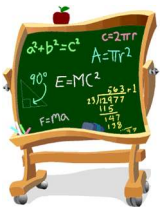
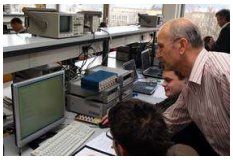
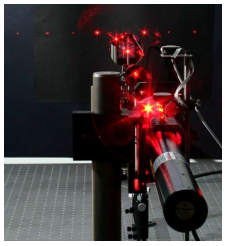
OPTOELECTRONICS
Lab Work







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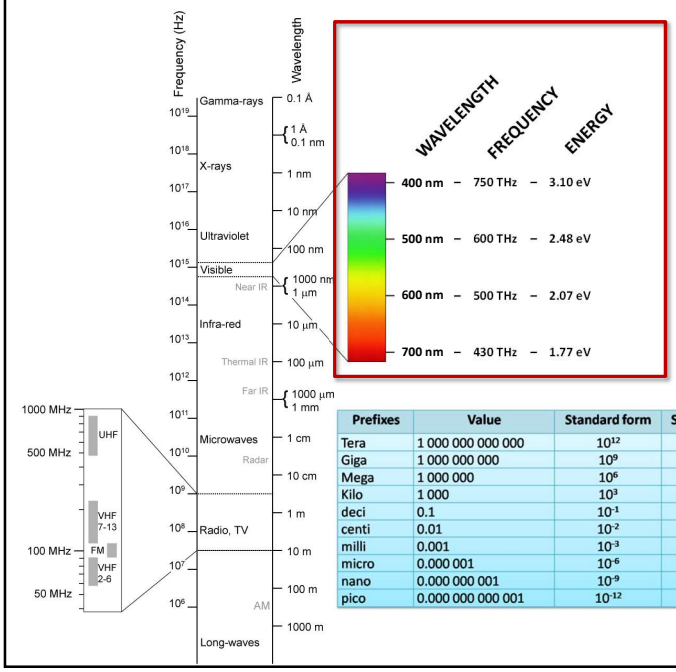
ENERGY, FREQUENCY, WAVELENGTH



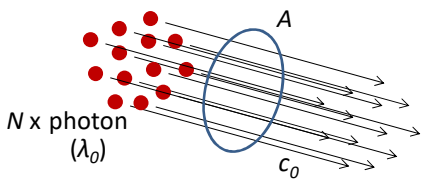
Prefixes	Value	Standard form	Symbol
Tera	1 000 000 000 000	10^{12}	T
Giga	1 000 000 000	10^{9}	G
Mega	1 000 000	10^{6}	M
Kilo	1 000	10^{3}	k
deci	0.1	10^{-1}	d
centi	0.01	10^{-2}	c
milli	0.001	10^{-3}	m
micro	0.000 001	10^{-6}	µ
nano	0.000 000 001	10^{-9}	n
pico	0.000 000 000 001	10^{-12}	p

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

LIGHT AS PHOTON FLUX (QUANTUM MODEL)



$$c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

Photon energy:	$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$	[J], [eV]
Photon flux:	$\Phi_{ph} = \frac{N}{A \cdot t}$	[1/m²s]
Optical power density:	$J_{ph} = \Phi_{ph} \cdot E_{ph}$	[W/m²]
Optical power (intensity):	$P_{ph} = J_{ph} \cdot A$	[W]

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

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LIGHT AS ELECTROMAGNETIC WAVE (WAVE MODEL)

I. $\oiint \vec{E} \cdot d\vec{A} = \frac{\rho}{\epsilon_0}$ – Gauss law for *E* field

II. $\oiint \vec{B} \cdot d\vec{A} = 0$ – Gauss law for *B* field

III. $\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$ – Faraday law (induction)

IV. $\oint \vec{B} \cdot d\vec{s} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$ – Ampere law

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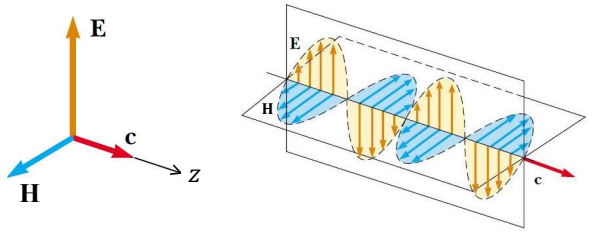
LIGHT AS ELECTROMAGNETIC WAVE (WAVE MODEL)



Electric field: $E = E_0 \cdot e^{-j \cdot k_0 \cdot z}$ [V/m]

Wave number: $k_0 = \omega\sqrt{\mu_0 \varepsilon_0} = \frac{\omega}{c_0} = \frac{2\pi}{\lambda_0}$ [1/m]

Wave impedance: $Z_0 = \frac{|E|}{|H|} = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ [377 Ω]

Optical power density: $J_{ph} = \frac{1}{2} Re\{E \times H^*\}$ [W/m²]

$$J_{ph} = \frac{1}{2Z_0}|E|^2$$

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

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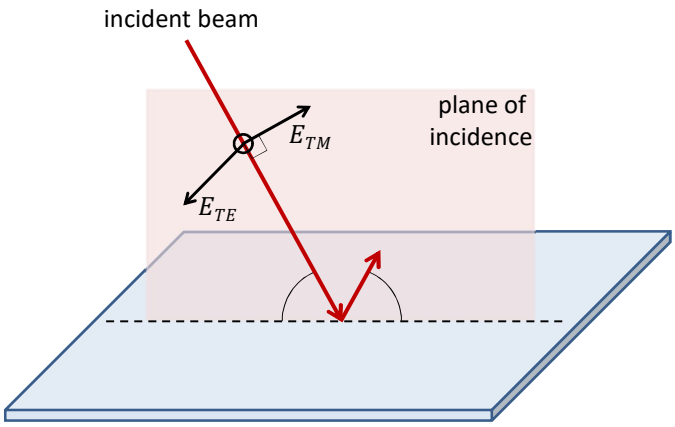
POLARIZATION OF LIGHT – ORIENTATION OF *E* FIELD



- **Transverse electric:** TE, horizontal, perpendicular, *s*, σ
  (vector *E* is perpendicular to the plane of incidence)
- **Transverse magnetic:** TM, vertical, parallel, *p*, π
  (vector *E* is parallel to the plane of incidence)

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LIGHT AND MATTER

1. Change of velocity:

$$c = \frac{1}{\sqrt{\mu\varepsilon}}$$

$$f = \frac{c}{\lambda}$$

$$\boxed{\frac{c_0}{c} = \frac{\lambda_0}{\lambda} = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}} = n}$$ – refractive index

$$c = \frac{c_0}{n} \qquad \lambda = \frac{\lambda_0}{n}$$

Wave number: $k = \frac{2\pi}{\lambda} = \frac{2\pi \cdot n}{\lambda_0}$

Electric field: $E = E_0 \cdot e^{-j \cdot k \cdot z} = \boxed{E_0 \cdot e^{-j\frac{2\pi \cdot n}{\lambda_0} \cdot z}}$

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

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LIGHT AND MATTER

2. Absorption:

$$\boxed{N = n - j \cdot k}$$ – complex refractive index

n – refractive index
k – extinction coefficient

$$E = E_0 \cdot e^{-j\frac{2\pi \cdot N}{\lambda_0} \cdot z} = E_0 \cdot \underbrace{e^{-j\frac{2\pi \cdot n}{\lambda_0} \cdot z}}_{\text{phase change}} \cdot \underbrace{e^{-\frac{2\pi \cdot k}{\lambda_0} \cdot z}}_{\text{attenuation}}$$

$$P_{ph} \propto |E|^2$$

$$P_{ph} = P_{ph,0} \cdot e^{-2 \cdot \frac{2\pi \cdot k}{\lambda_0} \cdot z}$$

$$\alpha = \frac{4\pi \cdot k}{\lambda_0}$$ absorption coefficient

$$\boxed{P_{ph} = P_{ph,0} \cdot e^{-\alpha \cdot z}}$$

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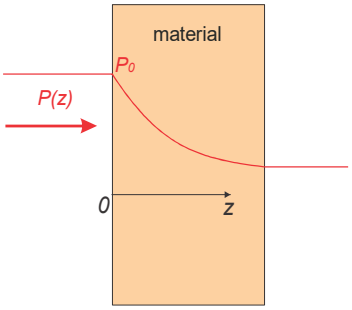
LIGHT AND MATTER

a) Absorption coefficient α of crystaline silicon (*c*-Si) at wavelength 550 nm equals 7150 cm^{-1}. What is the thickness of a *c*-Si layer that absorbs 95 % of light as it passes through the layer?



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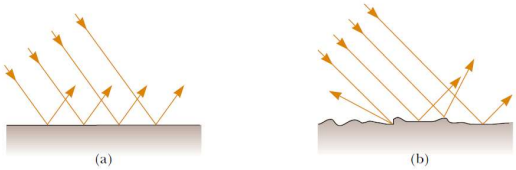
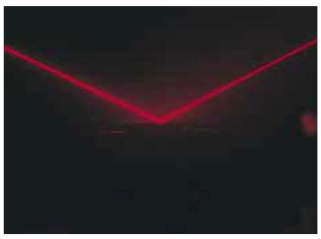
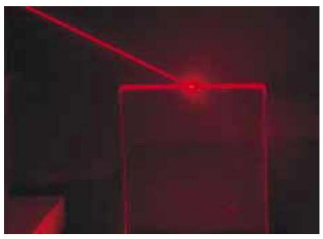
LAW OF REFLECTION

$$\theta_{incident} = \theta_{reflected}$$





Specular reflection



Diffuse reflection

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

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$c_0 = 299792458\ m/s$
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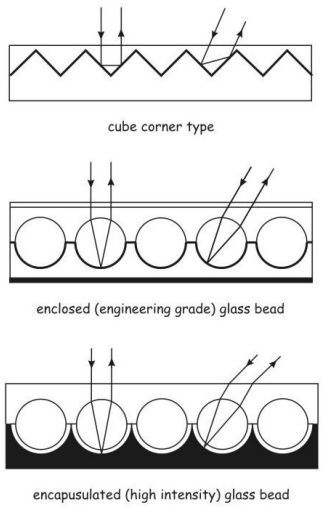
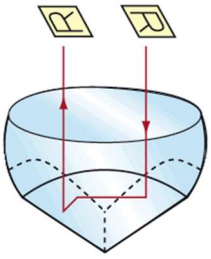
LAW OF REFLECTION – Retro-reflector





$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] \quad 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

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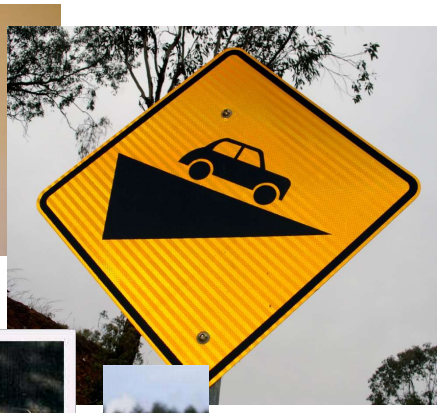

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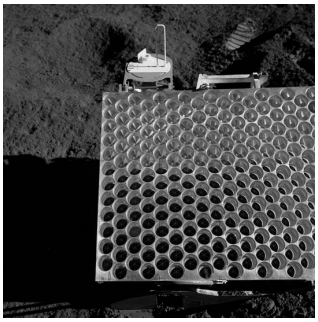
LAW OF REFLECTION – Lunar Laser Ranging



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LAW OF REFLECTION – F-117A Stealth Fighter

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$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

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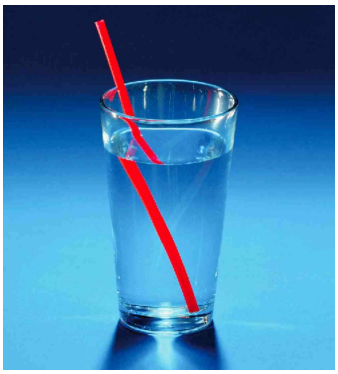
LAW OF REFRACTION (SNELL LAW)

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



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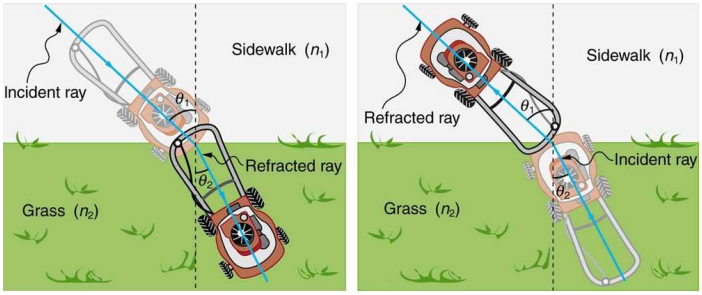

Light propagates slower in a material with larger refractive index.

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

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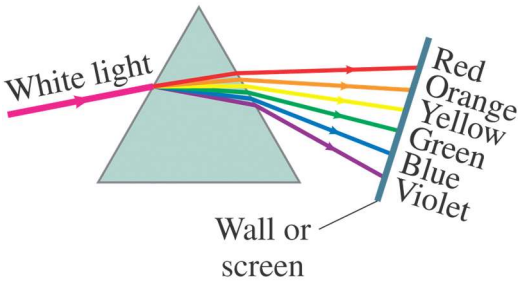
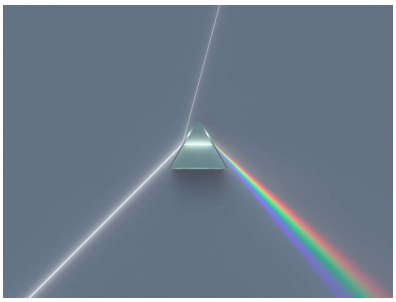
DISPERSION – Prism





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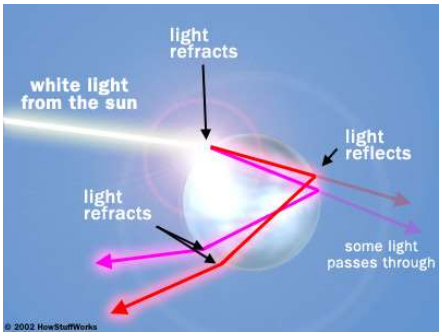
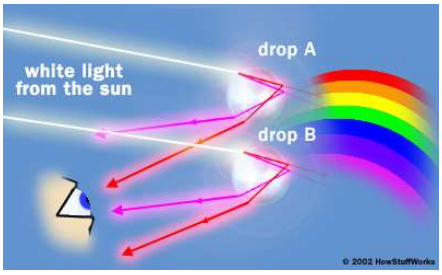
DISPERSION – Rainbow





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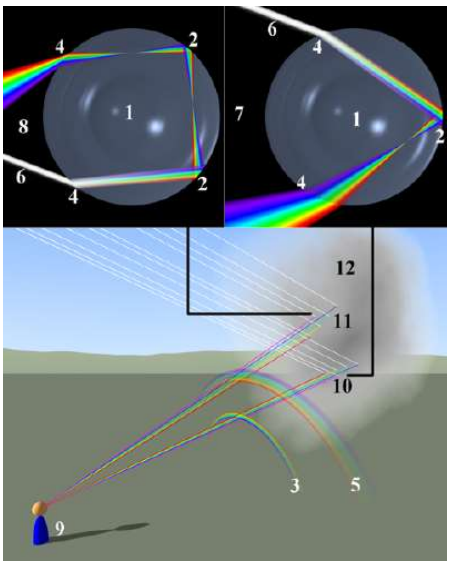
DISPERSION – Rainbow



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TOTAL REFLECTION

a) Example: air → glass

$$\left.\begin{array}{l} n_1 < n_2 \\ \theta_1 = 0 \ldots 90\,° \end{array}\right\} \quad \sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} = \underbrace{\frac{n_1}{n_2}}_{<1} \cdot \underbrace{\sin\theta_1}_{\leq 1}$$

b) Example: glass → air

$$\left.\begin{array}{l} n_1 > n_2 \\ \theta_1 = 0 \ldots 90\,° \end{array}\right\} \quad \underbrace{\sin\theta_2}_{>1\ ???} = \frac{n_1 \sin\theta_1}{n_2} = \underbrace{\frac{n_1}{n_2}}_{>1} \cdot \underbrace{\sin\theta_1}_{\leq 1}$$

Critical angle of incidence: $\sin\theta_2 = 1 \rightarrow \boxed{\sin\theta_{1,crit} = \frac{n_2}{n_1}}$

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

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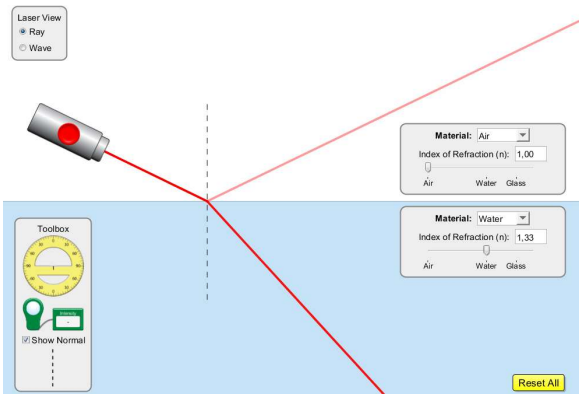
LAW OF REFRACTION (SNELL LAW)

ANIMATION:



http://phet.colorado.edu/en/simulation/bending-light

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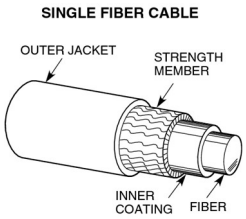
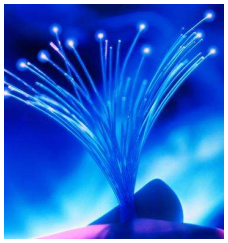
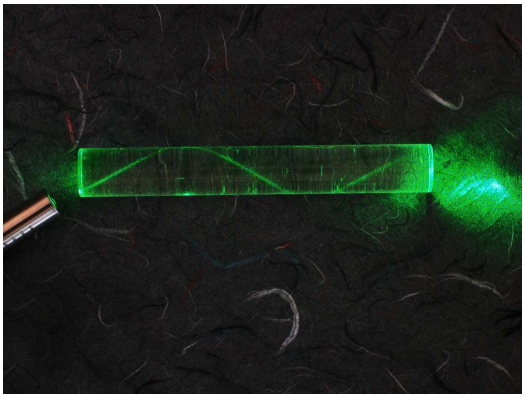
TOTAL REFLECTION – Optical fiber







$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] \quad 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

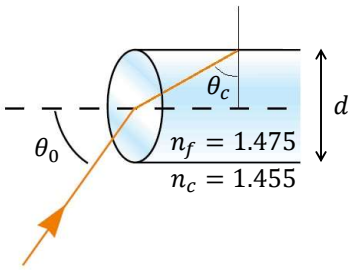
$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

TOTAL REFLECTION – Optical fiber

a) A light beam shines into the center of an optical fiber. The refractive index of the fiber is 1.475, the refractive index of the coating is 1.455, the refractive index of air (surrounding) is 1.

What is the maximum angle θ_0 under which the light beam will still be successfully coupled into the fiber? What is the numerical aperture *NA* of the fiber?

b) The length of the fiber *L* is 1 km. How long does it take for the light beam to cross the fiber, if the incident angle is 0° or θ_0?



$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

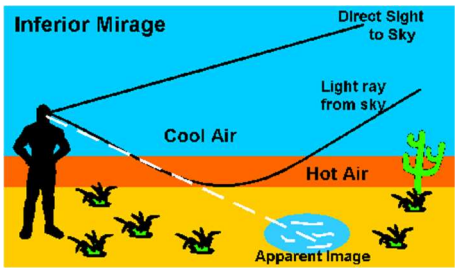
$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda}$ $\quad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

TOTAL REFLECTION – Mirrage



→ n_{cool} = 1.0003

→ n_{hot} = 1.0001

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda}$ $\quad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
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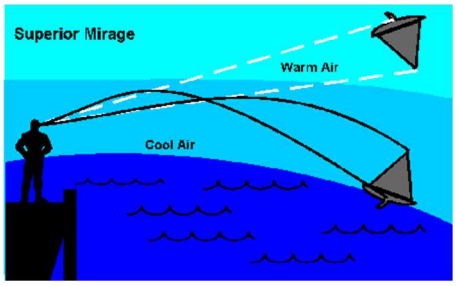
TOTAL REFLECTION – Mirrage



$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] \quad 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

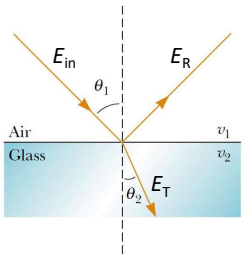
$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

FRESNEL COEFFICIENTS – Electric field

$$r_{TE} = \frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}$$

$$r_{TM} = \frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}$$

$$t = 1 + r$$



$$\boxed{E_R = r \cdot E_{in} \qquad E_T = t \cdot E_{in}}$$

Perpendicular incidence: $r_{TE} = r_{TM} = \frac{n_1 - n_2}{n_1 + n_2}$

a) $n_1 > n_2$ → $t > 0$, $r > 0$

b) $n_1 < n_2$ → $t > 0$, $\underline{r < 0}$ **(phase shift of π!)**

Phase shift in reflection: **„From LOW to HIGH is PI (π)!"**

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

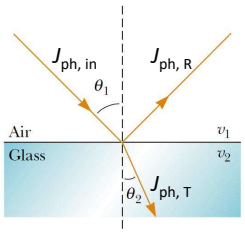
FRESNEL COEFFICIENTS – Optical power density

$R_{TE} = |r_{TE}|^2$

$R_{TM} = |r_{TM}|^2$

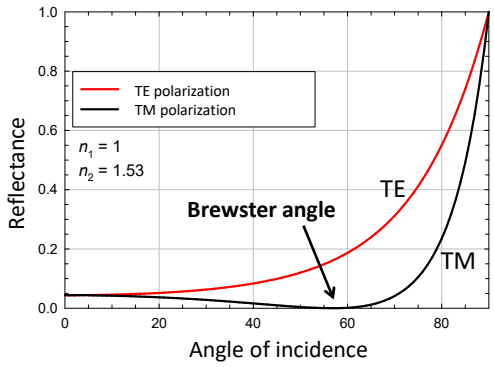
$T = 1 - R$

$$\boxed{J_{ph,R} = R \cdot J_{ph,in} \qquad J_{ph,T} = T \cdot J_{ph,in}}$$



Reflection:
air / glass

$n_1 = 1$
$n_2 = 1.53$



$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

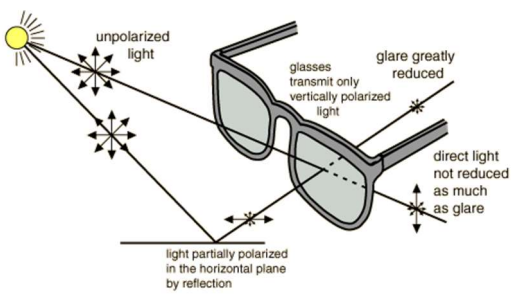
$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$

$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$

$T = 1 - R$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

REFLECTION OF POLARIZED LIGHT



$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

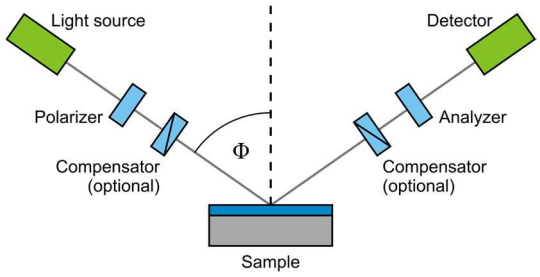
$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$

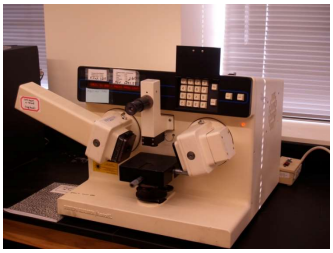
$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$

$T = 1 - R$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

REFLECTION OF POLARIZED LIGHT – Ellipsometry





$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

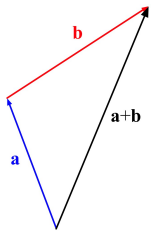
$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

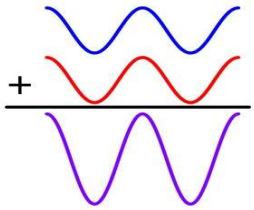
$$T = 1 - R$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

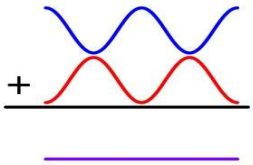
INTERFERENCE



Constructive interference:



Destructive interference:



Phase shift:
0, 2π, 4π, … = *m* * 2π

Phase shift:
π, 3π, 5π, … = (*m* + ½) * 2π

m = 0, 1, 2, 3, …

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

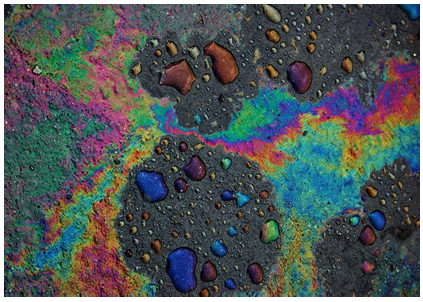
$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON THIN FILMS



$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

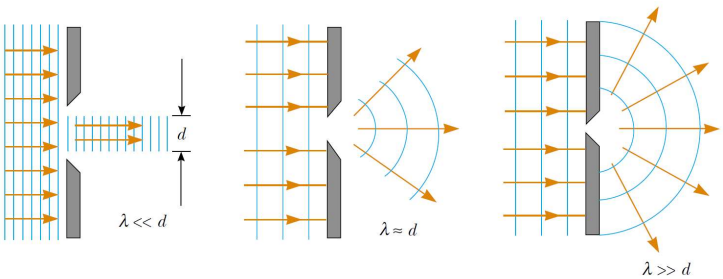
$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

DIFFRACTION



$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

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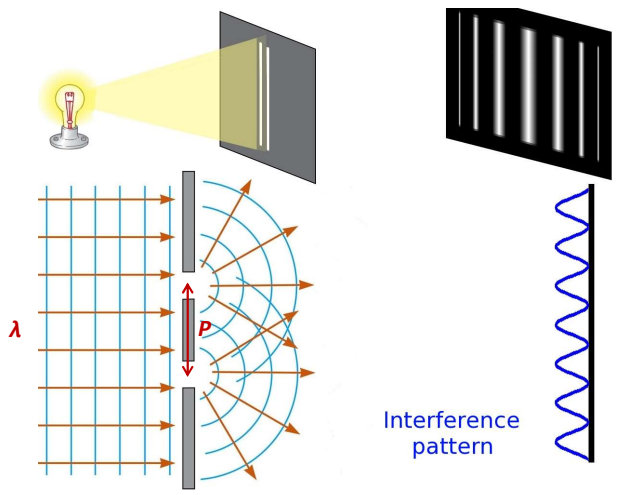
$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON SLITS



Interference conditions: coherent, monochromatic source

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$

$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$

$T = 1 - R$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON SLITS

VIDEO:

$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$

$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$

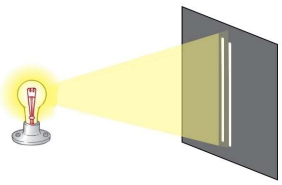
$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$

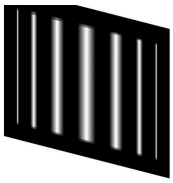
$T = 1 - R$

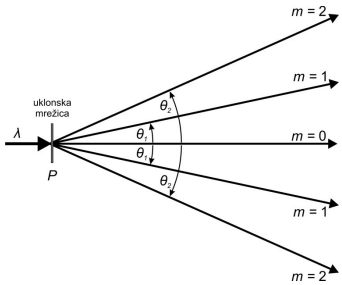
$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON SLITS – Diffraction grating







$$\sin\theta_m = \frac{m\cdot\lambda}{P}$$

diffraction grating equation

Interference conditions: coherent, monochromatic source

$E_{ph} = h\cdot f = \frac{h\cdot c_0}{\lambda_0}$

$E_{ph}[eV]\cdot\lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda}$ $\quad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$R_{horiz,s,TE} = \left|\frac{n_1\cdot\cos\theta_1 - n_2\cdot\cos\theta_2}{n_1\cdot\cos\theta_1 + n_2\cdot\cos\theta_2}\right|^2$

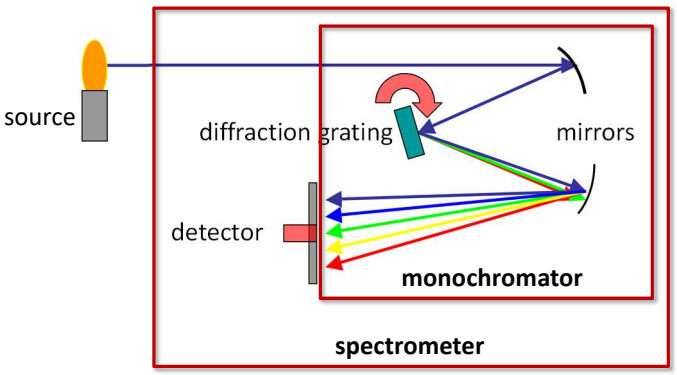
$R_{vert,p,TM} = \left|\frac{n_1\cdot\cos\theta_2 - n_2\cdot\cos\theta_1}{n_1\cdot\cos\theta_2 + n_2\cdot\cos\theta_1}\right|^2$

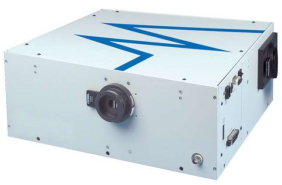
$T = 1 - R$

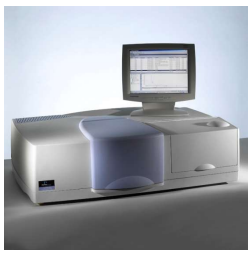
$\sin\theta_{m,konst} = \frac{m\cdot\lambda}{P}$

$c_0 = 299792458\ m/s$
$h = 6.6261\cdot10^{-34}\ Js$
$q = 1.6022\cdot10^{-19}\ As$

SPECTROSCOPY USING A DIFFRACTION GRATING







$E_{ph} = h\cdot f = \frac{h\cdot c_0}{\lambda_0}$

$E_{ph}[eV]\cdot\lambda_0[nm] = 1240$

$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda}$ $\quad \alpha = \frac{4\pi k}{\lambda_0}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$

$R_{horiz,s,TE} = \left|\frac{n_1\cdot\cos\theta_1 - n_2\cdot\cos\theta_2}{n_1\cdot\cos\theta_1 + n_2\cdot\cos\theta_2}\right|^2$

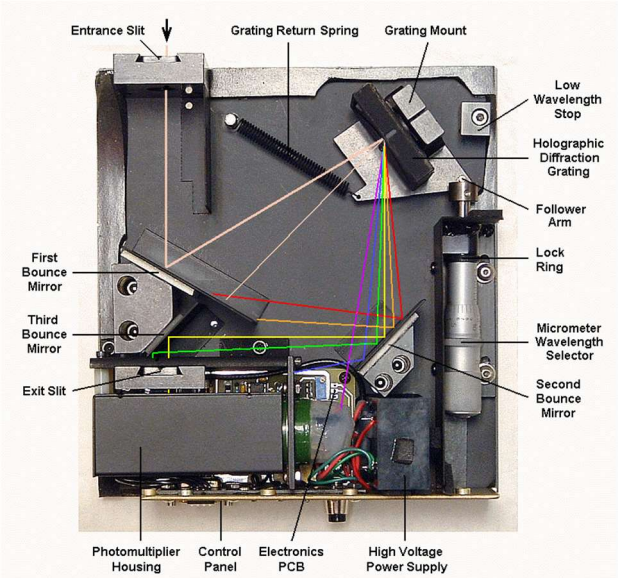
$R_{vert,p,TM} = \left|\frac{n_1\cdot\cos\theta_2 - n_2\cdot\cos\theta_1}{n_1\cdot\cos\theta_2 + n_2\cdot\cos\theta_1}\right|^2$

$T = 1 - R$

$\sin\theta_{m,konst} = \frac{m\cdot\lambda}{P}$

$c_0 = 299792458\ m/s$
$h = 6.6261\cdot10^{-34}\ Js$
$q = 1.6022\cdot10^{-19}\ As$

SPECTROSCOPY – MONOCHROMATOR



Verity Instruments EP200 Monochromator/Detector Organization

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON SLITS – Diffraction grating

a) A light beam from a source that contains three spectral components (λ_1 = 320 nm, λ_2 = 550 nm, λ_3 = 640 nm) shines through a diffraction grating with the period P = 847 nm. What are the angles of the first interference order (m = 1) for each of the three spectral components?

b) What is the maximal wavelength for which the first interference order (m = 1) would still be observed?

c) What are the angles of the second interference order (m = 2) for each of the three spectral components?

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

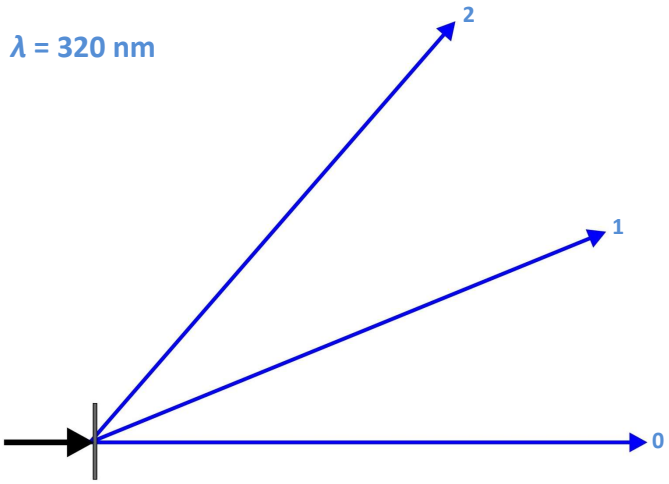
$$T = 1 - R$$

$$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON SLITS – Diffraction grating

λ = 320 nm



diffraction grating

$$\sin\theta_m = \frac{m \cdot \lambda}{P}$$

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
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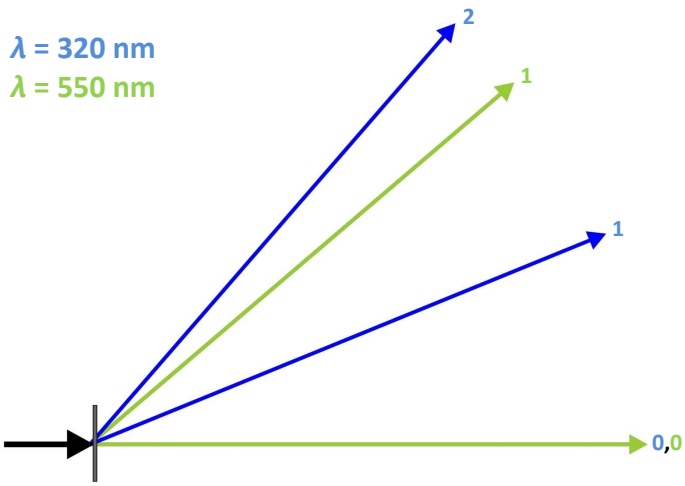
INTERFERENCE ON SLITS – Diffraction grating

λ = 320 nm
λ = 550 nm



diffraction grating

$$\sin\theta_m = \frac{m \cdot \lambda}{P}$$

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

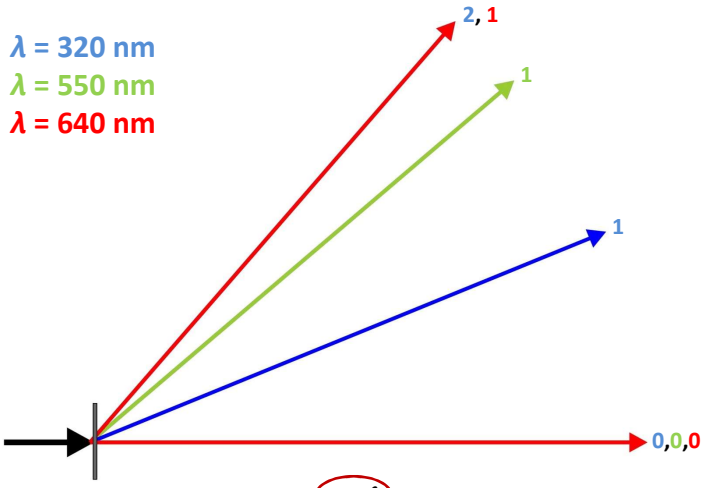
$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-34}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE ON SLITS – Diffraction grating



$$\sin\theta_m = \frac{m \cdot \lambda}{P}$$ → 1·640 = 2·320

$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$$

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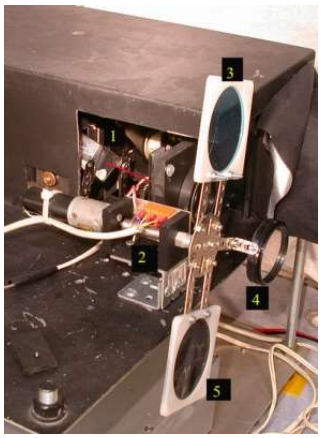
$q = 1.6022 \cdot 10^{-19}\ As$

INTERFERENCE – Optical filters



$$E_{ph} = h \cdot f = \frac{h \cdot c_0}{\lambda_0}$$

$$E_{ph}[eV] \cdot \lambda_0[nm] = 1240$$

$$n = \frac{c_0}{c} = \frac{\lambda_o}{\lambda} \qquad \alpha = \frac{4\pi k}{\lambda_0}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$

$$R_{horiz,s,TE} = \left|\frac{n_1 \cdot \cos\theta_1 - n_2 \cdot \cos\theta_2}{n_1 \cdot \cos\theta_1 + n_2 \cdot \cos\theta_2}\right|^2$$

$$R_{vert,p,TM} = \left|\frac{n_1 \cdot \cos\theta_2 - n_2 \cdot \cos\theta_1}{n_1 \cdot \cos\theta_2 + n_2 \cdot \cos\theta_1}\right|^2$$

$$T = 1 - R$$

$$\sin\theta_{m,konst} = \frac{m \cdot \lambda}{P}$$

$c_0 = 299792458\ m/s$
$h = 6.6261 \cdot 10^{-3}\ Js$
$q = 1.6022 \cdot 10^{-19}\ As$