Linear and quadratic electrooptic effect

When an electric field is applied to a crystal, the ionic constituents move to new locations determined by the field strength, the charge on the ions and the restoring force. Unequal restoring forces along three mutually perpendicular axes in the crystal lead to anisotropy in the optical properties of the medium. When an electric field is applied to such a crystal, in general, it causes a change in the anisotropy. These changes can be described in terms of the modification of the indicatrix by the field - both in terms of the principle refractive indices of the medium and in the orientation of the indicatrix. If these effects can be described, to first order, as being linearly proportional to the applied field then the crystal exhibits the linear electrooptic effect. We shall see that this results only if the crystal lattice lacks a center of symmetry. So, some cubic crystals can exhibit the linear electrooptic effect. If the crystal possess a center of symmetry (or is even an isotropic material such as a gas or liquid) a change in optical properties can result that depends, to first order, on the square of the applied field. This is the quadratic electrooptic effect. Both the linear and quadratic electrooptic effects can be used effectively in various optical devices.

Birefringence was first observed in the 17th century when sailors visiting Iceland brought back to Europe calcite crystals that showed double images of objects that were viewed through them. This effect was explained by Christiaan Huygens (1629 - 1695, Dutch physicist), as double refraction of what he called an ordinary and an extraordinary wave. With the help of a polarizer we can easily see what these ordinary and extraordinary beams are.
Simple model of the electrooptic effect

The birefringence changes censed by external force like stress, magnetic or electric field is called the induced birefringence.

The change in birefringence inducted by electric field is called electrooptical effect.

For certain materials $n$ is a function of $E$, as the variation is only slightly we can Taylor-expand $n(E)$:

$$n(E) = n + a_1 E + \frac{1}{2} a_2 E^2 \ldots$$

(1)

where $n = n(0)$, $a_1 = \frac{\partial}{\partial E} n|_{E=0}$, $a_2 = \frac{\partial^2}{\partial E^2} n|_{E=0}$.

Lets introduce the electrooptics coefficient like, as

$$r = -\frac{2a_1}{n^3}, \quad R = -\frac{a_2}{n^3}.$$  

(2)

Then the Taylor-expand from Eq.1 can be written as

$$n(E) = n - \frac{1}{2} r n^3 E - \frac{1}{2} R n^3 E^2 \ldots$$

(3)

Electrooptic coefficients $r$ and $R$ were taken as

$$\frac{1}{n(E)} = \frac{1}{n} + rE + RE^2$$

(4)

Using Taylor series from Eq.3 we can consider two different case:

- $R \ll r$
- $r = 0$

I. $R \ll r$

For $R \ll r$ series from Eq.3 is given by

$$n(E) = n - \frac{1}{2} r n^3 E$$

(5)

In that case we are talking about Pockels effect and $r$ in Eq.5 is called Pockels coefficient or linear electrooptics coefficient. Typical magnitudes of the $r$ coefficients are $10^{-12} \, \text{m/V}$. 
II. $r = 0$

When $r = 0$ then Taylor-expand from Eq.3 can be written as

$$n(E) = n - \frac{1}{2} R n^3 E^2$$

(6)

Therefore changes of refractive index does not depend on sign of electric field. In such case we are talking about Kerr effect or quadratic electrooptic effect. $R$ is called Kerr coefficient or quadratic electrooptic coefficient. Typical magnitudes of the $R$ coefficients are $10^{-18}$-$10^{-14} \ m^2/\sqrt{\text{V}}^2$ in crystals and $10^{-22}$-$10^{-19} \ m^2/\sqrt{\text{V}}^2$ in liquid.

Kerr effect occurs in crystals with symmetry center and without it. In crystals without symmetry center also Pockels effect occurs, which is much stronger then Kerr effect in such crystals. That's why in that crystals (without symmetry center) Kerr effect can be ignore.