# PHY2208 Lecture 17

Random polarization
Basics of EM theory of light/matter interactions
Generation of polarization by scattering and dichroism
Polarization by reflection

Y&F section 34-6
Pedrotti & Pedrotti 15-1, 15-2, 15-3

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Light from a **thermal** source (e.g. a light bulb) is **randomly polarized** i.e. the direction of ***E*** varies randomly with time.

But when randomly polarized light **interacts** with matter, some polarization states are attenuated relative to others. The light gains a net overall polarization.

To understand why light/matter interactions affect the state of polarization, we must review classical EM theory of such interactions:

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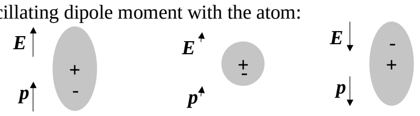
EM radiation is generated by **accelerating** (e.g. oscillating) electric charges.

When EM radiation illuminates matter, the time-varying ***E*** field causes the cloud of atomic electrons to oscillate.

These oscillating electrons re-radiate EM radiation i.e. EM radiation is **scattered** by atoms.

Specifically, an incident time-varying E-field induces an oscillating dipole moment with the atom:




The motion of the centre-of charge of the electron cloud can be described as a **forced harmonic oscillator**.

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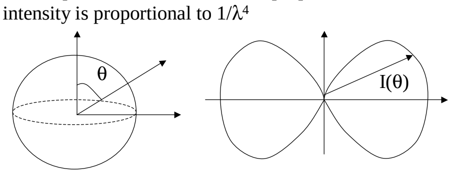
EM radiation from an oscillating dipole has the following features:

An infinitesimal dipole generates a spherical EM wave.

The angular distribution $|E(\theta,\phi)| \propto \sin\theta$

$$I \propto \sin^2\theta$$

The amplitude of the EM wave is proportional to $1/\lambda^2$ so the intensity is proportional to $1/\lambda^4$

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The sky appears bright because sunlight is scattered into our line of sight by nitrogen and oxygen molecules in the atmosphere.

The sky is blue because *I* is proportional to $1/\lambda^4$

The scattered light is partially polarized because the polarization component perpendicular to the line is scattered with high intensity for all scattering angles.

So why are sunsets red?

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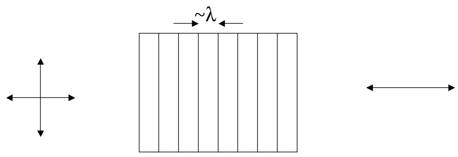
Many materials exhibit **dichroism** i.e. a preferential absorption of light possessing a certain polarization direction.

A simple example is the wire-grid polarizer used for microwave EM radiation




An incident EM wave with ***E*** parallel to the wires can readily induce electrons to flow in the wires. The induced currents rapidly dissipate the wave energy due to **ohmic heating**.

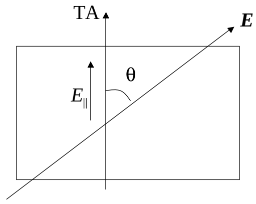
If ***E*** is perpendicular to the wires, the flow of electrons is impeded over length scales ~λ.

E parallel to the wires **is not** transmitted.

E perpendicular to the wires **is** transmitted.

Initially unpolarized EM radiation becomes linearly polarized after passing through such a polarizer. The direction of polarization is perpendicular to the wires. This direction is the **transmission axis.**

In 1928 Land invented an optical equivalent of the wire-grid polarizer, a plastic film containing directionally aligned long-chain molecules of high conductivity called **Polaroid**. Polaroid is constructed by stretching a sheet of polyvinyl alcohol, thereby aligning its very long molecules (polymers). The sheet is then impregnated with iodine, which attaches itself to the polymers. Conduction electrons from the iodine move freely along the molecules (c.f. the wire grid polarizer).




$$E_{||} = |\mathbf{E}|\cos\theta$$

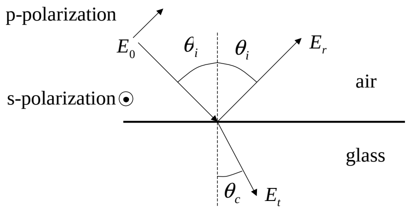
The transmitted wave has: $|\mathbf{E}| \propto \cos\theta$

i.e. $I \propto \cos^2\theta$ which is **Malus's Law**

Consider unpolarized light, intensity $I_0$ incident on the polarizer:

$$I_{\text{out}} = I_0\langle\cos^2\theta\rangle = I_0/2$$

Consider rays reflected and refracted at a plane dielectric interface:




Definition of the amplitude reflection and transmission coefficients:

$$r = \frac{E_r}{E_0} \qquad t = \frac{E_t}{E_0}$$

We have previously stated approximate expressions for these, but in general they will depend on a) the angle of incidence and b) the polarization state of the incoming wave.

To calculate *r* and *t*, we require that the total electric and magnetic fields obey the following conditions at the dielectric interface:

a) the normal component ***D*** is continuous across the interface

b) ditto the tangential component of ***E***

c) ditto the normal and tangential components of ***H***

EM theory requires that the incident, reflected, and transmitted rays are co-planar. Then, with reference to the plane containing the waves, we define:

**p-polarized** radiation has ***E*** orientated parallel to this plane

**s-polarized** radiation has ***E*** orientated perpendicular to this plane

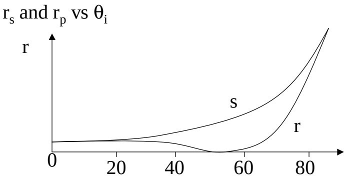
Then (**see handout**) applying the boundary conditions yields:

$$r_p = -\frac{\tan(\theta_t - \theta_i)}{\tan(\theta_t + \theta_i)} \qquad r_s = \frac{\sin(\theta_t - \theta_i)}{\sin(\theta_t + \theta_i)}$$

and similar expressions are found for *t*.

NB as usual $\theta_t$ and $\theta_i$ are related by Snell's Law

e.g. for $n_i = 1.0$ and $n_t = 1.5$ (reflection from glass) we can plot $r_s$ and $r_p$ vs $\theta_i$




For $\theta_i \approx 0$ $|r_s| \approx |r_p|$

For $\theta_i > 0$ $|r_s| \neq |r_p|$

So at anything other than normal incidence, reflection from a dielectric interface induces a net polarization in unpolarized incident radiation.

NB as $(\theta_i + \theta_t) \rightarrow 90^\circ$ $\tan(\theta_i + \theta_t) \rightarrow \infty$ so $r_p \rightarrow 0$

This is **Brewster's angle**, defined by:

$$\theta_t = 90^\circ - \theta_i$$

$$\sin\theta_t \left( = \frac{n_i}{n_t}\sin\theta_i \right) = \cos\theta_i$$

$$\theta_i = \tan^{-1}\frac{n_t}{n_i}$$