

INTERFERENCE & DIFFRACTION (Using a Laser)

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You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/intdif.pdf>

Light can be considered to be an electromagnetic wave and different rays of light can interfere with each other. If two waves are exactly “in phase”, they will reinforce each other. This is called *constructive interference*. In this case, the difference in phase angle is 0° , 360° (one full wavelength), or 720° (two wavelengths), etc.

If, however, they are exactly “out of phase”, they will cancel each other. This is *destructive interference*. If their phase relationship is somewhere between these two extremes, some intermediate result will be observed. In this case, the difference in phase angle is 180° (half a wavelength) or 540° (one and a half wavelengths), etc.

The well-known phenomena of diffraction and interference are easily demonstrated and measured using a laser light source. Laser light is much more coherent than light from conventional sources. Coherence, which is the extent in time and/or space to which the beam of light is in phase with itself, is necessary for the observation of interference.

Several experiments are suggested:

- a) **Interference from a Double Slit system** (Thomas Young’s classic interference experiment)
- b) **Diffraction from a Single Slit**
- c) **Interference with Three or more Slit Systems** (When the number of slits intercepting the beam becomes large, the system is called a *diffraction grating*.)

D. Halliday, R. Resnick, and J. Walker. Fundamentals of Physics, 6th edition. Wiley, 2003.

E. Hecht. Physics (Calculus). Brooks/Cole, 1996.

REFRACTION OF LIGHT

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☞ You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/refraction.pdf>

An important optical property of any transparent material is the **refractive index (n)**, the ratio of the speed of light in a vacuum (c_{vac}) to the speed of light in the transparent material (v_{mat}):

$$n = \frac{c_{\text{vac}}}{v_{\text{mat}}} \quad (1)$$

Light always travels more slowly in a material than in a vacuum, so the refractive index is always greater than 1.0.

Although light usually travels in straight lines through optical materials, something different happens at surfaces. Light is bent as it passes through a surface where the refractive index changes, for example, as it passes from air into glass. The amount of bending depends on the refractive indexes of the two media and the angle at which the light strikes the surface between them.

If light passes from a medium with a lower n (n_1) to one with a higher n (n_2) the light is bent toward the normal. If the light passes from n_2 to n_1 it is bent away from the normal. **Snell's Law** determines the amount the light is bent, and for the passage from air to glass shown in Figure 1 it is given by:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad (2)$$

At the upper surface, θ_1 is called angle of incidence and θ_2 the angle of refraction. The goal of this experiment is to use Snell's Law to determine the index of refraction of a glass prism, as well as the refractive index of a liquid.

MICROWAVE OPTICS

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☞ You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/microwav.pdf>

The Microwave Optics set is essentially a sophisticated toy that can be employed to illustrate, in a qualitative and often quantitative fashion, many of the phenomena associated with wave propagation in general and electromagnetic wave propagation (including polarization) in particular.

In this experiment you should make qualitative observations to the best of your, or the apparatus', ability. There are several possible experiments you can do with the apparatus:

- Polarization
- Law of Reflection
- Standing Waves
- Arrangement in Michelson Interferometer
- Thickness of a Thin Film
- Single Slit Diffraction
- Double Slit Diffraction
- Index of Refraction

Your work will be counted as one to three weights, according to the following guidelines:

- One weight: experiments 1-3.
- Two weights: experiments 1-6.
- Three weights: all experiments.

D. Halliday, R. Resnick, and J. Walker. Fundamentals of Physics, 6th edition. Wiley, 2003.

R.A. Serway. Physics for Scientists and Engineers, 4th edition, vol. 2. Saunders College Publ., 1996.

E. Hecht. Physics (Calculus). Brooks/Cole, 1996.

OPTICAL ACTIVITY



 You may find the complete guide sheet at <http://faraday.physics.utoronto.ca/IYearLab/OpticalActivity.pdf>

“Optical Activity” refers to the property of some materials, particularly biological ones, to rotate the plane of polarization of light waves. In this experiment you will

- explore the phenomenon of polarization of light and
- study the optical activity of some biological materials.

The experiment will be counted for two weights.

Background information on the polarization of light may be found in virtually any first year university physics textbook.

Information on the optical activity of biological molecules may be found in:

Mikhail V. Vol'kenshtein. **Molecules and Life**. Plenum/Rosetta, 1974. p. 91.

(ISBN 0-306-20007-4)

Russell K. Hobbie. **Intermediate Physics for Medicine and Biology**. Wiley, 1978.

p. 359. (ISBN 0-471-03213-0)

ELECTRON DIFFRACTION

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You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/elecdiff.pdf>

This experiment is a demonstration of the wave nature of the electron and provides a confirmation of the de Broglie relationship:

$$\lambda = \frac{h}{p}$$

where λ is the electron wavelength, h is Planck's constant, and p is the electron momentum. It also provides an introduction to the use of diffraction in the analysis of crystals.

The guide sheet outlines a method for the analysis of cubic crystal forms, this being useful to you for interpreting the transmission diffraction pattern produced by scattering electrons off a thin film target of polycrystalline aluminum. The apparatus also contains samples with hexagonal structures. These are pyrolytic graphite targets and are available both as single crystals and in polycrystalline form.

We suggest you do a full analysis of the polycrystalline aluminum. The diffraction pattern will look like a series of concentric rings resulting from many spots very close together. From the diffraction pattern one can determine the type of crystal structure and the lattice parameter. You should also look at a single crystal of pyrolytic graphite, identify the pattern and obtain the lattice constant.

D. Halliday, R. Resnick, and J. Walker. Fundamentals of Physics, 6th edition. Wiley, 2003.
Electron Diffraction Tube (Instruction Manual) - Welch Scientific Co. Cat. No. 2639. A copy is available at the Resource Centre.

OPTICAL FIBERS

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You may find the complete guide sheet at
http://faraday.physics.utoronto.ca/IYearLab/optical_fibres.pdf

Optical fibers offer a faster, clearer, and more efficient method of transmission of information than copper wires. They are lighter, cheaper and provide a better signal quality than any other cable alternative. In the field of medicine, the ability to insert optical fibers inside small hollow tubes that are pushed through small incisions in the body has provided a number of successful surgical procedures that do not call for large cuts of tissues.

In the first part of this experiment you will learn how an optical fiber is built and how the fiber geometry and mechanical properties may influence the signal transmission. You will also prepare the fiber ends to ensure an optimal coupling with a light source and a detector. You will then investigate some of the physical properties of a fiber such as the index of refraction and speed of light propagation.

Optical scattering and absorption usually reduce the efficiency of optical power transmission through an optical fiber. You will study the attenuation along a fiber as a function of distance and you will determine the specific attenuation coefficient of the fiber material.

In this study, you will also get familiar with a modern type of oscilloscope, a digital Tektronix model. A number of preliminary exercises are recommended before you start using the oscilloscope in your measurements.

D.R. Goff. *Fiber Optic Reference Guide, second edition*. Focal Press, 1999.

E. Hecht. *Understanding Fiber Optics*. Sams, 1989.

Projects in Fiber Optics (Applications Handbook), Newport Corporation (1986). A copy is available at the Resource Center.

SPECTRA

You may find the complete, interactive guide sheet of this experiment at <http://faraday.physics.utoronto.ca/IYearLab/Intros/Spectra/Spectra.html>

ABSTRACT

Atomic systems can be studied by observing the electromagnetic waves they emit. Suppose an evacuated gas tube is filled with some gas. If a high voltage is applied between metal electrodes in the tube, there will be an electric current in the gas which will determine the emission of light with specific colours (characteristic wavelengths). A prism spectrometer uses the principle of light diffraction and “breaks” the light into single colours or spectral lines that can be analyzed.

In this experiment you will calibrate a prism spectrometer and use this calibration curve to obtain a several numerical results.

You can study the spectral lines of atomic hydrogen (Balmer series) and determine the Rydberg constant R_H .

You can also use the calibration curve to identify an “unknown” gas by measuring its spectral lines. The apparatus consists of a spectrometer and a variety of spectral “tubes” which are the sources of the line spectra to be studied.

GAMMA-RAY SPECTRA

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☞ You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/gammaray.pdf>

In this experiment, you will investigate the properties of gamma-ray spectra as observed with a scintillation counter (a sodium iodide, NaI(Tl) scintillation tube and a multichannel analyser). You will calibrate the detection system using radioactive sources with gamma-rays of known energy (available at the Resource Centre) and then measure the energy of gamma-rays from an unknown source.

If you were to place a mono-energetic source of gamma-rays (e.g. ^{137}Cs) near a scintillation detector, you would expect, ideally, a spectrum which is a single *photo peak* caused by *the photoelectric effect* in the NaI crystal. However, other processes take place by which the gamma-ray energy is absorbed, thus altering the spectrum shape.

When a gamma-ray enters the crystal, instead of ejecting an electron from an atom, it may collide with a (more or less) free electron giving up only a part of its energy to the electron. If the scattered gamma ray escapes from the crystal then only part of the energy of the original gamma ray is left with the electron in the crystal. This results in a smaller amount of light and it is as if a gamma ray of smaller energy were completely absorbed in the crystal. Simple kinematics (conservation of energy and momentum) forbids the electron from receiving more kinetic energy than *the Compton edge*.

Any photons scattered into the crystal by shielding material, table tops, holders etc., will have less than the full energy of the original gamma-ray and this process will give rise to a general distribution of pulses (*Compton plateau*) on the lower energy part of the spectrum and a bump called *the backscatter peak*.

After doing a number of preliminary exercises in nuclear counting, you will analyse the gamma-ray spectrum of a ^{137}Cs source and will learn other techniques (gain-energy calibration; measurement of detector resolution; finding the sum peak; non-destructive analysis by X-ray fluorescence). Analysis of the gamma-ray spectrum of an unknown source is possible.

K. Siegbahn. *Alpha, Beta and Gamma-Ray Spectroscopy*, Vol. I. Chapters. 5, 8A.
Table of Gamma-Ray and X-Ray Energies. (Available from the Resource Centre.)

H. Enge. *Introduction to Nuclear Physics*. Chapter 7.

INSTRUCTION MANUAL for "THE NUCLEUS" model Quantum 8 Multichannel Analyser. (Available from the Resource Centre.)

RADIOACTIVITY IN THE AIR

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You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/radair.pdf>

This experiment involves filtering atmospheric air using the provided blower and then measuring and identifying the radioactive substances deposited on the filter (available at the Resource Center). The blower is placed outside. The results, both the amount and type of radioactivity, generally depend on the length of time for filtration and on the weather conditions on a given day.

The experiment is carried out with a Geiger-Muller counter. One should therefore first find the high-voltage range where the counting rate shows little variation with the applied high voltage. This is best done by plotting counting rate vs. high voltage and work in the middle of this range.

Following the Chernobyl accident on April 26, 1986 air samples taken here in the Physics Department were found to contain ^{137}Cs , ^{134}Cs , and ^{131}I . These products arrived quite suddenly on May 11, 1986. With the ban on atmospheric testing being more or less successful and with the current absence of nuclear accidents, the radioactivity you will measure is probably completely natural and has been in the environment for billions of years.

The three natural radioactive families you are likely to observe originate with the isotopes ^{238}U , ^{232}Th , and ^{235}U . All three occur naturally with half-lives greater than the age of the earth. They each decay through a long chain of radioactive daughters, ending with stable ^{206}Pb , ^{208}Pb , and ^{207}Pb , respectively. The identification of the radioactive isotopes in your sample hinges on two criteria: the measured half-life and the type of radioactivity, alpha, or beta.

M. Sternheim and J. Kane, *General Physics*. See the discussion on half life.

P. Evans. *The Atomic Nucleus*. pp. 518-522.

M. Segre. *Nuclei and Particles*. p. 156.

SCATTERING

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You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/scatteri.pdf>

The principal methods of investigating phenomena on a nuclear scale ($\sim 10^{-15}$ m) involve projecting particles into the region of the nucleus and observing what comes out. One process that is commonly seen in using these techniques is scattering, whereby the incident particle gets bounced back out, having had its momentum and maybe its energy changed.

This experiment is a model experiment. It is a *simulation* on a larger scale, in two dimensions, of a wide range of experiments particularly in atomic, nuclear, and particle physics in which a beam of particles is scattered from a target particle at measured angles. From this information the effective area or cross-section of the target is deduced.

This lab may be used for either 2 or 3 weights according to the guidelines given below:

2 weights: check validity of Equation 1 (30-40 scattering events are suggested.)

3 weights: check Equation 1 + check validity of Equation 2. See the complete description of this experiment. (150 or more scattering events are suggested.)

Small ball bearings are shot from a simple air gun towards a rigid, cylindrical, plastic target. The angles at which they are scattered are found by recording the impacts of the ball on the wall of a large cylindrical tank which surrounds the target. The scattering process in the model is a simple elastic collision and it is not difficult to show that

$$\cos \frac{\theta}{2} = \frac{b}{(R+r)} \quad (1)$$

Note that in your experiment the angles $\theta \approx \phi$. In this experiment the impact parameter b can be varied systematically, but in an atomic or nuclear scattering experiment it cannot. One can, however, predict the probable number of scattering events that have a given b .

D.J. Prowse. *American Journal of Physics* **29**, 854 (1961). Reports a description of the design of this experiment. Copies are available at the Resource Centre.

X-RAY AND γ -RAY ABSORPTION IN MATTER

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☞ You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/xapsorpt.pdf>

An X-ray or gamma-ray (γ -ray) travelling through matter can interact with the neighbouring atoms, often leading to its absorption. The probability of such an interaction is linked to the atomic structure of the material and sometimes to its molecular structure. The whole field of radiology rests on this variation in the X-ray or γ -ray absorbing power of different elements, namely, the calcium of bones and the carbon and oxygen of soft tissues.

The aim of this experiment is to study the absorbing power, at different X-ray or γ -ray energies, of a variety of materials.

The experimental arrangement includes: scintillation detector, Picker scaler (power supply and counter for scintillation tube), gamma source, collimator, and different absorbing materials.

For a monoenergetic, collimated X-ray or γ -ray beam, the intensity of radiation passing through an absorber is:

$$I(x) = I_0 e^{-\mu x}$$

where $I(x)$ is the transmitted beam intensity,

I_0 is the beam intensity if no absorber is inserted between source and detector,

μ is the linear attenuation coefficient (depends on material and photon energy), and

x is the thickness of the absorber.

Measure the count rate for different thicknesses of a given material. Repeat for different materials.

Relate the results semi-quantitatively to some material properties such as the density, atomic number, etc.

K. Siegbahn. *Alpha, Beta and Gamma-Ray Spectroscopy*, Vol. I. Chapters 5, 8A.

R.D. Evans. *The Atomic Nucleus*. McGraw-Hill, Toronto, 1955. pp. 711-718.

G.F. Knoll. *Radiation Detection and Measurement*, 2nd edition. John Wiley & Sons, Toronto, 1989. pp. 54-57 and 74-76.

e/m FOR AN ELECTRON

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You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/IYearLab/em.pdf>

This is a variation of the original experiment carried out by J.J. Thomson in 1895. The deflection of a charged particle moving in a magnetic field is clearly demonstrated.

A particle of mass m and charge e moving with velocity \vec{v} in a magnetic induction field \vec{B} will experience a force \vec{F} perpendicular to both \vec{v} and \vec{B} . If \vec{B} is constant and \vec{v} is perpendicular to \vec{B} , the particle will move in a closed circular orbit. The curvature of the electron orbit is:

$$\frac{1}{r} = \sqrt{\frac{e}{2m}} \frac{B}{\sqrt{V}}$$

where V is the accelerating voltage for the electrons.

In this experiment, the magnetic induction \vec{B} is generated by current flowing through a pair of Helmholtz coils. Note that each coil radius is equal to the separation between the coils. This configuration gives the minimum variation of B near the centre of the pair of coils.

The apparatus consists of a glass bulb containing an electron gun and hydrogen gas at low pressure. Electrons emitted by the hot filament of the gun are shaped into a beam by accelerating them through a specially shaped anode.

The beam of electrons becomes visible when the electrons have enough kinetic energy to excite the gas by collision. The collisions, however, are sufficiently rare that the beam is scarcely affected; a full, circular trajectory should be clearly visible. The bulb can be rotated to ensure the beams follow closed paths. Their diameters can be measured with the self-illuminated scale and plastic reflector provided.

R.M. Whittle and J. Yarwood. *Experimental Physics for Students*. p.274.

D. Halliday, R. Resnick, and J. Walker. *Fundamentals of Physics*, 6th edition. Wiley, 2003.

THE SPEED OF LIGHT

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/ You may find the complete guide sheet at
<http://faraday.physics.utoronto.ca/YearLab/SpeedofLight.pdf>

This experiment is a modification of Foucault's method of 1862 in which there is no requirement for the use of a concave mirror. Foucault achieved a measurement of the speed of light to an accuracy of $\pm 0.17\%$ using a baseline of only 20 m. Although the technique you use is similar, you can probably expect to achieve an accuracy $\pm 5\%$ in one afternoon's work. You will find, as did Foucault, that there is a limit to the accuracy achievable in a technique dependent on the measurement of the displacement of a light beam.

The other challenge of this experiment is the *isolve* of the problem of how to set-up an apparatus systematically. If you work out your systematic alignment carefully, you can perform the experiment easily. However, if you do not proceed systematically, you could spend days without achieving one observation.

The light source used in this experiment is a He-Ne laser. The light path includes a rotating mirror M_r , a spherical lens, two fixed mirrors M_i and M_o , a "scoop" mirror and a viewing scale.

J. Mulligan. "Some Recent Determinations of the Velocity of Light" *American Journal of Physics* 44, 960 (1976).

D. Halliday, R. Resnick, and J. Walker. *Fundamentals of Physics*, 6th edition. Wiley, 2003.