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FARADAY EFFECT EXPERIMENT - KSCIFEE

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FARADAY EFFECT EXPERIMENT

1. Key Concepts

- Optical activity
- Polarization
- Faraday rotation
- EM field interaction
- Verdet's constant

2. Introduction

Michael Faraday was the first to discover, in 1845, the physical phenomenon linking light and magnetism. He observed that the plane of polarization of light rotated when a magnetic field was introduced in the same direction as the path of the light, when light passed through a transparent dielectric medium. This effect came to be known as the Faraday Rotation or Faraday Effect. Applying a magnetic field to the dielectric medium causes it to exhibit circular birefringence (birefringence is the optical property of a material having a refractive index that depends on the polarization and propagation direction of light). Birefringent materials split light into ordinary and extraordinary rays. In circular birefringent materials, these rays have the additional property of being circularly polarized with opposite rotations. Different indices of refraction exist for the left and right circularly polarized light. As a result, these rays propagate at different speeds through the medium. The two rays combine at the end, yielding a ray that is offset in polarization from the incident ray.



Figure 1: Michael Faraday observing rotation of plane of polarization due to magnetic field. Source: Cosmos 2.0, The Electric Boy

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3. Objective

- Observe the effect of a magnetic field on plane of polarization of polarized light as it passes through a dispersive medium.
- Measure the Verdet's constant of a given dispersive material.

4. Theory

Mathematical relation between the angle of rotation(ϕ) of polarization axis and the magnetic field is given by

$$\phi = V BL$$

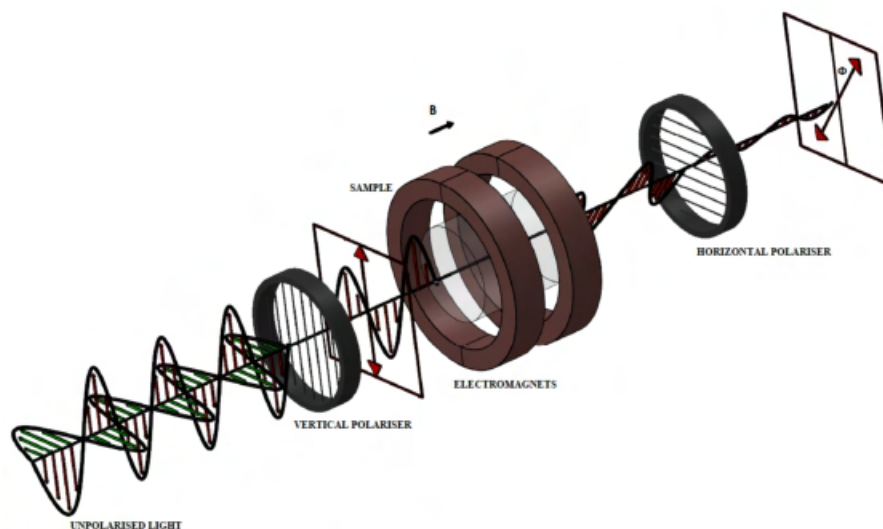
Where,

V is the Verdet's constant,

L is the length of the dispersive medium

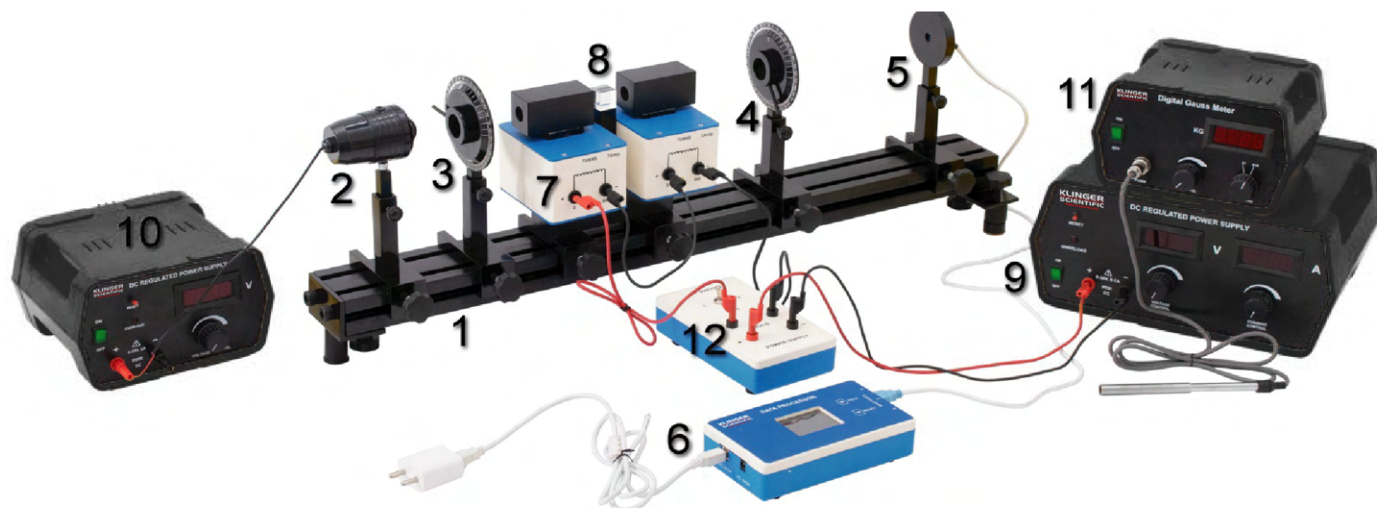
B is the magnetic field intensity.

The constant of proportionality is called the Verdet's constant, named after the French physicist Emile Verdet. It describes the strength of the Faraday effect for a given material. The unit of Verdet's constant is radian per tesla meter [rad/Tm]



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5. Equipment

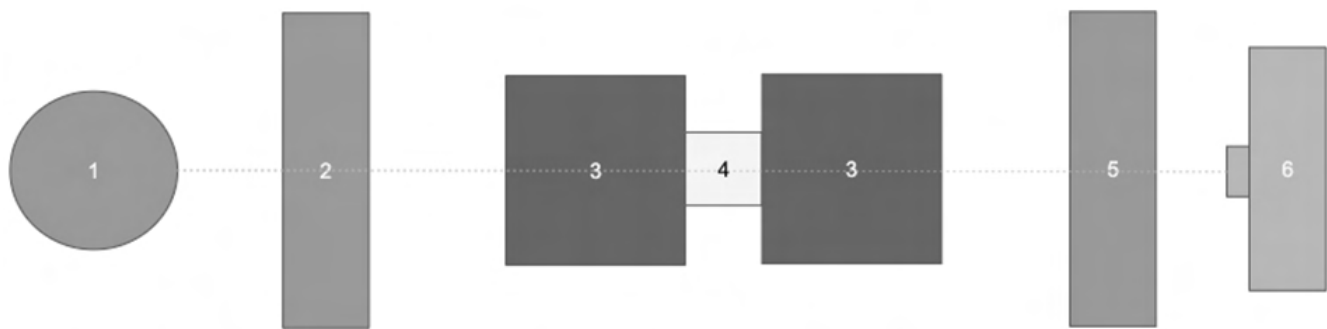


S.No	Equipment	Item Code	QTY
1	Optical Bench Set 0.8m	KSCIOB1	1
2	Light Source Holder	KSCIHA001	1
3	Polarizer Holder	KSCIHA004	1
4	Analyzer Holder	KSCIHA006	1
5	Light Sensor Holder	KSCIHA510	1
6	Data Processor	KSCIDP1	1
7	Electromagnet Set Assembly	KSCIUP025	1
8	Glass Block 20 x 20 x 20 mm	KSCIAC004	1
9	Power Supply for Electromagnet 0-30V,7A	KSCIPS61035D/7	1
10	Power Supply for Light Source 0-15V,2A	KSCIPS61022D/2	1
11	Gauss Meter	PH93225G	1
12	DP Switch	DP	1

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6. Experimental setup

Block diagram of the setup: 1. Light source with collimator; 2. Polarizer; 3. Electromagnets; 4. Dielectric medium (sample); 5. Analyzer; 6. Light sensor



7. Safety Instructions

- Components like optical bench, electromagnet setup, power supplies are heavy. Take adequate safety measures when handling them.
- The power supply for the electromagnet is a high current power supply. Do not use any non- insulated wires. Do not touch any unshielded electrical terminals. Take adequate safety steps.
- The electromagnet setup will be hot when powered ON. Do not touch them with bare hands when in use. Give adequate time for the coils to cool down before handling them.
- Do not increase or decrease the current through the coils suddenly. Do it gradually always.
- Do not keep the power supply of the coils ON for more than two minutes continuously.
- Glass sample is fragile. Handle it with care.
- Use only the power adapter provided in the package for powering up the data Processor.

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- Place the optical bench on a stable horizontal surface such as a sturdy table top and make sure the bench is parallel to the horizontal surface.
- Mount the light source securely on the upright, place the upright on the optical bench and lock the slide screw on the slider.
- Mount the polarizer stage on the upright, place it adjacent to the light source (along the optical path) and lock the slide screw on the slider.
- Place the U- core jig of the electromagnet setup on the optical bench adjacent to the polarizer and secure it to the optical bench.
Caution: the jig is heavy, take adequate care to ensure safety.
- Insert the electromagnet coils into the U-core setup.
- Place the bored pole pieces on the U-core, place the glass sample in between them. Make sure there is no gap between pole pieces and the glass sample
- Mount the analyzer on the upright, place it adjacent to the electromagnet setup and lock the slide screw on the slider.
- Mount the light sensor on the upright and place it adjacent to the analyzer. Connect the light sensor to the data processor.

7.1 Electrical setup

The experiment requires a four electrical main connections for the following.

Sl. No	Equipments
1.	Power Supply for light source
2.	Power Supply for Electromagnet
3.	Gauss Meter
4.	Adapter for Data Processor
5.	DP Switch

- Connect the light source to the appropriate power supply. Make sure that the polarities are appropriate.
- Connect the coils of the electromagnet and the ammeter in series to the high current electromagnet power supply. The electrical connections for the electromagnet setup is shown in the figure 5.

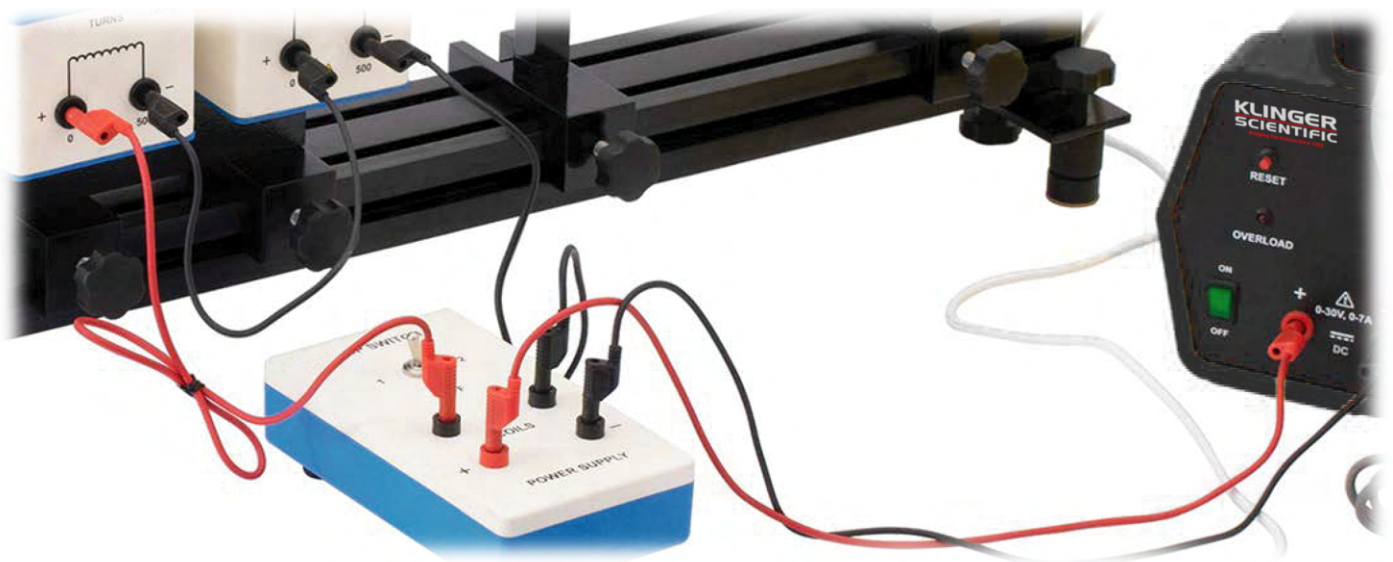
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- Connect the light source to the appropriate power supply. Make sure that the polarities are appropriate.



- Connect the coils of the electromagnet in series with the help of DP switch to the high current electromagnet power supply 30V , 7Amp at DC socket
- DP switch reverse the polarity of the electromagnet or we can say reverse polarity of coil current with the help of toggle switch given without changing of the connections manually.
- DP switch remains off when toggle switch is at center position.

Note: The maximum coils current under permanent use is 7 Amp. Do not operate for more than 15 minutes to prevent damage to coils by overheating.



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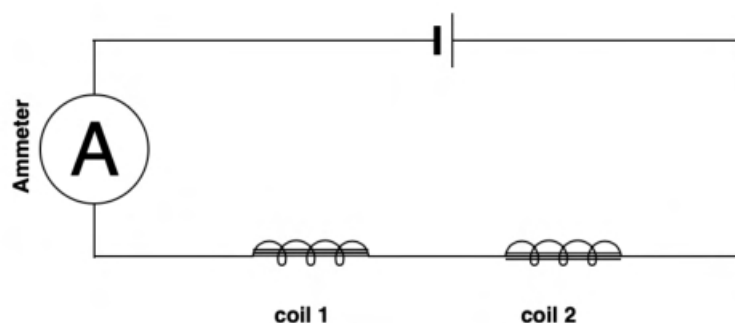


Figure 5: Electrical connections for the electromagnet setup

7.2 Procedure for optical alignment

- Keeping the coil OFF, turn ON the light sensor and adjust the heights of light source, polarizer, analyzer and light sensor such that the light passes through the polarizer, pole pieces, the analyzer and falls exactly on the light intensity sensor. Check the light sensor value to ensure the optical alignment.
- Rotate the analyzer and check the light intensity values for different angles of rotation of the analyzer. Record the positions of analyzer at which maximum and minimum values of light intensities are observed.
 1. The light intensity is maximum when the analyzer is in parallel orientation with the polarizer.
 2. The light intensity is minimum when the analyzer is in perpendicular orientation with the polarizer.
- Keeping the coil OFF, rotate the analyzer such that the value of the light intensity indicated by the light sensor is between the maximum and the minimum values previously observed. Note down the Light sensor value as (L-ref) and also the analyzer angle as (A-ref). (L-ref - Light Reference) (A-ref - Angle Reference). L-ref values may vary slightly based on the ambient light conditions. L-ref is not absolute. It is advisable to record it during every trial of the experiment.

Note: Do not disturb the positions of the components in the setup after the optical alignment is complete.

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8. Experiment

8.1 Calibration of magnetic field

1. Place the pole pieces 20 mm apart. Mount the hall probe on its stand and connect it to the Gauss Meter. Adjust the position of the stand such that the tip of the hall probe is precisely at the midpoint between the two poles and make sure that hall probe is perpendicular to the magnetic field direction.

Caution: Do not bring any electronic gadgets near the electromagnet unless specified.

2. Ensure that all the electrical connections are in order.

Caution: Since the current through the coils is large, take adequate safety measures and not touch any live wires.

3. Vary the supply current from 1A to 7A in uniform step of 1A. Record the magnetic field strength between the pole pieces at each step. Plot a graph of supply current vs magnetic field strength.

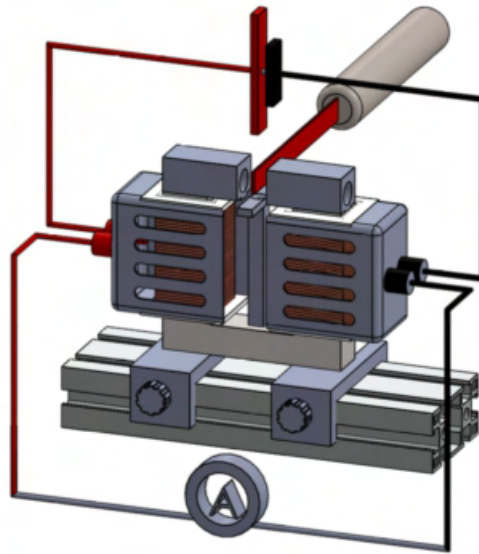
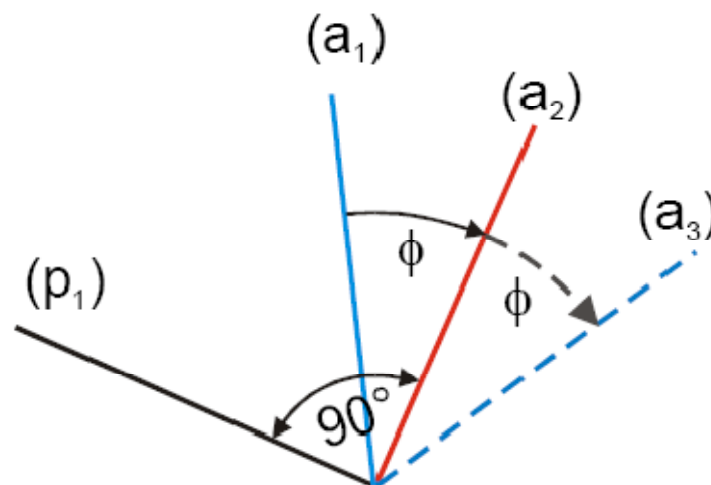


Figure 6: Setup for calibration of magnetic field

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8.2 Rotation of polarization angle (ϕ) as a function of magnetic field (B)

- Switch ON the light source.
- Align the flint glass square between the bored pole pieces.
- Set the analyzer to 0° position & find the intensity b/w maximum & minimum ie. at 45°
- Note down the above light intensity value.
- Set the desired magnetic field with the help of power source connected to the coils & gradually increase the current.
- As the light passes through the magnetic field, note down the light sensor value
- Rotate the analyzer gently till the light sensor indicates value before magnetic field. This gives the angle of rotation. Note down the angle of rotation
- Now, reverse the polarity of the magnetic field without changing the magnet current with the help of DP switch
- When the polarity is reversed the double angle of rotation 2ϕ is measured



Measuring the doubled angle of rotation 2ϕ by reversing the polarity of the magnetic field.

ϕ : angle of rotation of the polarization plane

(a_1) : analyzer position at the start

(a_2) : polarization plane of the light after passing through the flint glass square in both experiments.

(p_1) : polarizer position for the first magnetic field setting.

(a_3) : analyzer position after reversing the polarity of the magnetic field.

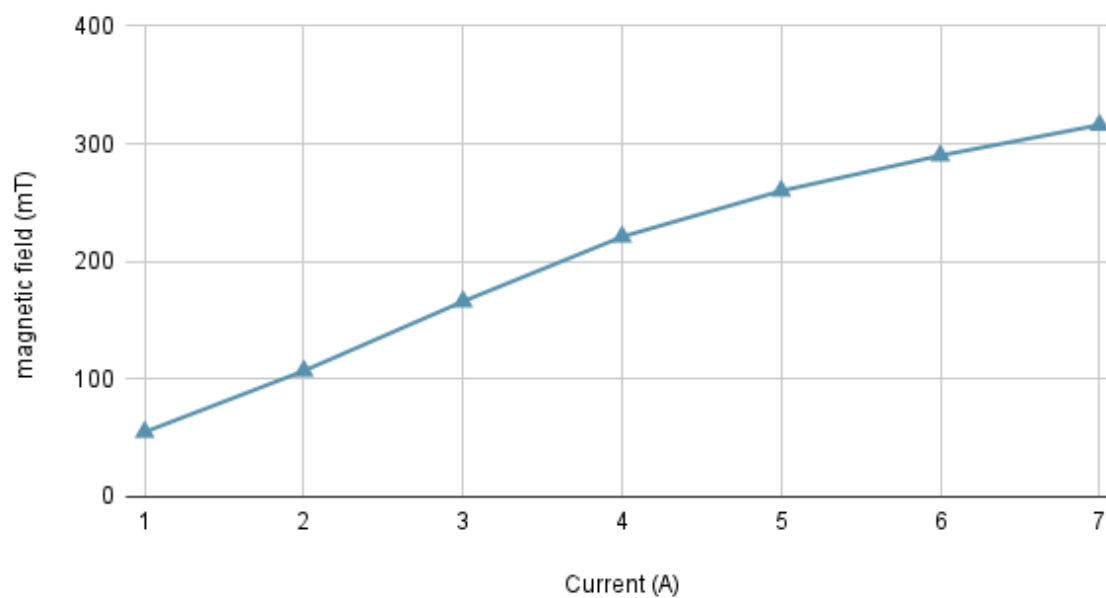
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9. Sample Measurements

9.1 Calibration of magnetic field results

Current (A)	Magnetic field between the poles at separation of $d = 20$ mm (mT)
1	55
2	107
3	166
4	221
5	260
6	290
7	316

magnetic field (mT) vs. Current (A)



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9.2 Rotation of polarization angle (ϕ) as a function of magnetic field (B)

A sample measurement, for the glass sample (SF 6) of length (L) = 0.02 m is given below.

Current I (in A)	Magnetic Field B (in mT)	2ϕ (in rad)
7	316	0.283

9.3 Computation of Verdet's constant

The Verdet's constant of the given material is computed using the relation

$$V = \phi/BL$$

Using the values of B, ϕ and L. We can compute the Verdet's constant for the given glass sample. (An example is shown below)

- B = 316 mT
- ϕ = 0.1415 rad
- L = 0.02 m

The Verdet's constant for this combination is 22.386 rad/Tm

10. Applications

10.1 Fiber optics communication

Optical diode/optical isolator : An optical isolator is a passive magneto-optic device that allows light to travel only in one direction. They are used to protect a laser source from back reflections or signals that may occur after the isolator (as the back reflections can damage the laser source). Optical feedback can cause a source to become unstable resulting in amplitude fluctuation, frequency shift, mode hopping.

Working of an optical isolator:

Forward mode: Laser light, either polarized or unpolarized, enters the input polarizer and becomes plane polarized. The Faraday rotator will rotate the plane of polarization (POP) by 45° in the positive direction. Finally, the light exits through the output polarizer which has its axis at 45°. Therefore, the light leaves the isolator with a POP of 45°.

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Figure 8: Optical isolator, source; SK photonics

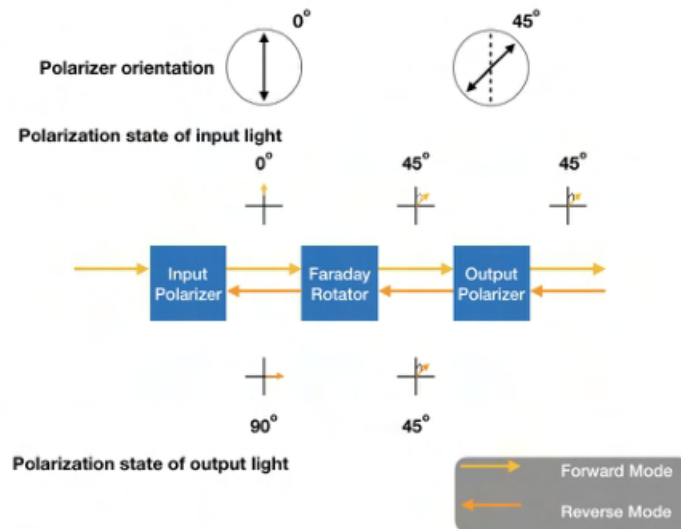


Figure 9: Components of a optical isolator

Reverse mode: Light traveling backwards through the isolator will first enter the output polarizer, which polarizes the light at 45° with respect to the input polarizer. It then passes through the Faraday rotator, and the POP is rotated another 45° in the positive direction. This results in a net rotation of 90° with respect to the input polarizer, and thus, the POP is now perpendicular to the transmission axis of the input polarizer. Hence, the light will either be reflected or absorbed.

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10.2 Astrophysics

Faraday rotation is used to measure the magnetic field in the ISM (interstellar medium) in the vicinity of AGN (active galactic nuclei) and pulsars. The rotation measure (RM) provides us a measure of an average of the magnetic field parallel to the line of sight, as a function of the electron density in the line of sight.

EM wave emission (radio emission) from astronomical objects is often polarized. If the radiation is linearly polarized with the electric-field vectors oriented perpendicular to the projection of the magnetic field in the emission region, with respect to the plane of the sky. The direction of the polarization may change as the EM wave (radio waves) propagates through the interstellar medium due to Faraday rotation.

With the information of the electron density (and its spatial distribution) along the line of sight, the RM provides an estimate of the parallel magnetic field in the regions with high electron densities. It has been observed that, the polarization angle of radio waves will rotate by an angle 57° , when they travel through ISM of magnetic field intensity of a few μG and electron densities of (n_e of 1 cm^3).

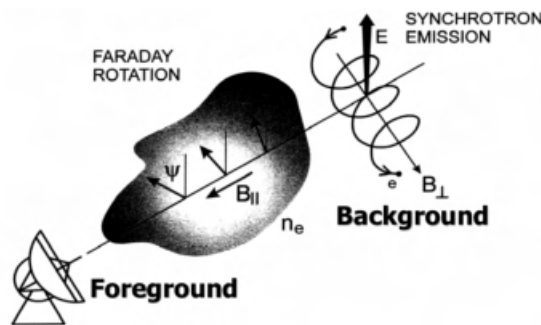


Figure 10: Faraday Rotation in ISM

$$RM = 0.81n_e B_{||} L$$

$$\Phi = \Phi_{\text{int}} + RM \lambda^2$$

Note: RM: rotation measure, that is measured in $[\text{rad}/\text{m}^2]$, n_e : electron density, that is

measured in $[\text{cm}^{-3}]$, $B_{||}$: magnetic field parallel to the line of sight, that is measured in $[\mu\text{G}]$, L : distance in parsec, Φ : polarization angle and λ : wavelength of the radio wave.

Faraday rotation has wavelength dependency, utilizing this property, the astronomers compute RM that can be used to measure the magnetic fields around the AGN, pulsars and along the line of sight (ISM).

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