

## Extrinsic Chirality: Optical Activity in Non-Chiral Materials

**It is a widely believed myth that only twisted materials can twist the polarization state of light. Our observation of strong and tunable polarization rotation in non-chiral metamaterials has not only various potential applications but also profoundly questions analytic techniques used in chemistry and other disciplines.**

Optical activity, that is the ability to rotate the polarization state of light, is one of the most fundamental phenomena of electrodynamics. It was discovered by F. Arago in 1811 and through the efforts of several generations of researchers it was linked to the three-dimensional property of some molecules and crystals known as chirality. Any object that is different from its mirror image is 3D-chiral, e.g. our hands, sugar-molecules or helices, see Fig. 1 (a). Now optical activity is widely used as a signature effect to identify chiral structures in analytical chemistry, biology and crystallography. Optical activity is even being used to detect life forms in space missions, as chiral molecules – like proteins or DNA – can be found in all life forms on earth.

It is not widely known that optical activity can also occur in structures that are not chiral at all, a finding of fundamental importance for the diagnostic applications mentioned above. The possibility of optical activity in non-chiral materials has been predicted by Bunn [1] in 1945 and was first observed in liquid crystals [2], however, it was long believed to be a weak and insignificant effect. Recently we have shown that optical activity in non-chiral structures is of practical importance as it can be just as strong as in chiral materials [3, 4].

Of course, rotation of the state of polarization can only occur if the polarization state can “know” whether it should rotate to the left or right. Thus mirror-experiments, which must lead to rotation in opposite directions, must be different from each other. Importantly, this mirror-asymmetry does not have to be an intrinsic property of the material [Fig. 1 (a)], but it can also arise extrinsically from the mutual orientation of incident beam and material structure [Fig. 1 (b)]. We have termed the latter type of mirror-asymmetry “extrinsic chirality”.

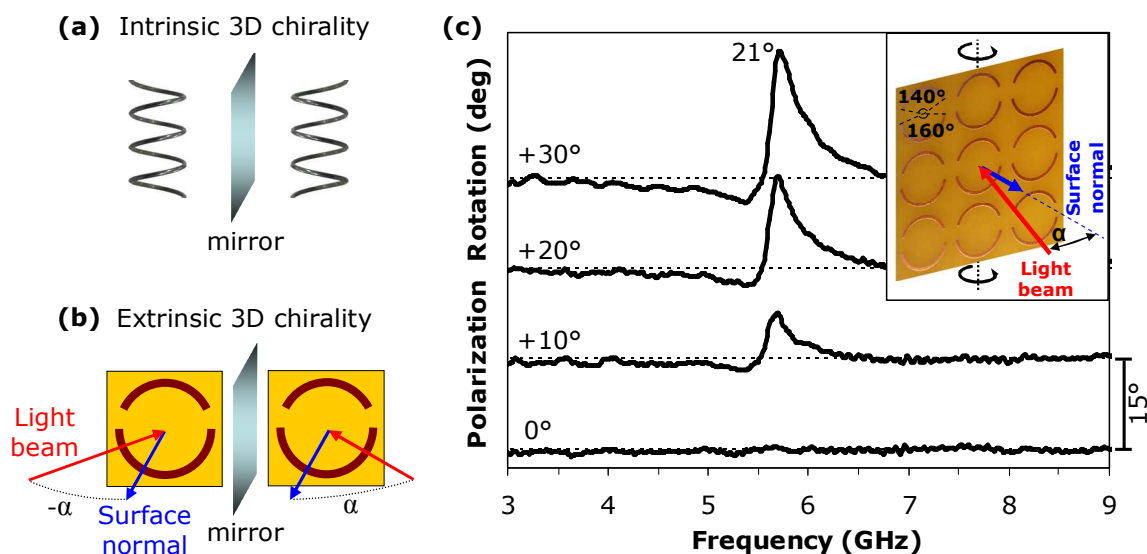


Fig. 1: (a) Example of intrinsically chiral structures: helices of opposite handedness. (b) Extrinsically chiral arrangements of opposite handedness. Here chirality arises from the mutual orientation of light beam and structure. (c) Measurements of optical activity due to extrinsic chirality for different angles of incidence between 0° and 30° (adapted from [4]). The structure is a non-chiral metamaterial with a 15mm square unit cell.



Apart from optical activity, extrinsic chirality also leads to different transmission levels for left and right circular polarizations. Both effects can be very strong in planar metamaterials. As they depend on the direction of the incident wave, they can be easily tuned. They are “switched off” at normal incidence, while opposite angles of incidence correspond to opposite signs of the effects.

Extrinsic chirality has potential applications in polarization control and vibration sensors and recent research shows that strong optical activity due to extrinsic chirality may even lead to negative refraction [3].

### References

- [1] C. W. Bunn, *Chemical Crystallography* (Oxford University Press, New York, 1945), p. 88.
- [2] R. Williams, *Phys. Rev. Lett.* **21**, 342 (1968).
- [3] E. Plum, X.-X. Liu, V. A. Fedotov, Y. Chen, D. P. Tsai, and N. I. Zheludev, *Phys. Rev. Lett.* **102**, 113902 (2009)
- [4] E. Plum, V. A. Fedotov, and N. I. Zheludev, *Appl. Phys. Lett.* **93**, 191911 (2008)