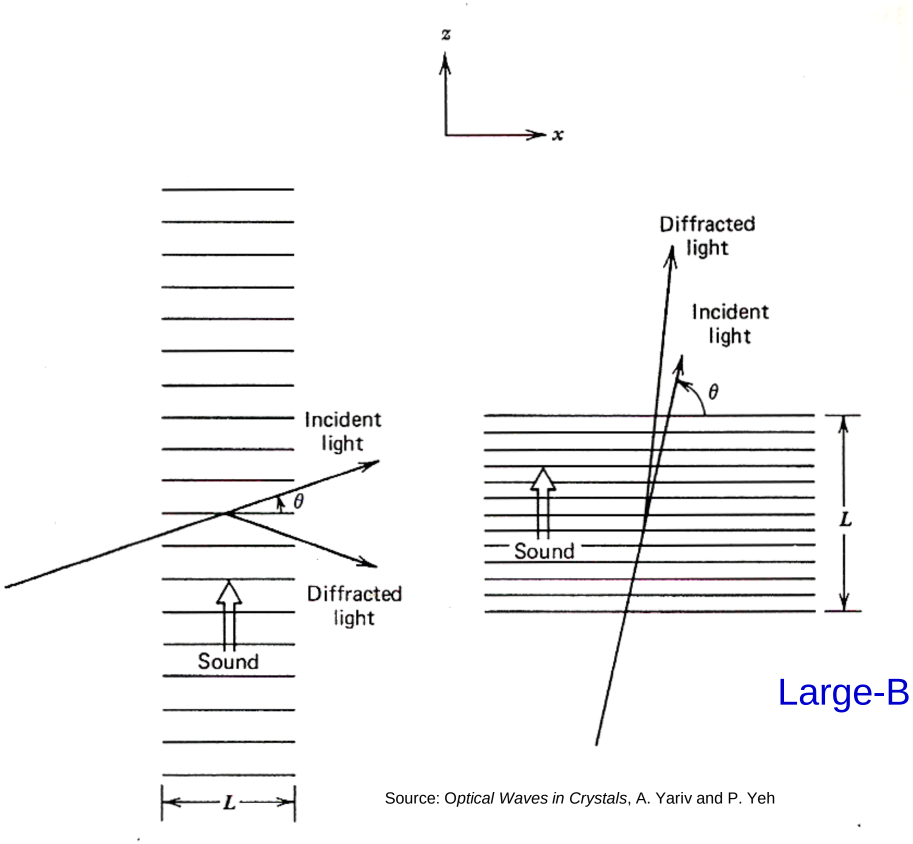
$$\omega' = \omega + \Omega$$

Bragg diffraction in an anisotropic medium



Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

Two common interaction configurations



Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

Large-Bragg-angle diffraction

Small-Bragg-angle diffraction

Properties of acousto-optic media

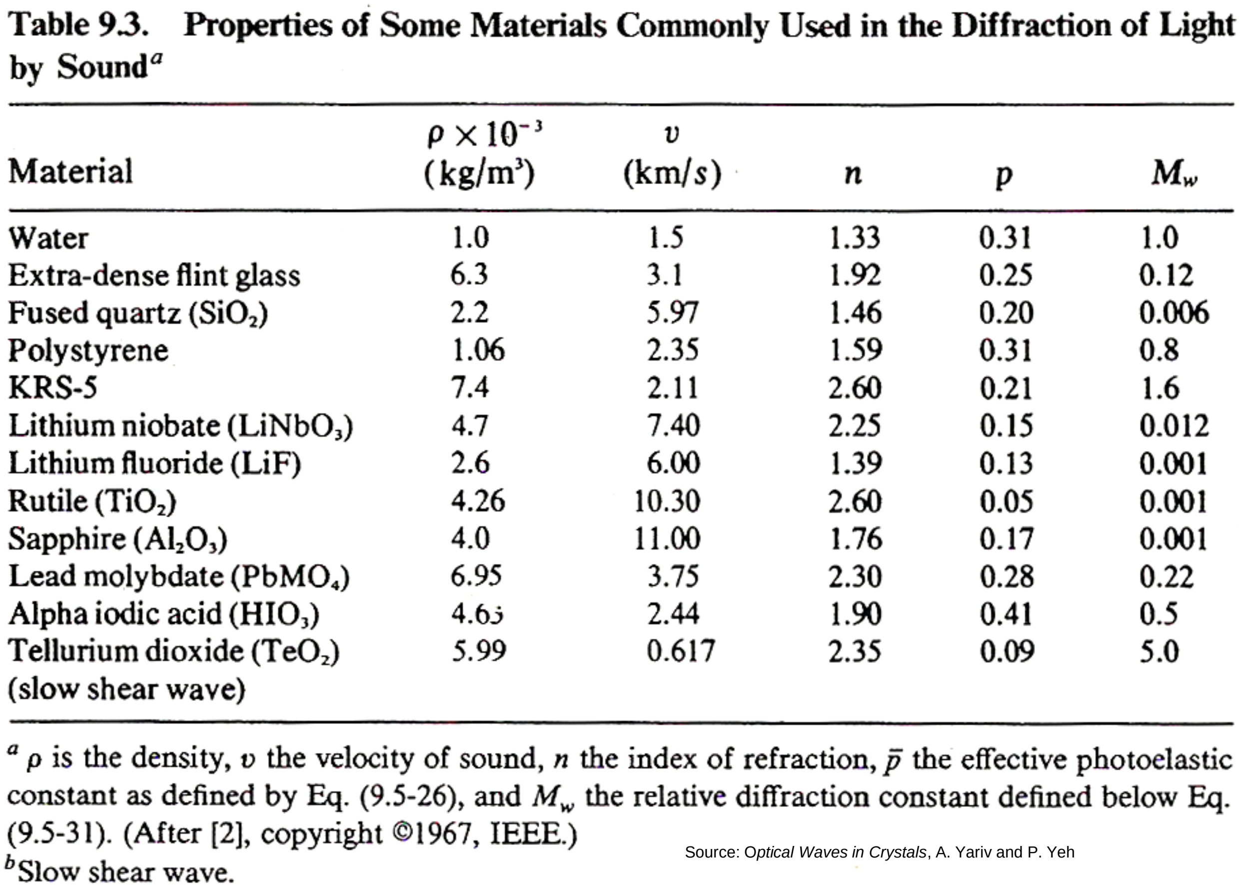


Table 9.3. **Properties of Some Materials Commonly Used in the Diffraction of Light by Sound**[a]

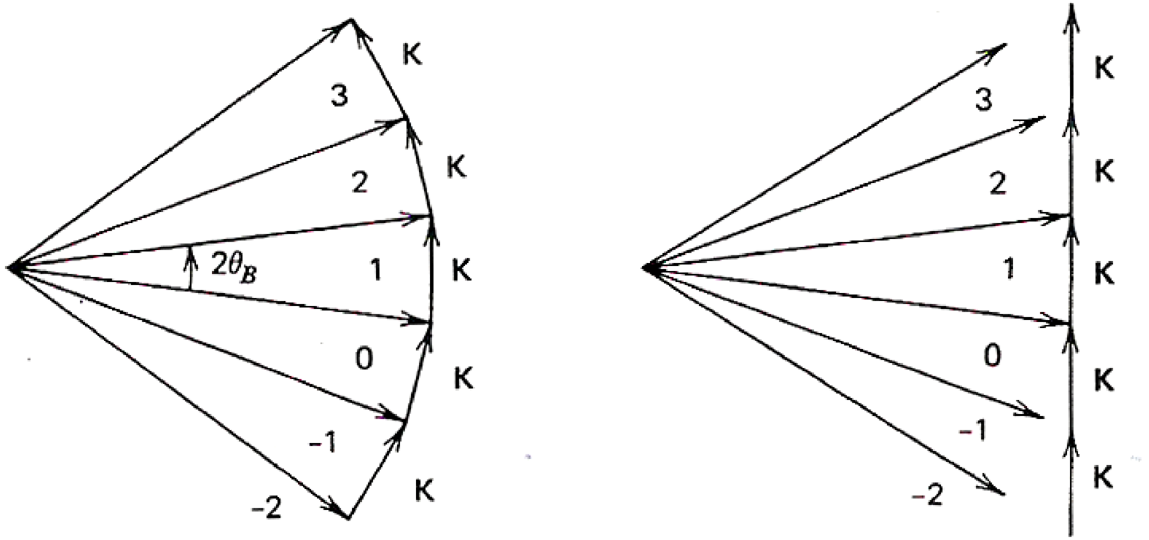
Material	$\rho \times 10^{-3}$ (kg/m^3)	v (km/s)	n	p	M_w
Water	1.0	1.5	1.33	0.31	1.0
Extra-dense flint glass	6.3	3.1	1.92	0.25	0.12
Fused quartz (SiO_2)	2.2	5.97	1.46	0.20	0.006
Polystyrene	1.06	2.35	1.59	0.31	0.8
KRS-5	7.4	2.11	2.60	0.21	1.6
Lithium niobate ($LiNbO_3$)	4.7	7.40	2.25	0.15	0.012
Lithium fluoride (LiF)	2.6	6.00	1.39	0.13	0.001
Rutile (TiO_2)	4.26	10.30	2.60	0.05	0.001
Sapphire (Al_2O_3)	4.0	11.00	1.76	0.17	0.001
Lead molybdate ($PbMO_4$)	6.95	3.75	2.30	0.28	0.22
Alpha iodic acid (HIO_3)	4.63	2.44	1.90	0.41	0.5
Tellurium dioxide (TeO_2) (slow shear wave)	5.99	0.617	2.35	0.09	5.0

[a] ρ is the density, v the velocity of sound, n the index of refraction, $\bar{p}$ the effective photoelastic constant as defined by Eq. (9.5-26), and M_w the relative diffraction constant defined below Eq. (9.5-31). (After [2], copyright ©1967, IEEE.)

[b] Slow shear wave.

Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

Raman-Nath diffraction

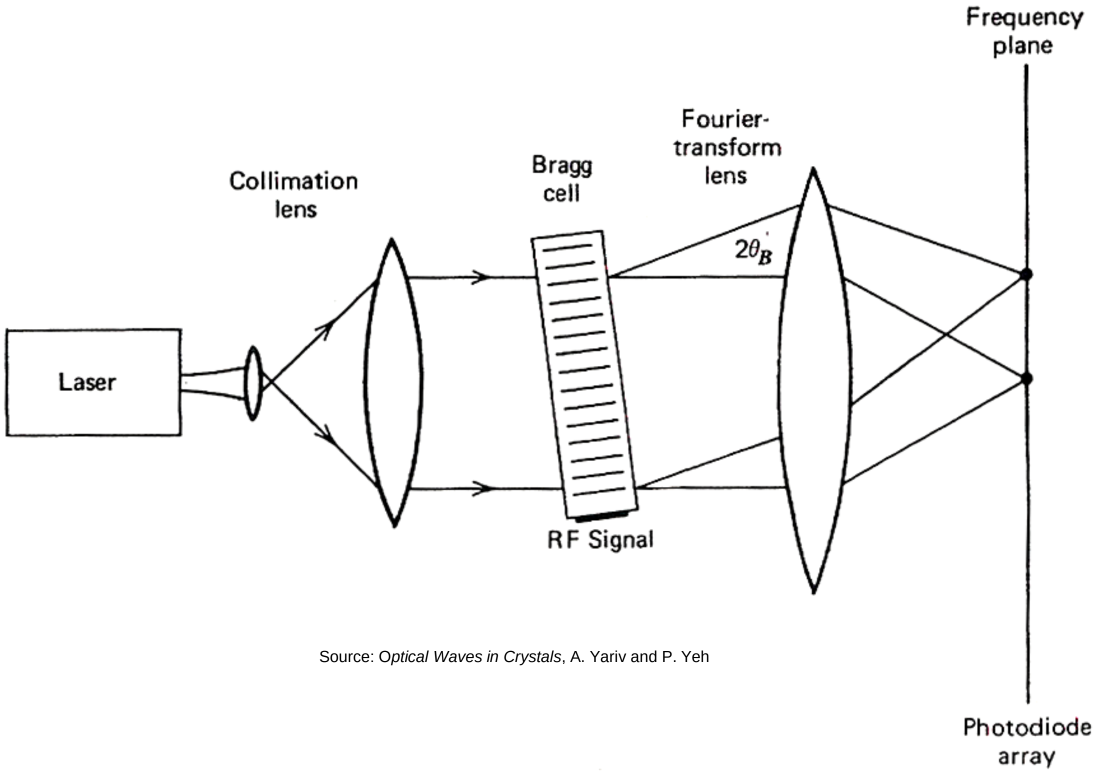


Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

Wave vector diagrams for multiple scattering:

Multiple scatterings are allowed if the acoustic wave vector has an angular distribution.

Acousto-optic devices



Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh