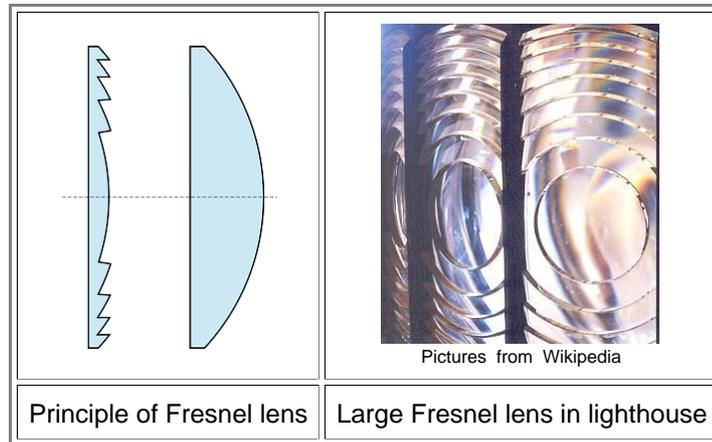


5.2.7 Specialities

Before we move on to more technical optics, we need to consider a few special effects that are of some importance to optical apparatus and not yet directly covered like (Rayleigh) scattering or indirectly like diffraction gratings. The list could be rather large, we restrict ourselves to a few effects here, however

Fresnel Lens

- Recalling that a lens "bends" the light rays impinging on it only at the air - lens interface while nothing much happens inside the glass, **Augustin-Jean Fresnel**, whom we [encountered before](#), had the great idea to turn this principle into practical use. Here is what a Fresnel lens looks like; the principle is obvious:



- It wasn't so easy way back to shape glass like that. Nowadays it is easy, especially if you use plastic material and just press it into form. Fresnel lenses are no all over the place - as long as the ultimate in resolution doesn't matter. The "tips" at the singularities scatter light to some extent. and if you make the structure too dense, you run into diffraction effects at the periodic structure.

Optical Activity

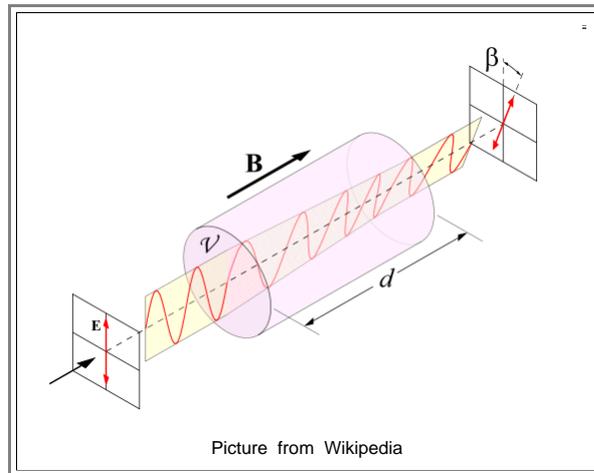
- Optical Activity generally is a type of [birefringence](#). It describes materials that rotate a linearly polarized wave as it travels through the material. All materials with some chiral symmetry (i.e. where you find some kind of "spiral" inside show this behavior (provided, of course, they are sufficiently transparent)
- The typical material is quartz but its internal spiral is not so obvious., So take DNA, where the spiral is obvious. Run light through such a material and its polarization vector either turns clockwise ("right") or counterclockwise ("left"), depending on how the internal spirals are "wound"
- Do not confuse optical activity with circular polarization, In both cases the electrical field vector rotates but for circular polarized light a full rotation occurs in the space of a wavelength, where it might take many mm of active material for that.

There are plenty of applications:

- Most prominent, perhaps, is what "**Polarimeters**" do. They measure how much a given substance at controlled conditions rotate light. This is very valuable in biology or medicine because most "biological" molecules are optical active - but invariably only "leftish". This means that all biomolecular spirals are always wound in just one way. Amazing! Think about that. So be careful when that sexy alien arrives. If she or he is wound the other way, all kinds of trouble will ensue on close contact. If you measure the amount of rotation in a controlled experiment, you can derive the concentration of the active molecules.
- Next we note that in the presence of magnetic fields, *all* molecules have optical activity. This is called the *Faraday effect* and is treated right below.

Faraday effect

- The picture shows it all. An incoming linearly polarized beam turns its polarization direction by an angle given by $\beta = bd \cdot V$. The **Verdet constant** V contains the material property as some number in minutes of angle per [Oersted/cm](#) (nobody really working in magnetics uses **SI** units). We have for example: $V(\text{diamond}) = 0,012$; $V(\text{glass}) \approx 0,015 - 0,025$; but crystals like terbium gallium garnets might have far larger values.

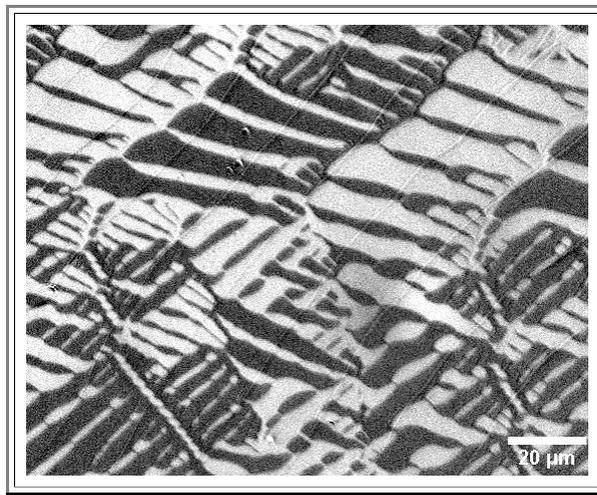


The obvious thing to do now is to derive the equations from above and to calculate the Verdet constant. Well, *forget it*. Just to give you an idea of what it would involve:

- What we would need to do is to go over the driven damped harmonic oscillator once more (we looked at that in some detail in the context of [dielectric polarization mechanisms](#)). But now we must add the force that the magnetic field exerts on the charge. Instead of just $-eE(\omega)$ as (oscillating) driving force we have now $-eE(\omega) - e \cdot (dx/dt \times B)$. This will change the dielectric susceptibility χ resulting from the solution - it will turn it into a tensor! It's not difficult to see why: The magnetic field produces a force that is at right angles to the principal axis of motion. The problem is thus no longer one-dimensional and the amplitude and thus the polarization will have components in other than the x -direction.
- In other words: An electric field in x -direction applied to a cubic crystal will only produce polarization on the crystal surface perpendicular to the x -direction, let's say the **(100)** sides, and it doesn't matter if the field oscillates or not for that. The dielectric susceptibility is proportional to the oscillation amplitude with the known frequency dependence. Now add a magnetic field - static or not - and the other surfaces of the cube will now become charged or polarized, too. A simple consequence is already that in a static magnetic field *all* materials are anisotropic because the polarization vector is no longer parallel to the electrical field vector.
- What is the Faraday effect good for? Well, you can measure magnetic fields with it. In particular if those fields are far away like in the next sun system or galaxy. Astrophysics is very big on using the Faraday effect but in terrestrial terms it is not used very much.

Kerr Effect

- There are *two* Kerr effects:
 - The **magneto-optic Kerr effect (MOKE)**. It describes how an applied *magnetic field* changes the *reflection* from some material.
 - The **electro-optic Kerr effect**, also called the *quadratic electro-optic effect (QEO)* effect, describes the change in the *refractive index* of a material in response to an applied *electric field*.
- If a magnetic field is turned on (or is present because the material is ferromagnetic), the polarization and the intensity of reflected light might be different from what one would calculate with the [Fresnel equations](#). How exactly depends on the material and the components of the magnetic field on the surface
- The magneto-optic Kerr effect is identical to the *Faraday effect* from above but deals with the reflected and not the transmitted light. It is very useful because it allows to image [magnetic domains](#). The [link](#) shows examples and here is one from the Uppsala University / Materials Physics:



The electro-optical Kerr effect describes an electrical field induced index change that is proportional to the *square* of the electric field; i.e. the *intensity*. If the index changes linearly with the field, the effect is called *Pockels effect*, see right below.

- All materials show this *quadratic electro-optic effect* but certain liquids display it more strongly than others. The electro-optical Kerr effect can and has been used to modulate light because it still works at very high frequencies.
- There is an fascinating emerging special use. If one does not apply the electrical field by conventional means (i.e. by applying a voltage across two electrodes) but by (intense) light, all kinds of strange things can happen. One needs strong electrical field not usually found in normal light (look at [exercise 5.1.-2](#)). So we use an intense Laser beam. The resulting (always nonlinear) optical effects go by names like self-focusing, self-phase modulation, modulational instability, and Kerr-lens modelocking. Whatever that might be (google it), we can expect to find applications based on that in the not too distant future

Pockels Effect

- The Pockels effect produces birefringence in an optical medium by applying a constant or varying electric field. It is distinguished from the Kerr effect above by the fact that the birefringence is proportional to the electric field, whereas in the Kerr effect it is quadratic in the field.
- The Pockels effect occurs only in crystals that lack inversion symmetry, such as lithium niobate or gallium arsenide or special polymers or glasses, while the Kerr effect occurs in all materials.
- Concerning applications one only needs to consider that optical communication via glass fibres depends on **Pockels cells**. Modulating light intensities with GHz or even THz simply cannot be done otherwise.

Concluding Remarks:

1. Above several effects are listed where electric or magnetic fields superimposed on some optic material does "something" to light. There are even more of those "named" effects not shown here, and they all have one thing in common:

- All that light can do inside material is to change what the electrons are doing. Since any change of what an electron is doing involves a change of it state, only electrons at the Fermi edge can do something, as we have asserted many times before.
- What a simple oscillating electrical field will do (i.e. a light wave) we have already treated with a simple mechanical model, when we discussed the [frequency dependence of polarization mechanisms](#). Straight away we got the complex dielectric function and thus also the [complex index of refraction](#).

All we need to do to cover *all* the effects of electric and magnetic fields on optics is to include the forces on the electron they add *in addition* to the force produced by the electric field of the light wave. The [equation above](#) for the Faraday effect hints at that. The new equations, however, are not so easy to solve any more. What we generally find is

- In the case of a isotropic material it now becomes anisotropic. Dielectric constant ϵ_r , susceptibility χ and index of refraction n (all simply related as you know) become tensors.
 - Those tensors may have imaginary components.
 - Any light wave can always be decomposed into two light waves with orthogonal polarization. They will travel through the material now with different wave vectors . We have two beams now.
 - In the case of an anisotropic material things get really complicated
 - In the case of high field strength of the extra field, things get also non-linear.
- So we have been lucky. Even if you hate the mathematical complexity, you must appreciate that a lot of useful effects result that are not even remotely exhausted at present. That's where some of you might find useful (and well paid) work to do!

▀ If you look at the applications listed above, one very major application is conspicuously missing. Close your eyes and think. For which product that *you* use daily is it absolutely essential that you can influence the transmittance of light by an electrical field?

- Right - liquid crystal displays (**LCD**) or practically all computer monitors, many TV's and plenty of cell phone displays. An electrical field between the [transparent electrodes](#) of a pixel change the polarization properties of the liquid crystals inside that capacitor and those how much light is transmitted. Are we using the electro-optical Kerr effect here? Or the Pockel effect? Personally, I don't know for sure. But I know that it doesn't matter. It's time to leave the past behind and look at the general picture and not at enumerated experimental descriptions of effects observed some 100 years ago.