

Acousto-optic effect

Dr Yoonchan Jeong

School of Electrical Engineering, Seoul National University

Tel: +82 (0)2 880 1623, Fax: +82 (0)2 873 9953

Email: yunchan@snu.ac.kr

Nonlinear polarisation

□ Constitutive relations

$$\mathbf{D} = \epsilon \mathbf{E} = \epsilon_0 \mathbf{E} + \mathbf{P},$$

$$\mathbf{P} = \epsilon_0 \chi \mathbf{E}$$

□ Origin of nonlinear response

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

$$\mathbf{P} = \epsilon_0 \chi \mathbf{E} = \epsilon_0 \left(\chi^{(1)} \mathbf{E} + \chi^{(2)} \mathbf{E} \mathbf{E} + \chi^{(3)} \mathbf{E} \mathbf{E} \mathbf{E} + \dots \right)$$

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. $\Delta n \propto \text{Strain}_{\text{sound}}$.

Predicted by Brillouin in 1922:

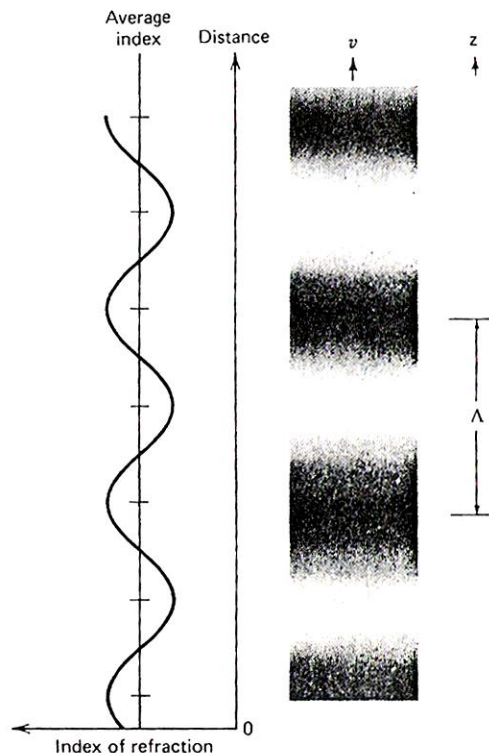


Léon Nicolas Brillouin (1889 -1969)

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

Traveling sound waves

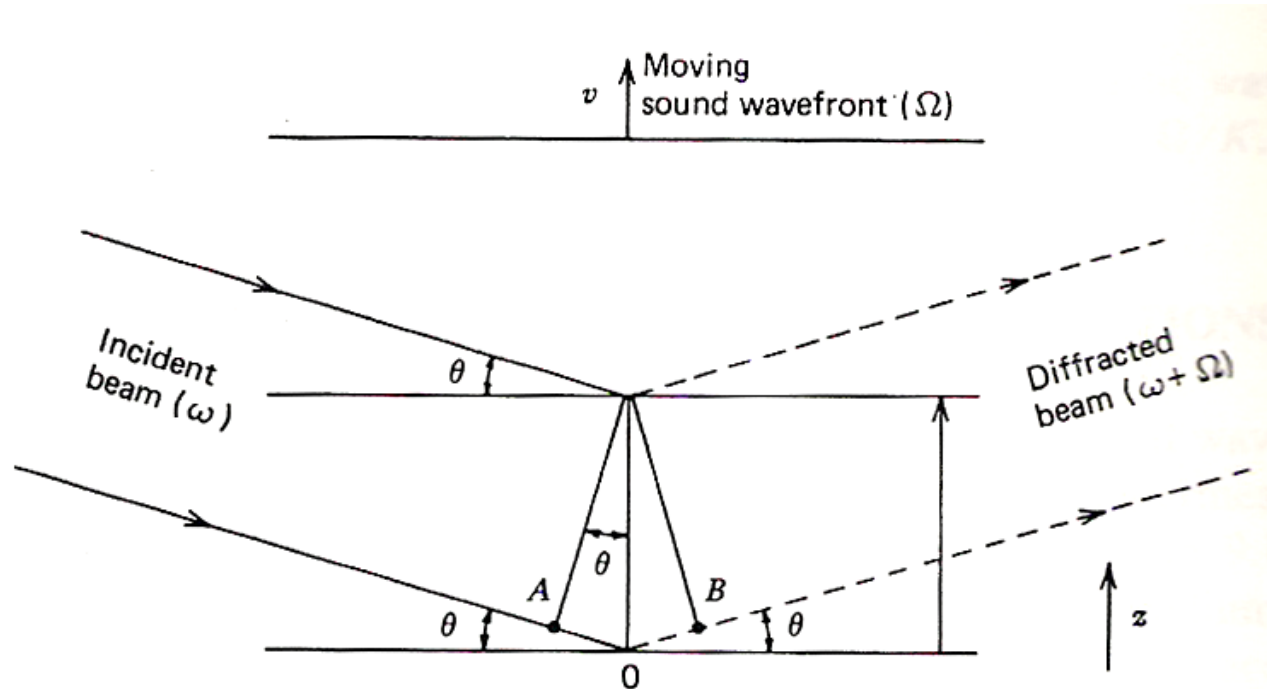
The traveling sound wave leads to compression and rarefaction of the medium: $\Delta n \propto S_{Sound}$.



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

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

Interaction of optical waves with sound



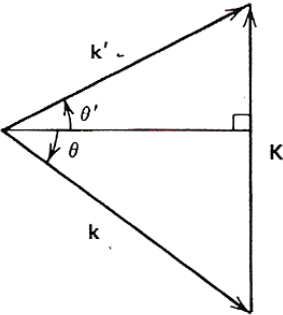
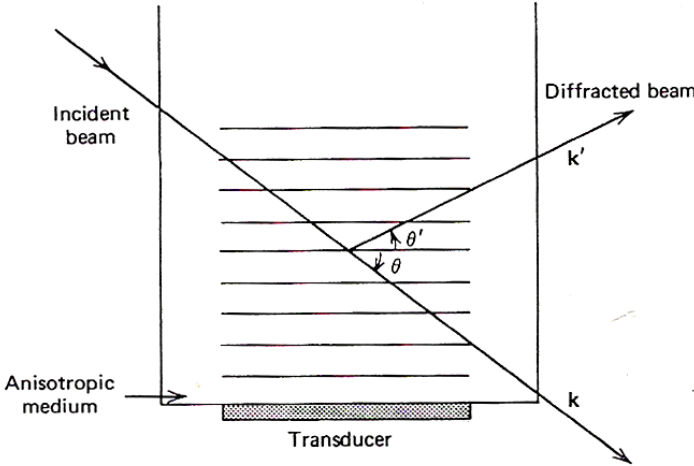
Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

The momentum and energy must be conserved:

$$k' = k + K$$

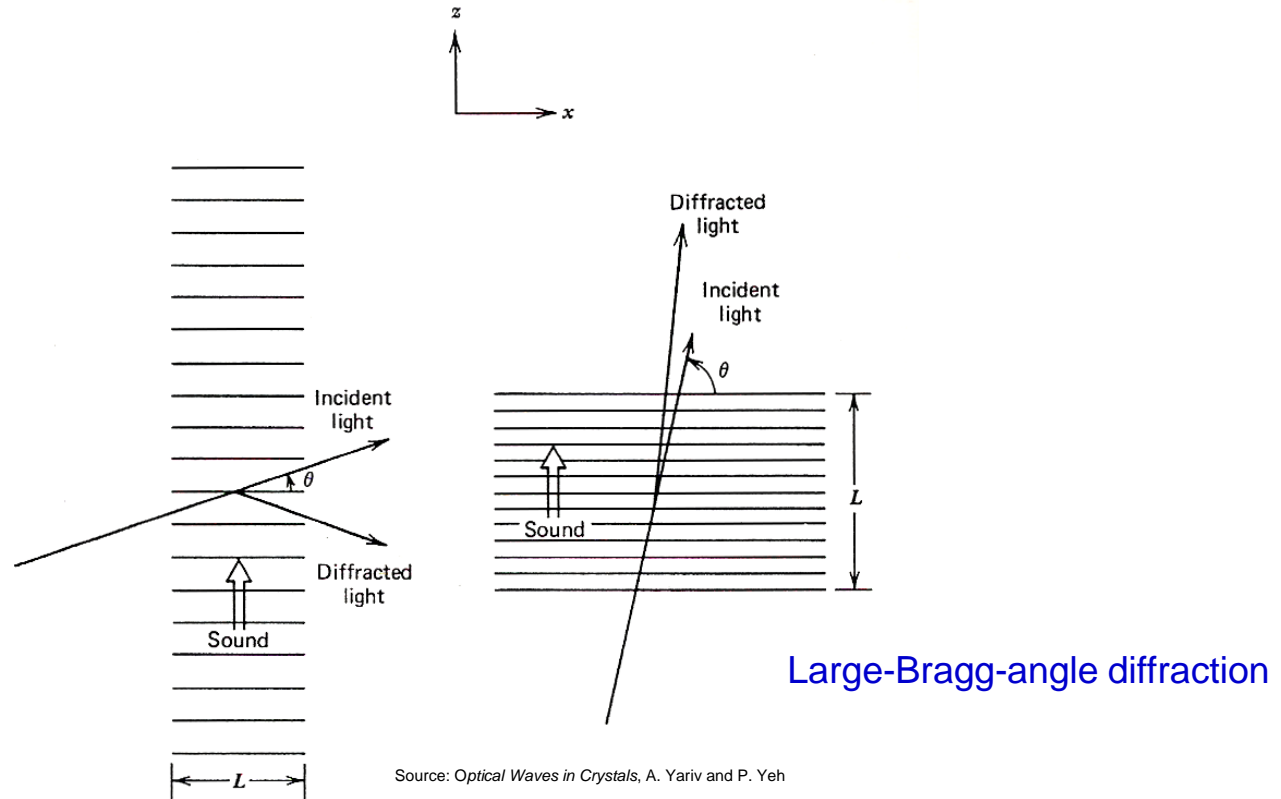
$$\omega' = \omega + \Omega$$

Bragg diffraction in an anisotropic medium



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

Two common interaction configurations



Properties of acousto-optic media

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

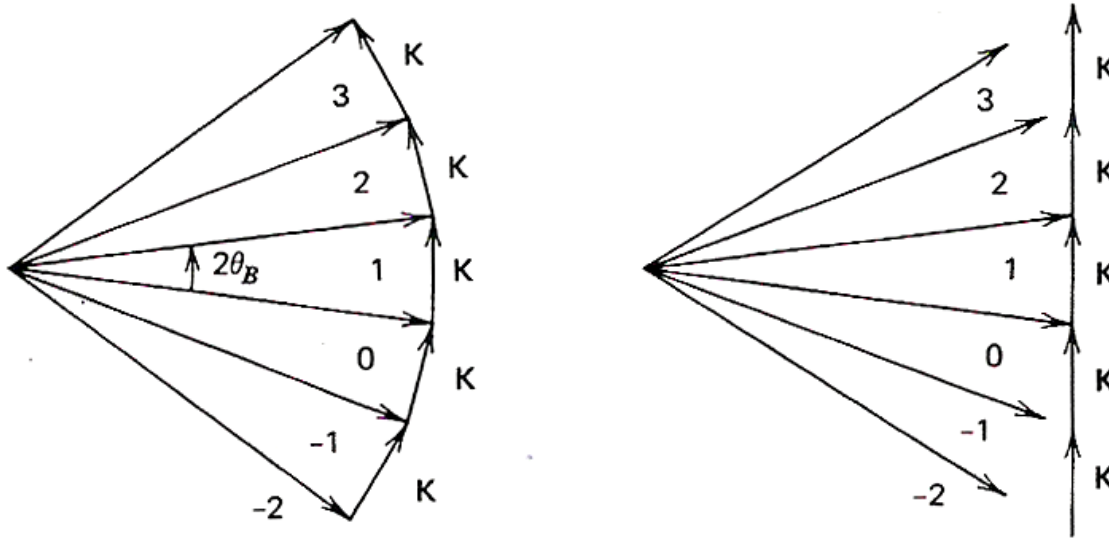
Material	$\rho \times 10^{-3}$ (kg/m ³)	v (km/s)	n	\bar{p}	M_w
Water	1.0	1.5	1.33	0.31	1.0
Extra-dense flint glass	6.3	3.1	1.92	0.25	0.12
Fused quartz (SiO ₂)	2.2	5.97	1.46	0.20	0.006
Polystyrene	1.06	2.35	1.59	0.31	0.8
KRS-5	7.4	2.11	2.60	0.21	1.6
Lithium niobate (LiNbO ₃)	4.7	7.40	2.25	0.15	0.012
Lithium 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 ₂ O 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

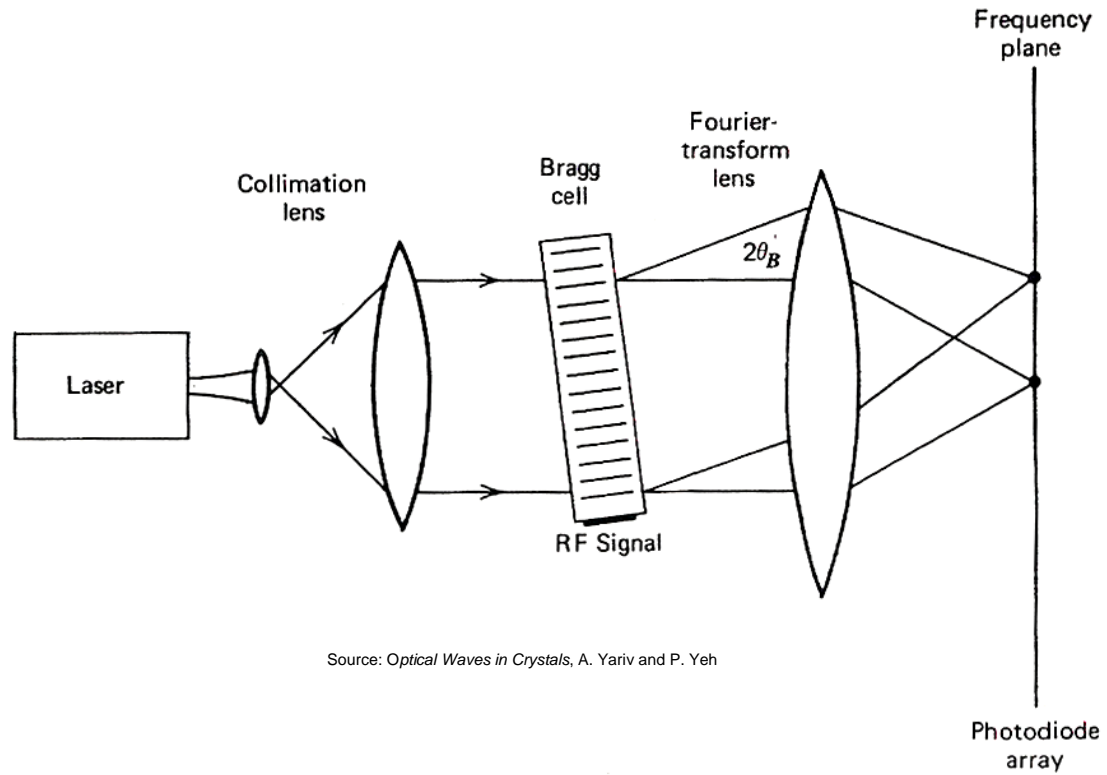


Source: *Optical Waves in Crystals*, A. Yariv and P. Yeh

Wave vector diagrams for multiple scattering:

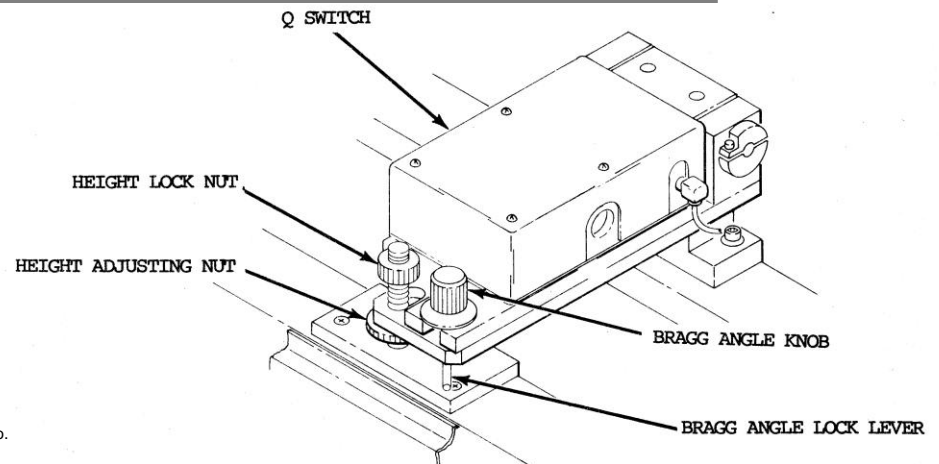
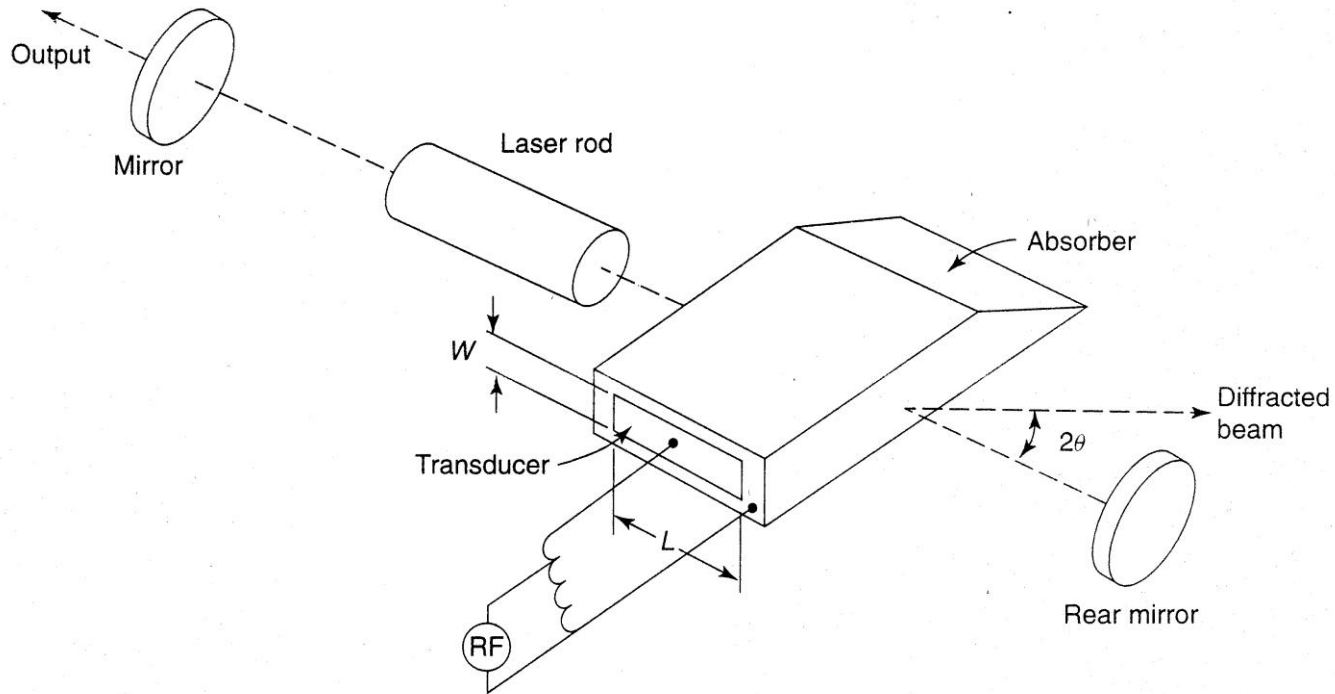
Multiple scatterings are allowed if the acoustic wave vector has an angular distribution.

Acousto-optic devices



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

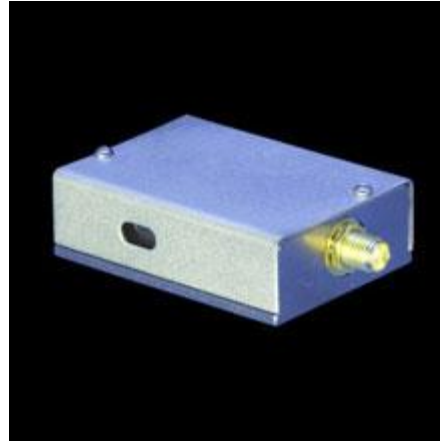
Acousto-optic Q-switch



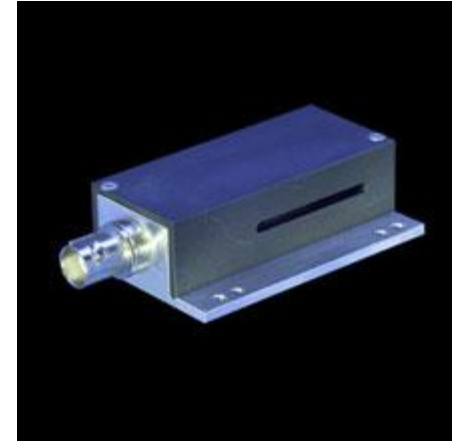
Various acousto-optic devices



Q-switch



Modulator/Frequency shifter



Deflector



Fibre-coupled device