Review

EM waves from Maxwell's Eqns:

- $E = E_0 \sin \frac{2\pi}{\lambda}(x - ct)$; $B = E/c$
- Wavelength λ
- Amplitude E_0
- frequency $f = c/\lambda$
- Irradiance $I = \frac{1}{2} c \varepsilon_0 E_0^2$ [W/m^2]

For a source of EM power emitting in all directions (isotropic)

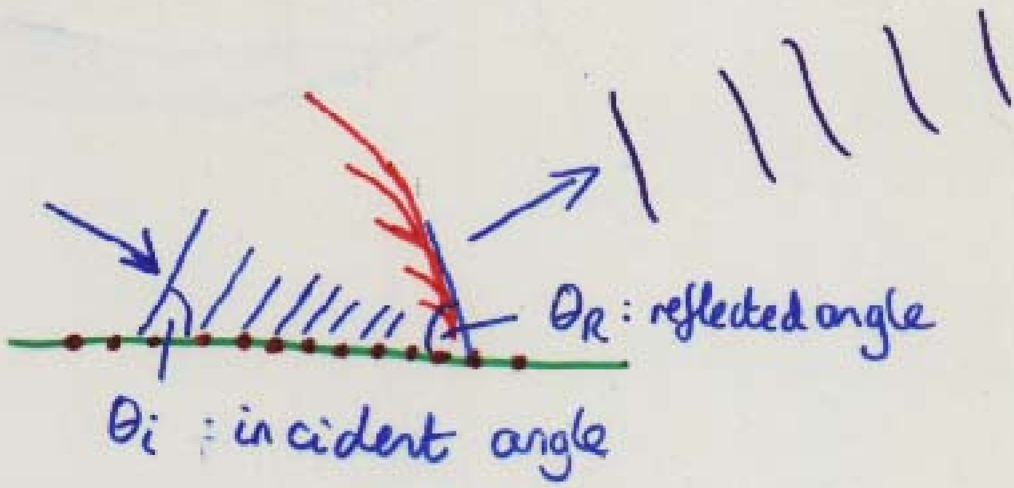
- $$I = \frac{P}{4\pi r^2}$$

(Note: $I \propto \frac{1}{r^2}$ so $E_0 \propto \frac{1}{r}$)

- Antenna length : ideally $= \lambda/4$
- "Wavelet" method to propagate EM wave through medium.

Reflection at a Surface

Fig. 23.14



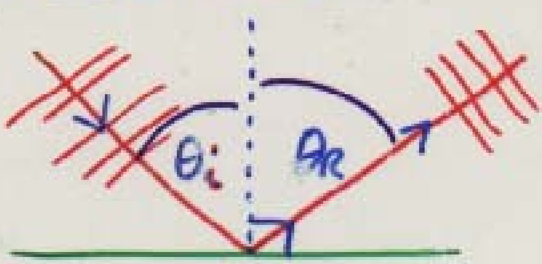
Surface has molecules spaced by $\approx 0.5\,nm \ll \lambda$

$\Rightarrow$ EM wave "sees" smooth surface

Now wavelets interfere constructively where $\theta_R = \theta_i$

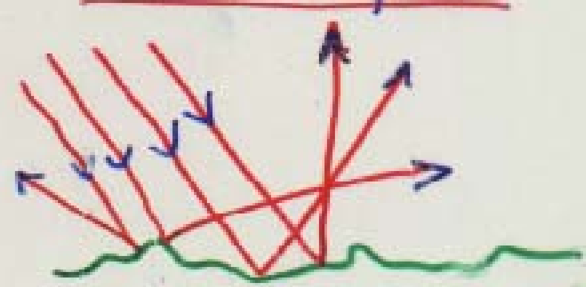
Law of Reflection: $\theta_R = \theta_i$, and reflected wave is in same plane as incident wave

Smooth surface:



specular reflection
(mirror)

Uneven surface:



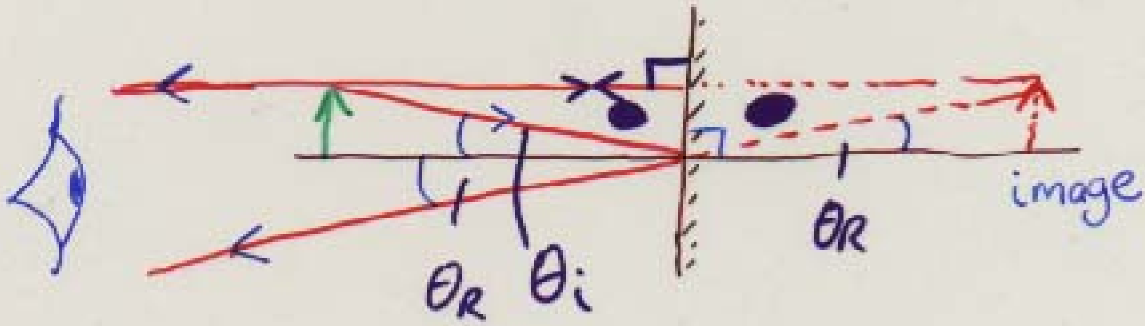
e.g. matte finish

note, as $\theta_i \uparrow$, reflection becomes more specular.

Plane Mirrors

Every ray striking mirror reflected with $\theta_i = \theta_R$

(measure relative to the normal, ⊥ to surface)



Light rays appear to diverge from image "behind"

mirror.

From congruent Δs ($\theta_i = \theta_r$), image is:

- same size as object
- same distance from mirror

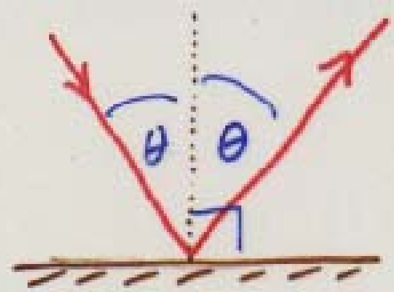
Also, image "laterally inverted" (right ⟺ left for writing).

Try: combing hair in mirror

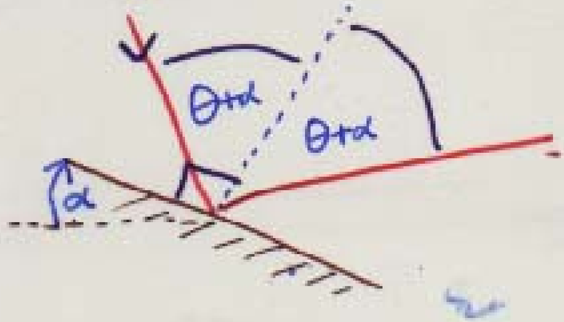
" " looking at your video image (camcorder screen, store security TV)

Mirrors can amplify small angles:

e.g. incident light makes angle θ to the vertical. Rotate mirror by angle α:



before



Reflected ray changes direction wrt. vertical from

θ to $\alpha + (\theta+\alpha) = \underline{2\alpha} + \theta$

i.e. direction changes by twice the mirror's change in angle.

- used in laser light shows
- banks of mirrors to amplify gravitational waves in detector.

Refraction of Light

In dense medium, light propagates at $v < c$ (absorption + re-emission by atoms).

Define refractive index $\boxed{n = \frac{c}{v}}$ (>1)

e.g. in water, $n = 1.33$ for yellow (590 nm) light

Where n changes with frequency of light

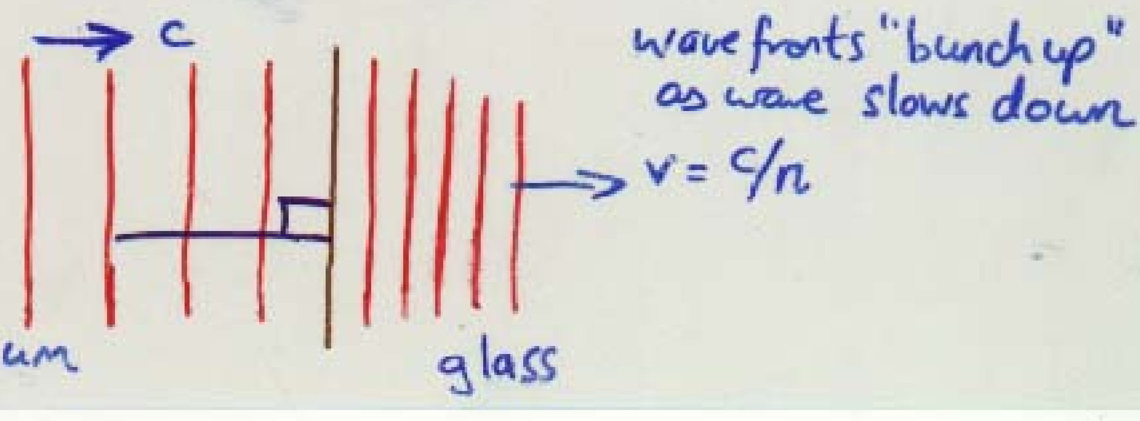
→ dispersion (different colors have different speeds)

e.g. diamond has $n = 2.42$

$\Rightarrow$ speed of light $= \frac{3 \times 10^8 \text{ m/s}}{2.42} = 1.24 \times 10^8 \text{ m/s}$

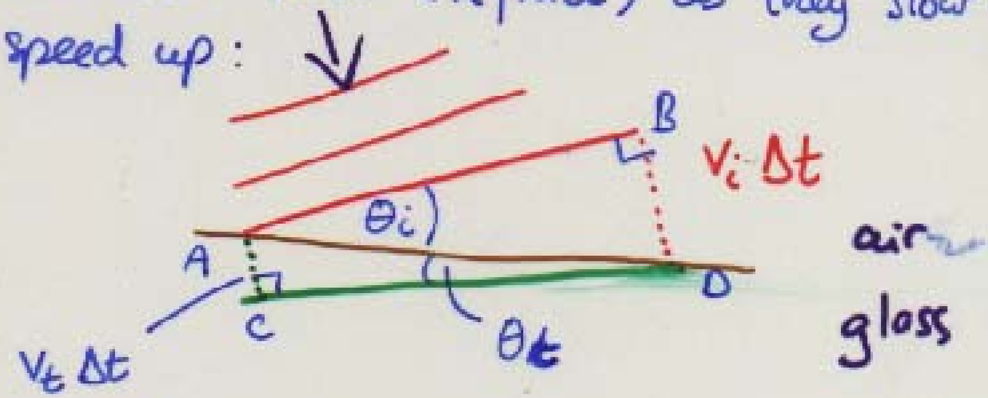
Also, since frequency f is constant between media,

wavelength $\lambda_n = \frac{v}{f} = \frac{c}{nf}$: shorter as $n \uparrow$.



Snell's Law of Refraction

Since wave speed changes between media, waves must "bend" (refract) as they slow down or speed up:



In time Δt, incident wave moves $v_i \Delta t$
transmitted $v_t \Delta t$

For both rt Δs ABD, ACD, hypotenuse

$$AD = \frac{v_i \Delta t}{\sin\theta_i} = \frac{v_t \Delta t}{\sin\theta_t}$$

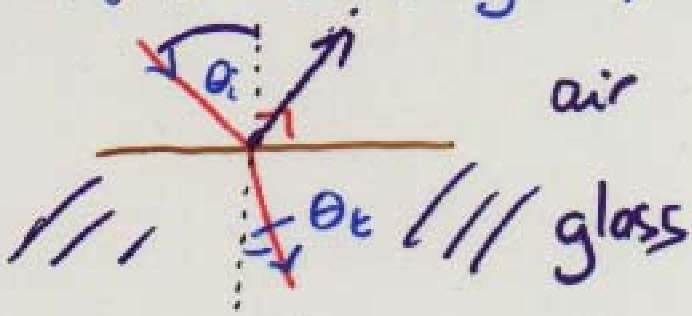
Put $v_i = c/n_i$ $\quad v_t = c/n_t$

$$\Rightarrow \quad n_i \sin\theta_i = n_t \sin\theta_t$$: Snell's Law of Refraction

Note: light rays bent toward normal when $n_t > n_1$
away $n_t < n_1$

Example:

Beam of light enters glass at $\theta_i = 60°$ - what is θ_t? (Take $n_g = 1.5$, $n_{air} = 1.0$)



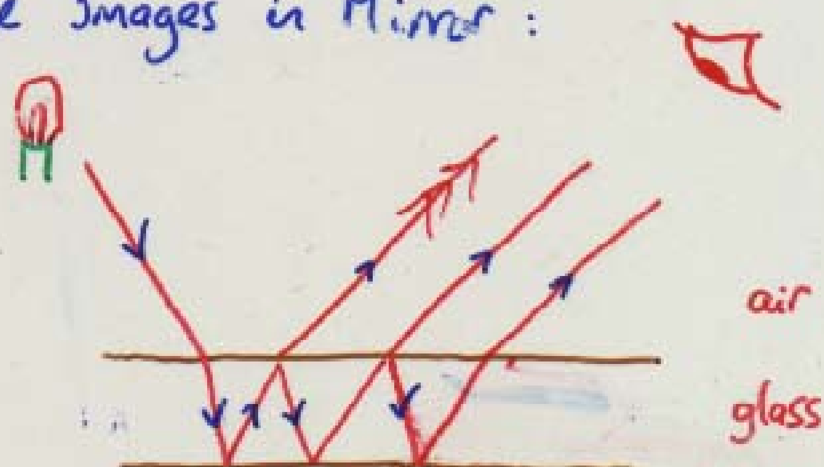
From Snell's Law, $\sin\theta_t = \frac{n_i}{n_t}\sin\theta_i$

$$\Rightarrow \sin\theta_t = \frac{1.0}{1.5} \times \sin 60° = 0.577$$

$$\Rightarrow \theta_t = 35.3°$$

(Also if $\lambda_i = 500\,nm$, $\lambda_t = \lambda_i \frac{n_i}{n_t} = 333.3\,nm$)

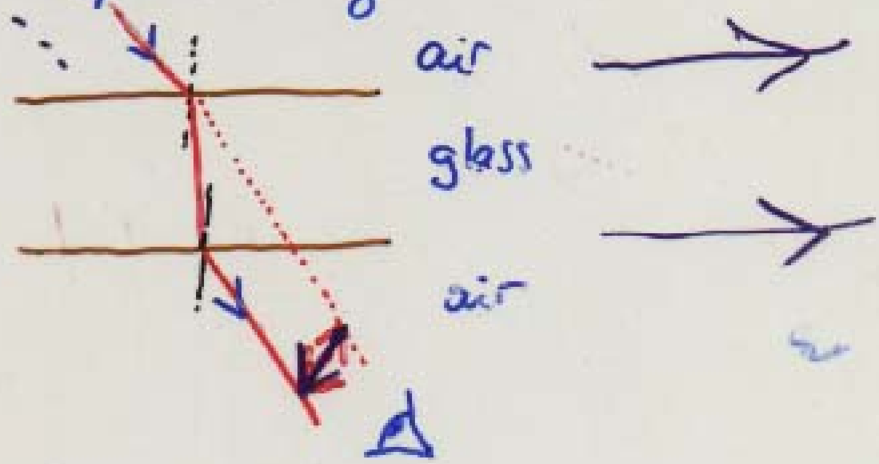
Multiple Images in Mirror:



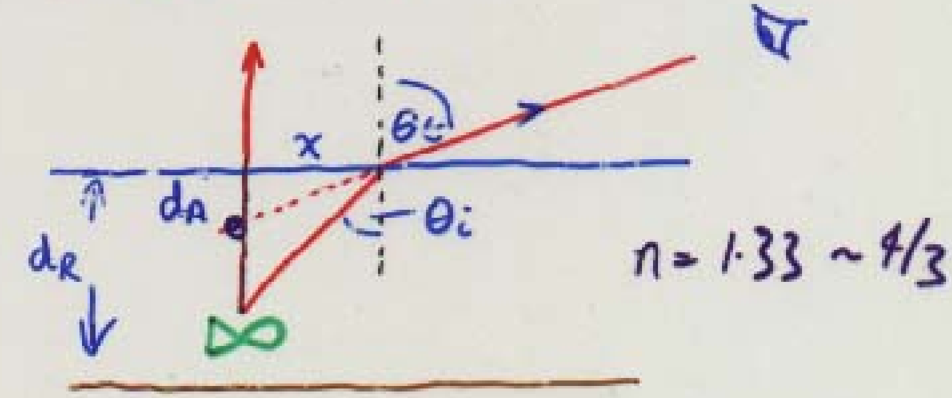
Refraction Effects

1. Thick window displaces image

light emerges
but displaced



2. Real vs. apparent depth



Geometry $\Rightarrow$ $x = d_R \tan\theta_i = d_A \tan\theta_t$

Use "small angle approx" $\Rightarrow$ $\tan\theta = \dfrac{\sin\theta}{\cos\theta} \approx \sin\theta$

$$\Rightarrow \frac{d_A}{d_R} \approx \frac{\sin\theta_i}{\sin\theta_t} = \frac{n_i}{n_t} \approx 3/4 \text{ for water} \rightarrow \text{air}$$