Studio Physics

Engineering Physics II

PHYS 214
Department of Physics
Kansas State University
Fall 2010

Studio Physics Laboratory Demonstrations and Numerical Problems

Success in physics is based on three elements: conceptual understanding, problem solving skills, and the concepts of measurement. Studio Physics has been created to integrate these three elements. It consists of you, your fellow students with whom you will interact, the instructors and a series of specially created laboratory demonstrations and accompanying numerical problems. Each of the laboratory demonstrations has been created to give tangible example to what may be considered standard problems in fundamental physics. These problems contain key concepts that reside at the core of physics. By solving problems and then experimenting with the real thing, the conceptual foundation of the problem will grow by example along with problem solving abilities. Moreover, quantitative measurement will, through experimental uncertainty, teach realistic expectations. Once exact agreement is deemphasized, the trends and functionalities will appear and conceptual understanding can again grow.

Your tasks for Studio Physics are straightforward. Problems for situations similar to these lab demonstrations will be given as the assignment for that day's work. These are best done the night before the Studio class. Many problems, which relate directly to the lab demonstrations, are included in this book. Your studio instructor may also assign some of these problems as in-studio group activities. Next, the lab demonstration should be performed, measurements made and trends in the data discerned. Numerical results and trends should be compared to the calculation.

Many of the laboratory demonstrations ask questions or suggest data manipulation procedures. These should be used as guides for further insight into the physics of the situation. Very important to this enterprise is your interaction with your lab partners to discuss the physics and procedures of the demonstration. With your peers, teach and be taught.

Integral to your studio experience is your lab notebook. Record your data and observations on what happened (right or wrong). Make graphs and straightforward conclusions, answer and perhaps pose questions. Keep it spontaneous and simple! A notebook is for notes, not refined dissertations.

Lastly, as you work on physics, remember to integrate as you learn the three basic elements of conceptual understanding, problem solving, and an appreciation how numbers can describe the physical world.

Acknowledgments: The creation of these laboratory demonstrations owes a great deal to Alice Churukian, William Hageman, Chris Long, Farhad Maleki, Corrie Musgrave and Jason Quigg. More recently, Peter Nelson, Dr. Kirsten Hogg, Dr. Rebecca Lindell and Professor C.L. Cocke have made valuable suggestions. This lab manual was revised during the Fall 2003 semester by Kevin Knabe, and during the Spring 2005 semester by Amit Chakrabarti. Dave Van Domelen has also contributed with minor revisions. This work was supported by a grant from NSF (CCLI) to Susan Maleki and Chris Sorensen.

Chris Sorensen
University Distinguished Professor

Amit Chakrabarti
Professor

Guidelines for Lab Notebooks in Studio

Observation is the essence of science, and controlled observation is experimentation. A Dutch proverb says elegantly: “Meten is Weten” which translates to: “measuring is knowing.” When you perform your lab work in Studio, controlled observation to measure and thereby know will be emphasized.

Integral to this experimental process is a written record of your experimental work. Your Lab Notebook is a working, written record of experimental work. It should contain sufficient information so someone else can understand what you did, why you did it and your conclusions.
Also, pragmatically, it is inevitable that the assessment of your experimental work in the Studio is largely based upon it.

The following is an outline of the expectations we have for the records you will keep in your Lab Notebooks.

Description of Experimental Work

1. The date should be recorded at the beginning of each session in the studio.
2. Each experimental topic should be given a descriptive heading.
3. A BRIEF introduction describing the purpose of the experiment, description of apparatus and experimental procedures should be included.
4. Schematic or block (rather than pictorial) diagrams should be included where appropriate.
5. Circuit diagrams should be included.

Records of Observations and Data

1. The lab notebook must contain the original record of all observations and data – including mistakes! Never erase ‘incorrect’ readings; simply cross them out in such a way that they can be read if need be. There is no such thing as bad data.
2. All relevant non-numerical observations should be clearly described. A sketch should be used whenever it would aid the description.
3. The nature of each reading should be identified by name or *defined* symbol, together with its numerical value and unit.

Tables

1. Observations and data should be gathered and tabulated whenever appropriate.
2. Each table should have an identifying caption.
3. Columns in tables should be labeled with the names or symbols for both the variable and the units in which it is measured. All symbols should be defined.

Engineering Physics II Studio
Table of Contents

21.1 Electrostatics 7
21.2 The Van de Graaf Generator 8
22.1 Electric Fields I 9
22.2 Electric Fields II 11
23.1 Gauss' Law and Field Magnitude 13
23.2 Gauss' Law and Flux 14
23.3 Gauss' Law, Gaussian Surfaces and Symmetry 16
24.1 Graphing Equipotentials 18
24.2 Field and Voltage in the Parallel Plate Geometry 20
25.1 Capacitor Charge and Energy Storage 21
25.2 Charging and Discharging a Capacitor 22
25.3 Dielectric Capacitors 23
25.4 Capacitor Circuits 24
27.1 Series and Parallel Resistor Combinations 26
27.2 Series Circuits 27
27.3 Parallel Circuits 28
27.4 A Kirchhoff Circuit 29
27.5 Real Batteries 30
27.6 RC Circuits 31
28.1 Force on a Current Carrying Wire in a Magnetic Field 33
28.2 A DC Motor (Torque on a Magnetic Dipole) 34
29.1 Amperes' Law 37
29.2 Magnetic Field of a Current Carrying Loop 39
29.3 The Solenoid 40
29.4 The Solenoid Continued 41
30.1 Induction 42
30.2 Induction and Lenz's Law 43
30.3 Electrical Generators 45
31.1 LC Oscillator 47
31.2 AC Circuit 49
32.1 Magnetic Materials 51
33.1 Polarization in Nature 52
33.2 Polarized Light 53
33.3 Refraction 54
33.4 The Prism 56
33.5 Fibers 59
34.1 Ray Optics 60
34.2 Mirrors 61
34.3 Lenses 62
34.4 The Telescope 63
34.5 The Microscope 64
35.1 Young's Double Slit Experiment 65
35.2 Thin Film Interference 67
36.1 Single Slit Diffraction 68
36.2 Circular Aperture Diffraction 69

36.3 Diffraction Grating..70
36.4 Diffraction..71
37.1 Time Dilation..73
38.1 The Photoelectric Effect..74
39.1 Line Spectra..76

Graphs

1. With graphs we often discover functionalities. Don't hesitate to graph your data or numerical results if you think it will help you see what's going on, even if it is not your "final," concluding result.
2. Graphs should be drawn directly into your lab notebook.
3. Each graph should have a descriptive caption. Axes of graphs should be labeled with the name or symbol for the quantity and its unit. Numerical values should be written along each axis.

Analysis and Results

1. The organization of calculations should be sufficiently clear for mistakes (if any) to be easily found.
2. Results should be given with an estimate of their uncertainty whenever possible. The type or nature of each uncertainty should be specified unambiguously.
3. Results should be compared, whenever possible, with accepted values or with theoretical predictions.
4. Serious discrepancies in results should be examined and every effort made to locate the reason.

Summary/Conclusions

1. A BRIEF summary should be written for each experiment.
2. The summary should report the results and contain a comparison with accepted values or with theoretical predictions. Any discrepancies should be mentioned.

21.1. Electrostatics

Lab Demonstration

Mess around with a number of simple electrostatic demonstrations. Rub a piece of PVC and a piece of acrylic with wool. Then:

- Show, using the electrometer, that these two plastics obtain different signs of charge.
- Attract an empty pop can and roll it across the table.
- Pick up small pieces of paper.
- Charge two pith balls that are attached to the same string.
- Deflect a thin stream of water.
- Charge the electrometer by directly touching the charged plastic rod to it. Then ground the electrometer by touching it with your hand. Where did the charge go?
- Charging by induction. With an uncharged electrometer bring the charged plastic rod near the metal sensing disk at the top. Touch the other side of the disk with your finger and as soon as the electrometer needle falls to zero deflection, remove the rod and your finger. What happens and why? What is the charge on the electrometer compared to that on the plastic rod?

Problems (5)

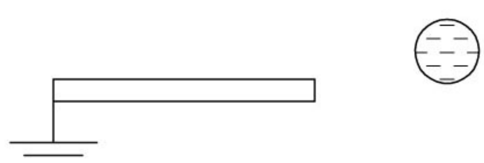
21.1.1. How many e^-'s would have to be removed from a neutral plastic rod to give it a charge of 1 nC?

21.1.2. What is the magnitude of the electrostatic force between two charged objects each having a charge of 1 μC and separated by 1 cm?

21.1.3. (a) Two small non-conducting spheres have a *total* charge of $+90.0\ \mu C$. When placed at a distance of 1.0 m apart, the force each exerts on the other is 16.2 N and is *repulsive*. What is the charge on each? (b) Two small non-conducting spheres have a *total* charge of $+90.0\ \mu C$. When placed at a distance of 1.0 m apart, the force each exerts on the other is 19.8 N and is *attractive*. What is the charge on each in this case?

21.1.4. If you bring a positively charged plastic rod near a small piece of paper on a table, the paper is attracted to the rod and can be lifted off the table. One explains this by saying that the piece of paper gets polarized in the presence of the positively charged rod, i.e., one side of the paper gets a net positive charge and the other side gets a net negative charge. The negative side of the paper is attracted by the rod. But there should be repulsion between the positive side of the paper and the positively charged rod as well. Why don't these attractive and repulsive forces cancel?

21.1.5. A negatively charged ball is brought close to a neutral isolated conducting rod. The far end of the conducting rod is then grounded while the ball is kept close. What will be the charge on the conducting rod (a) if the ground connection is first removed and then the ball taken away and (b) if the ball is taken away first and then the ground connection is removed?



21.2. The Van de Graaf Generator

Lab Demonstration

Run the Van de Graaf generator (VdG) to create large electrostatic charges.

- Insulate from the ground someone with long, dry hair and have them touch the upper globe of the VdG as it charges (i.e., discharge the VdG, touch your hand to the globe, then turn it on). Why does their hair stand on end?
- Try placing foil plates on the top of the VdG face down, then face up. Why do the reactions differ?
- Throw a spark. A spark results when the electric field ionizes or "breaks down" the air. The break down electric field of air is 3×10^{6} volts/m. Even if you haven't learned about fields and voltages yet, measure the length of a spark and use unit analysis to determine the voltage on the upper globe.
- Put the "pinwheel" on top of the VdG and notice the direction of rotation. How does it work?

Problems (2)

21.2.1. A charge of $q=24\,\mu C$ is placed on a sheet metal cube with a side dimension of 1.0 m. (a) What is the average surface charge density (i.e. charge per unit area) of each side? (b) Qualitatively, how does this surface charge density at the center of each face of the cube compare to that near the corners?

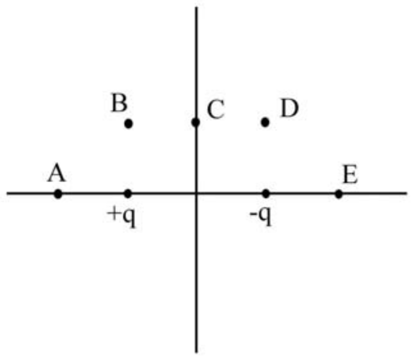
21.2.2. (a) How many coulombs of positive charge are there in 1 liter of air at standard temperature and pressure? (b) How many coulombs of negative charge are there in 1 liter of air at standard temperature and pressure? You can consider air to be neutral and made of 80% nitrogen gas and 20% oxygen gas.

22.1. Electric Fields I

Lab Demonstration

On large scale graph paper, plot the electric field vectors at several points around:

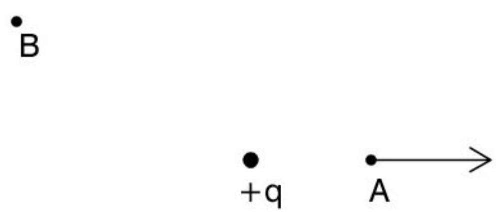
- A point charge $q = 4\times10^{-6}\,C$ at several distances from 3 to 20 cm. Use a scale of 1 cm equals 10^6 N/C. Label all drawn vectors with their respective magnitudes (in N/C). Note the strong variation of the field with distance.
- A dipole with $q = \pm10^{-6}\,C$ separated by 20 cm. With this, calculate and draw the resultant field at points A, B, C, D, E on the sketch below (spacings BC, CD, etc. are all 10 cm). Take advantage of symmetry as much as possible! Use both graphical vector-addition as well as x- and y-component vector addition to verify your results.



- For each case above draw Faraday's lines of force based on your vector fields and understand the relation between these two pictures of the field. Compare your sketches to given drawings of Faraday's lines of force. What do these lines mean qualitatively?

Problems (4)

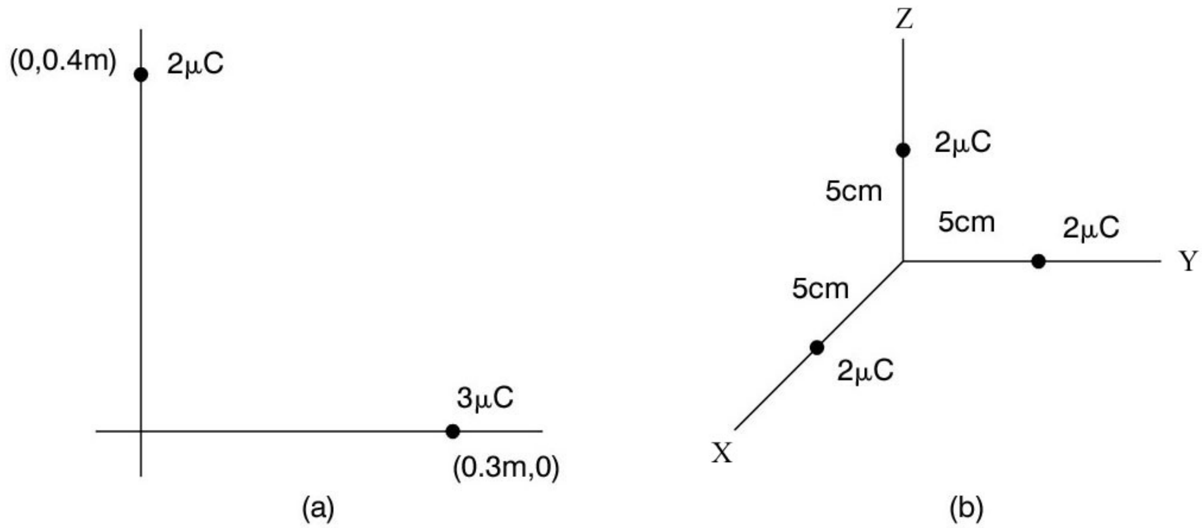
22.1.1. The electric field vector $\vec{E}_A$ at a point A, at a distance of 2.5 cm from the charge q is shown in the figure. (a) Draw accurately, in both direction and magnitude, the electric field vector at the point B, which is at a distance of 5 cm from the charge q. (b) How would the magnitude and the direction of the electric field vectors at A and at B change if the charge q is replaced by a charge 2q and (c) by a charge –q?



22.1.2. Two charges $q_1= q_2=2.0\,\mu C$ are held in place at x=0 and x=10 cm. Sketch a plot of the electric field as a function of x (along the x-axis) from x= -10 cm to x= +20 cm.

22.1.3. Repeat problem 23.1.2 for $q_1=2.0\,\mu C$ and $q_2= - 2.0\,\mu C$.

22.1.4. Find the net electric field at the origin due to the charges shown in Figs. (a) and (b).



22.2. Electric Fields II

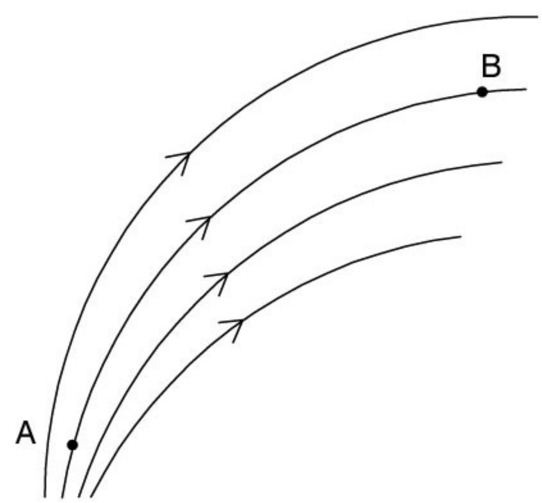
Lab Demonstration

In this demo you will have closed, plastic containers with electrodes and an oily liquid inside. Suspended in this liquid are small, elongated grains of a polarizable dielectric. In an applied electric field these grains develop an electric dipole moment and then align parallel to the field (so that the torque on them is zero). In this way Faraday's field lines can be visualized.

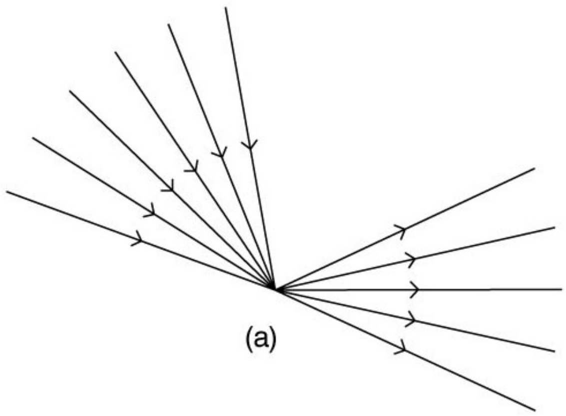
- Charge the electrodes with the means provided (plastic rods and wool, Van de Graaf, high voltage). Observe and draw the field lines displayed by the alignment of the grains.
- How does the field orient itself relative to the surfaces of the metal electrodes (conductor)?
- How can you tell if the field is strong or weak? Near what shape of surface does the field appear strongest?

Problems (3)

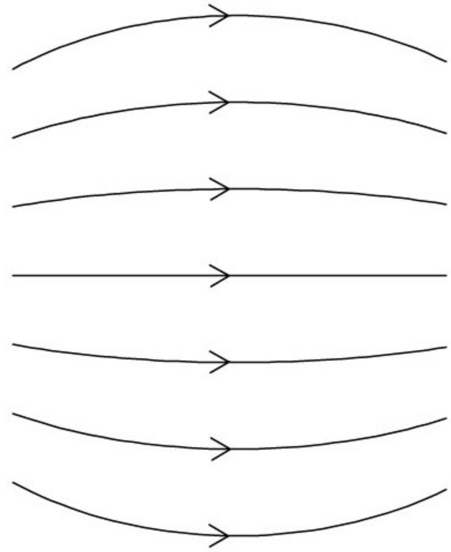
22.2.1. The figure below shows several electric field lines. (a) What is the direction of the electrostatic force on a proton at point A and at B? (b) What is the direction of the electrostatic force on an electron at point A and at B? (c) Where is the magnitude of the force on the proton larger, at A or at B?



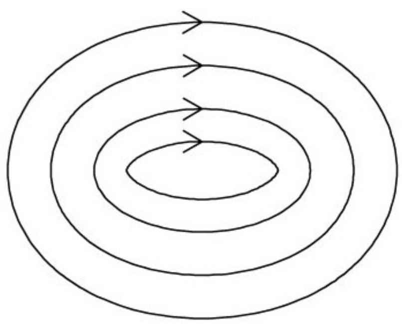
22.2.2. Consider the three field patterns shown. Which of the patterns represent(s) a possible electrostatic field?



(a)



(b)



(c)

22.2.3. What is the magnitude and direction of the electric field necessary to suspend a rain drop of diameter 1.0 mm carrying a charge of –4 nC?

23.1. Gauss' Law and Field Magnitude

Lab Demonstration

Go back to the Electric Field created by a point charge in lab 22.1. Look at how small the field vectors are at $r > 10$ cm and how large they are at $r < 5$ cm. Multiply the length of the vectors at some r by the surface area of the sphere centered on the charge with surface at r for a few different r-values.

- What do you find and why?
- The field's magnitude falls quickly with increasing r, but what "compensates" for this quick fall?
- What remains the same, independent of r?
- What is the reason for the rapid variation of the field magnitude?

23.2. Gauss' Law and Flux

Lab Demonstration

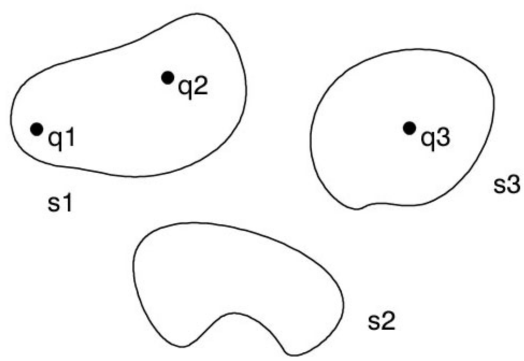
Use a flexible piece of wire to represent an arbitrarily shaped Gaussian surface for 2d pictures of fields near a point source (a monopole), a dipole, and a uniform field (possibly your pictures from 22.1). Lay this Gaussian surface on these field examples and note qualitatively how many field vectors point into the "surface" and how many point out. Consider and comment on the following cases where the Gaussian surface encloses:

- No charge
- A single charge
- Two like charges
- Two opposite charges

Vary the position and shape of the loop and develop your intuition for Gauss' Law.

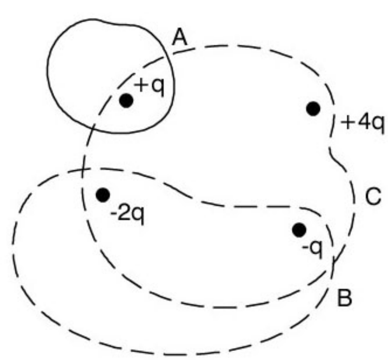
Problems (6)

23.2.1. Three surfaces S_1, S_2 and S_3 and three point charges q_1=3 nC, q_2= -3 nC, and q_3= 10 nC are shown in the figure. Find the electric flux through the surfaces S_1, S_2 and S_3.



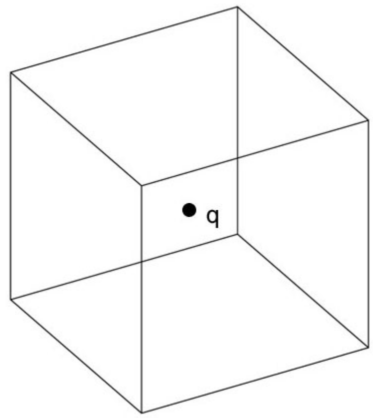
23.2.2. A point charge q=6 nC is placed at the center of a hollow plastic sphere of radius 5 cm. (a) What is the electric flux through the surface of the plastic sphere? (b) If the point charge is displaced by 1 cm from the center of the sphere, what will be the net flux through the surface?

23.2.3. The flux through the Gaussian surface A is 10 units. What are the fluxes through the surfaces B and C.

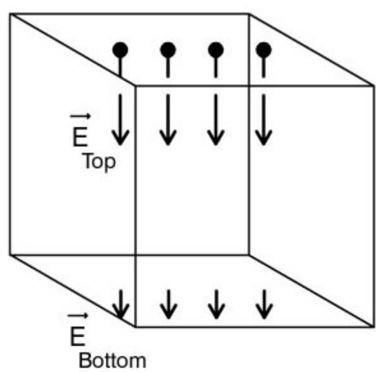


23.2.4. A point charge q_1= 4 nC is placed at the center of a hollow plastic sphere of outside radius 5 cm. Another point charge q_2 of unknown magnitude is placed 10 cm from q_1. (a) Does the electric flux through the surface of the sphere depend on the magnitude of q_2? (b) Does the electric field on the surface of the sphere depend on the magnitude of q_2? (c) Explain how the results of (a) and (b) are consistent with Gauss' Law.

23.2.5. A point charge q = 4 nC is placed at the center of a cube of side a=2 cm. (a) What is the electric flux through the top surface of the cube? (b) Is the flux different for any other surface of the cube? If so, which one?



23.2.6. A cubic box of side L=20 cm is placed in an electric field as shown. The electric field is pointing downwards but it is not uniform. The magnitude of the electric field on the top surface of the cube is 200 N/C while the magnitude of the electric field on the bottom surface of the cube is 50 N/C. (a) What is the electric flux through each of the six surfaces of the cube? (b) What is the electric flux through the entire cubic box? (c) How much charge is enclosed by the box?



23.3. Gauss' Law, Gaussian Surfaces, and Symmetry

Lab Demonstration

Here we explore the consequences of symmetries on electric fields and Gauss' Law. Complete the following table and show all calculations of integrals and assumptions made.

Charge Shape	Charge Density Units and common symbol	Simplest Gaussian Surface	E(r)
Sphere			
Straight Line			
Plane			

- Assume the small styrofoam ball is uniformly charged, i.e., no place on the sphere's surface has anything other than the average charge density. This is a statement of symmetry. With this symmetry, how can Nature place an electric field emanating from the sphere? Construct such a field with toothpicks, sticking them into the sphere.
- Now recall Gauss's Law. Consider the E-field emanating from the sphere above, represented by toothpicks. Enclose this sphere and its field in the containers provided (sphere, cylinder, box).
  - Since the containers are closed, what is $\oint \vec{E} \cdot \overrightarrow{dA}$ for each container (i.e. the Gaussian surface)?
  - Consider the integrand $\vec{E} \cdot \overrightarrow{dA}$. For which Gaussian surface is this dot product simplest? What does this have to do with symmetry?
  - What is the simplest of these three Gaussian surfaces? Solve the integral for this container only and find $\vec{E}(r)$ where r is the distance from the center of the distribution.
  - Comment on why the other shapes do not work well for calculating $\oint \vec{E} \cdot \overrightarrow{dA}$.
- Now consider a uniform plane and uniform rod (line) of charge. Follow the arguments above and answer the corresponding questions.

Problems (4)

23.3.1. A plastic sphere of radius 10 cm has a charge 20 μC *uniformly distributed on its surface.* Find the magnitude of the electric field at a distance of (a) 5 cm, and (b) 12 cm from the center of the sphere. (c) Sketch a plot of the electric field for all distances 0-20 cm from the center of the sphere.

23.3.2. A plastic sphere of radius 10 cm has a charge 20 μC *uniformly distributed throughout its volume.* Find the magnitude of the electric field at a distance of (a) 5 cm, and (b) 12 cm from the center of the sphere. (c) Sketch a plot of the electric field for all distances 0-20 cm from the center of the sphere.

23.3.3. An infinitely large plane of charge with surface charge density $\sigma = 2.0 \mu C / m^2$ resides along the xz plane. Another infinitely large plane of charge $\sigma = -6.0 \mu C / m^2$ resides along the xy plane. Find the electric field at the point P whose coordinate is (1 m, 2 m, 3 m).

23.3.4. A very long plastic cylinder of radius 10 cm has a charge density of 2 nC/m^3 *uniformly distributed throughout its volume.* Find the magnitude of the electric field at a distance of (a) 5 cm, and (b) 12 cm from the axis of the cylinder. (c) Sketch a plot of the electric field for all distances 0-20 cm from the axis of the cylinder.

24.1. Graphing Equipotentials

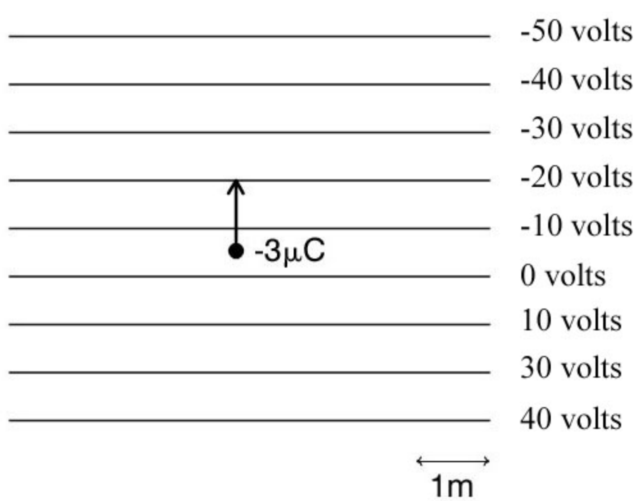
Lab Demonstration

In this lab you are given a voltage source and spatially separated electrodes that can be connected to the voltage (one to plus, one to minus). This creates an electric field (volts/meter). Conducting paper can then be placed between the electrodes. The voltage, relative to a given electrode, at some place on this paper will vary with position. Set your power supplies to 5V and find the following:

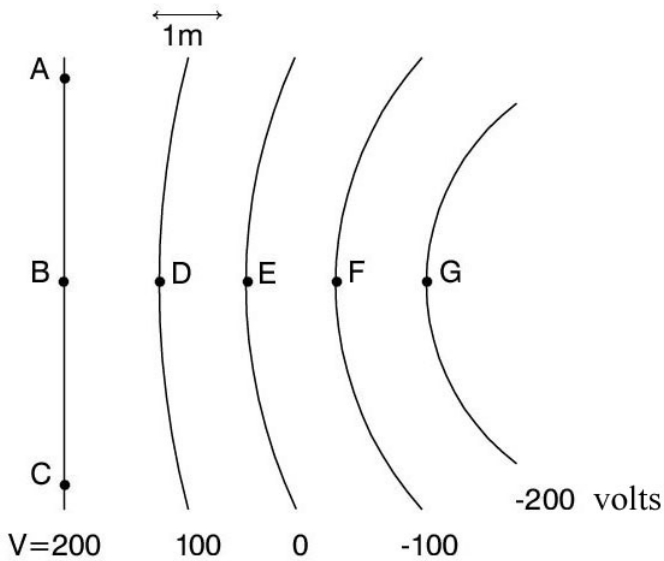
- Use conducting paper and a voltmeter to map out equipotential lines for different electrode shapes. To do this connect one probe of the voltmeter to an electrode. Then touch the other probe to the paper. The voltmeter will read the voltage difference between the electrode and the point on the paper. Map out the equipotential lines for a couple voltages between 0 and 5 volts.
- Now draw in the electric field lines. (How is the field related to the equipotentials?) What is a typical magnitude of the field?

Problems (2)

24.1.1. Drawn below are a series of equipotential lines and a 1 meter scale bar. A small particle having total charge of $-3\,\mu$C and a kinetic energy of $75\,\mu$J is moving upward as drawn. (a) Where, if at all, will it momentarily stop? (b) What is the magnitude and direction of the electric field in the region? (c) What is the magnitude and direction of the force on the particle? (d) Does the force change as the particle's speed changes?



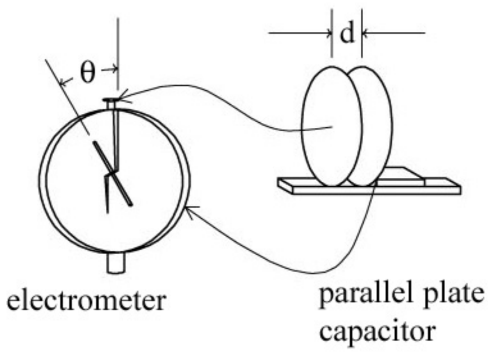
24.1.2. Drawn below are equipotentials for an electric field. Find the work done by the electric field when a charge $q = 5\ \mu C$ moves from (a) A to C (b) F to A and (c) A to F. (d) Find the magnitude and direction of the electric field at D. (e) Accurately draw electric field lines from A, B, and C as far as to the right as possible.



24.2. Field and Voltage in the Parallel Plate Geometry

Lab Demonstration

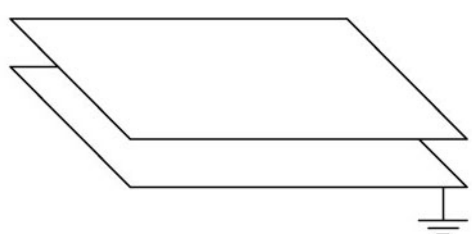
Charge the parallel plate capacitor with the van de Graaf generator. Use the electrometer to measure the "voltage" between the plates. This voltage is approximately proportional to the angle θ of deflection from vertical of the electrometer needle.



- If you start with charged plates close together and then separate them, do you expect the voltage to go up or down? Why?
- Do this by varying the capacitor spacing 'd' from 1/2 to a few cm. Plot the "voltage" (deflection angle) versus spacing. Understand this result in terms of voltage, field, and the constant charge on the plates.

Problems (3)

24.2.1. Two equal and oppositely charged parallel metal plates are placed at a separation of 10 cm (their separation is small compared to their sizes) from each other as shown. Each plate has a uniform surface charge density of $2nC/m^2$. Let V=0 on the bottom plate. Find the electric field and electric potential in the region between the two plates at a distance of (a) 2 cm and (b) 8 cm from the bottom plate.



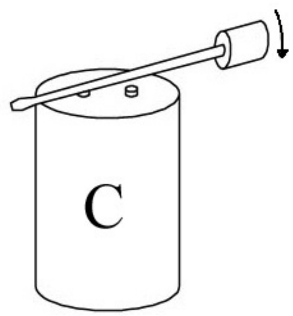
24.2.2. Two metal plates of dimension 2 m x 2 m are charged with equal but opposites charge of $24\mu C$. If the plates are placed parallel to each other 5 cm apart, what is their potential difference?

24.2.3. (a) What is the potential difference necessary between two large metal plates separated by a distance of 5 cm to suspend a rain drop of diameter 1.0 mm carrying a charge of $-4nC$ in between them? (b) Which plate should be positively charged?

25.1. Capacitor Charge and Energy Storage

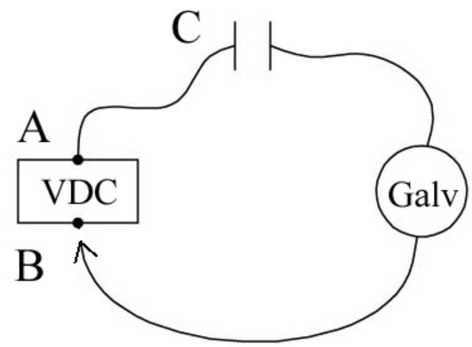
Lab Demonstration

This is a quicky. Charge a large capacitor ($\sim 10^4 \mu F$) with a DC power supply with at least 10 volts (the more, the better!). REMOVE THE POWER, then short the terminals ("crowbar it") with a piece of metal (e.g., a screw driver). What happens and why?



25.2. Charging and Discharging a Capacitor

Lab Demonstration



Arrange a DC voltage source, galvanometer and capacitor ($C \sim 0.05$ to $0.5 \mu F$) in series as drawn, leaving the circuit open at B. Now connect the wire to B while watching the galvanometer. The galvanometer is a device that sensitively measures current, which is the flow of charge. At the moment of connection, the needle on the galvanometer will impulsively swing or kick over, indicating charge flow, but will then swing back with diminishing swings about zero indicating no charge flow. This demonstrates important characteristics of capacitors in DC circuits: an initial transient of charge flow (as C is being charged) and a steady state, zero charge flow (after C is fully charged).

The kick during the transient is proportional to the total charge that flowed onto the capacitor, q. Hence you can determine the functionality of q with the applied voltage V and capacitance C. Do this:

- measure the galvanometer kick as a function of V (graph kick vs. V while keeping C constant)
- measure the galvanometer kick as a function of C (graph kick vs. C while keeping V constant)
- After you have charged a capacitor remove the connection at B and shortly thereafter reconnect to A. This discharges the capacitor. What do you observe on the galvanometer? Why?
- Measure the kick (remember, proportional to q) for a capacitor and then put it in series and then parallel with an identical capacitor. Then measure the kicks for these combinations. How do the kicks compare? What can you conclude about the equivalent (or effective) capacitance of series and parallel combinations?

Problems (5)

25.2.1. (a) When a battery is connected to a parallel-plate capacitor, why do both plates acquire charges of same magnitude? (b) Will this be true if the two plates are of unequal size and/or shape?

25.2.2. A parallel plate capacitor has rectangular plates of size 10 cm x 8 cm. The separation between these two plates are 1.5 mm. (a) Calculate the capacitance. (b) What charge will appear on the plates if a potential difference of 100 V is applied across the two plates? (c) When fully charged, how much energy is stored in the capacitor?

25.2.3. Consider a parallel-plate capacitor *connected to a battery*. How does the charge in this capacitor change if (a) plate separation is doubled, (b) potential difference is doubled (by varying the voltage of the battery), and (c) if both plate separation and potential difference are doubled? d) How does the energy stored change for a, b, and c, above?

25.2.4. Consider a parallel plate capacitor fully charged and *isolated from the battery*. a) How does the charge change if the plate separation is doubled? b) How does the energy stored change?

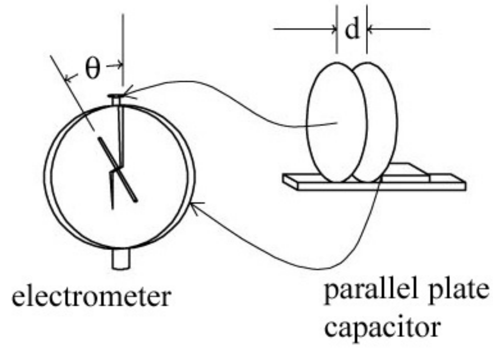
25.2.5. You are given two identical capacitors to be connected to one battery. Will the capacitors store more energy if connected in series or in parallel?

25.3. Dielectric Capacitors

Lab Demonstration

Use the VdG to charge the parallel plate capacitor. Use the electrometer to measure the "voltage" on the capacitor by the angle θ of the needle on the electrometer.

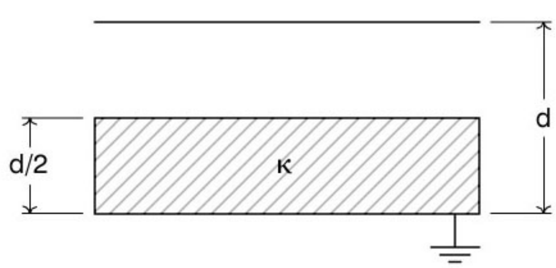
- Slide a dielectric between the plates of the capacitor (e.g., a notebook). What happens? What if the dielectric doesn't entirely fill the gap? Measure (approximately) the dielectric constant.



Problems (2)

25.3.1. A parallel plate capacitor of plate area A and plate separation d is connected to a battery supplying a potential difference V. A dielectric slab of thickness d and dielectric constant κ will now be inserted in the capacitor. (a) How will the charge stored in the capacitor change if the capacitor remains connected to the battery when the dielectric slab is inserted? (b) How will the charge stored in the capacitor change if the capacitor is first detached from the battery and then the dielectric slab is inserted? c) How does the stored energy change for a and b, above?

25.3.2. In the parallel plate arrangement shown, two metal plates of area A are separated by a distance d. On the lower plate is a slab of plastic dielectric with dielectric constant κ and thickness d/2. The plates are charged with opposite charges +Q and –Q. Answer the following questions in terms of Q, A, d, and κ only. (a) Find the magnitude of the electric field in the air space between the plates. (b) Find the magnitude of the electric field in the dielectric between the plates. (c) Find the voltage potential on the top of the dielectric (the lower plate is grounded).

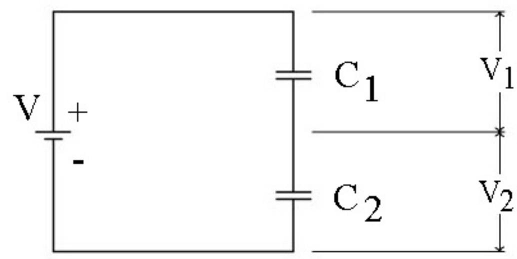


25.4. Capacitor Circuits

Lab Demonstration

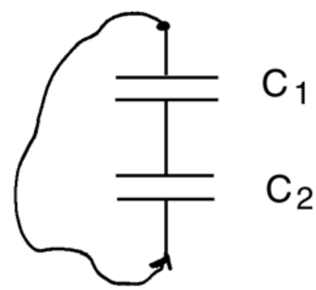
Hook up two different capacitors in series to a DC source. This experiment works best with large ($\geq 1000\mu F$) capacitors.

- Measure, calculate, and compare the voltage across each capacitor (see "Note on Voltmeters," below).

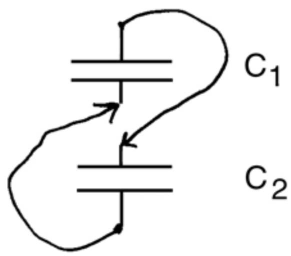


Now disconnect the capacitors from the battery (while they are still charged) and connect them in the following configurations:

- Connect the positive end of one capacitor to the negative end of the other. Measure, calculate and compare the voltage across the capacitors.

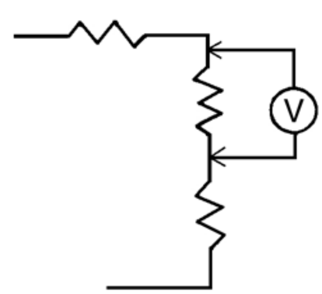


- Now recharge the capacitors in series and disconnect from the battery. Then connect the positive terminals together, and the negative terminals together. Measure, calculate and compare the voltages.



__Note on Voltmeters__. Voltmeters are high resistance (or more generally impedance) devices used to measure the voltage *across* a circuit element or device. To do this the voltmeter is put across, i.e., in parallel to, the circuit element, as drawn below. As you learn more about circuits the following characteristics will become clear to you:

1. Since the voltmeter is in parallel to the circuit element, it and the circuit element have the same voltage across them. Thus we measure the voltage across that circuit element.
2. The larger the impedance of the voltmeter, the better. Since the voltmeter is in parallel to the circuit element, a large impedance ("ohmage") will draw little current hence perturb the circuit only slightly. In fact, the ideal voltmeter would have infinite impedance, hence draw no current and cause no perturbation. When you learn about parallel resistors, revisit this paragraph and answer the question, "large relative to what"?
3. Because the voltmeter is placed in parallel to circuit elements, it can probe the system without physical modification of the circuit. The voltmeter probes simply touch each end of the element, voltage is read, and probes removed. Compare this to an ammeter which, because it must be placed in series to read the current, requires cutting and reconnecting the circuit to include the ammeter.

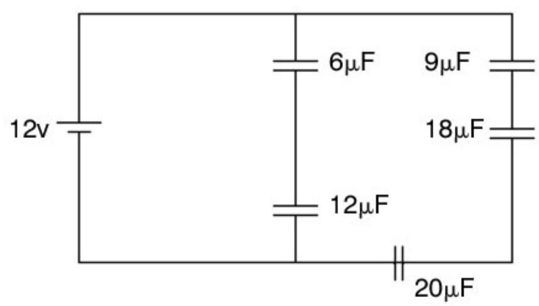


Problems (3)

25.4.1. You are given three capacitors of capacitances 6 μ F, 4 μ F and 3 μ F, respectively. List the different capacitances that can be generated by connecting these elements in various combinations.

25.4.2. A group of *identical* capacitors are connected first in series and then in parallel. The equivalent capacitance of the parallel combination is 144 times larger than the equivalent capacitance of the series combination. How many capacitors are there in the group?

25.4.3. Find the (a) equivalent capacitance and (b) the total charge and c) the total energy stored in the capacitance network shown. Find also (d) the charge on each capacitor and (e) the voltage across each capacitor.



27.1. Series and Parallel Resistor Combinations

Lab Demonstration

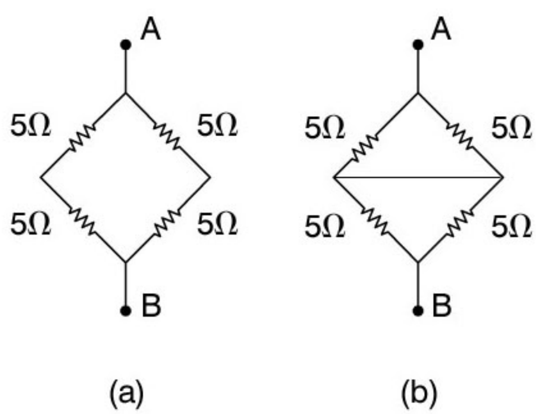
This is fairly quick. Use an ohmmeter to measure the resistance of a few resistors.

- Connect some in series and measure the series combination. Compare to theory.
- Connect some in parallel and measure the parallel combination. Compare to theory.
- Pay attention to the fact that R (series combo) > R (any individual) and R (parallel combo) < R (any individual).
- As a rough rule does the physical size of a resistor have anything to do with its value of resistance?

Problems (2)

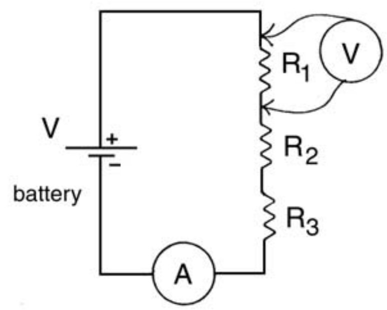
27.1.1. A group of *identical* resistors are connected first in series and then in parallel. The equivalent resistance of the parallel combination is 100 times smaller than the equivalent resistance of the series combination. How many resistors are there in the group?

27.1.2. Find the equivalent resistance between the points A and B in each of the situations shown below.



27.2. Series Circuits

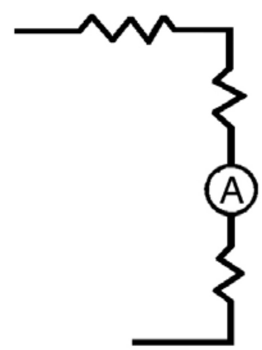
Lab Demonstration



Set up a simple series circuit with a battery, three different resistors, and an ammeter (A) (see "Note on Ammeters," below).

- Measure and calculate the current.
- Measure with a voltmeter (V) and calculate the voltage drop across each resistor. What is the total of the voltage drops? What would happen if the voltmeter's resistance was about the same as the resistor it was measuring across (i.e., what makes a good voltmeter)?

<u>Note on Ammeters</u>. Ammeters are low resistance (more generally, impedance) devices used to measure the current *through* a circuit element or device. To do this an ammeter is put in series with the circuit element as drawn below. As you learn more about circuits the following characteristics will become clear to you:



1. Since the ammeter is in series with the circuit element, it and the circuit element have the same current through them. Thus we measure the current through that circuit element.

2. The smaller the resistance of the ammeter, the better. Since the ammeter is in series with the circuit element, a small resistance will drop very little voltage hence perturb the circuit only slightly. In fact, the ideal ammeter would have zero resistance hence have no voltage drop across it and cause no perturbation. When you learn about series resistors, revisit this paragraph and answer the question, "small relative to what"?

3. A drawback to the DC ammeter is that it must be placed in series to read the current. This requires cutting and reconnecting the circuit to include the ammeter. This is not necessary with an AC ammeter. When you learn about induction see if you can design a "non-cut-and-paste" AC ammeter.

Problems (2)

27.2.1. Two resistances $R_1 = 3\Omega$ and $R_2 = 6\Omega$ are connected in series with an ideal battery supplying an EMF of 9 volts. (a) What is the current I_1 in R_1? (b) What is the current I_2 in R_2? (c) What is the potential difference V_1 across R_1? (d) What is the potential difference V_2 across R_2? (e) How are V_1 and V_2 related to the battery EMF? Next, the series circuit is replaced by an equivalent resistance R connected to the same battery. (f) What is current I in R? (g) What is the potential difference V across R? (h) How are I_1 and I_2 related to I? (i) How are V_1 and V_2 related to V?

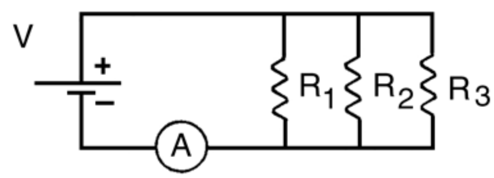
27.2.2. A resistance R is connected to an *ideal* battery with EMF $\mathcal{E}$. If one connects another identical resistances R in series, how does the current and voltage across the original resistance change?

27.3. Parallel Circuits

Lab Demonstration

Set up a simple parallel circuit with a battery, three different resistors and an ammeter (A).

- Measure and calculate the current. How do these compare? What would happen if the ammeter's resistance was about the same as the resistors in the circuit?
- Measure and calculate the voltage drop across each resistor. How do they compare?
- Disconnect a resistor or two and see what happens to the current and voltages.



Problems (2)

27.3.1. Two resistances $R_1 = 3\Omega$ and $R_2 = 6\Omega$ are connected in parallel with an ideal battery supplying an EMF of 9 volts. (a) What is the current I_1 in R_1? (b) What is the current I_2 in R_2? (c) What is the potential difference V_1 across R_1? (d) What is the potential difference V_2 a cross R_2? (e) How are V_1 and V_2 related to the battery EMF? Next, the parallel circuit is replaced by an equivalent resistance R connected to the same battery. (f) What is current I in R? (g) What is the potential difference V across R? (h) How are I_1 and I_2 related to I? (i) How are V_1 and V_2 related to V?

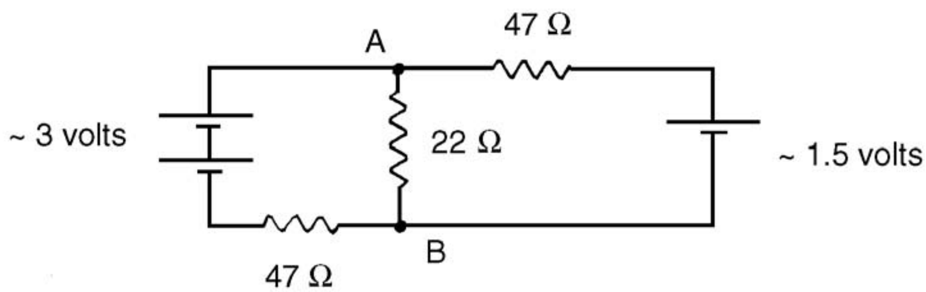
27.3.2. A resistance R is connected to an *ideal* battery with EMF $\mathcal{E}$. If one connects another identical resistances R in parallel, how does the current and voltage across the original resistance change?

27.4. A Kirchhoff Circuit

Lab Demonstration

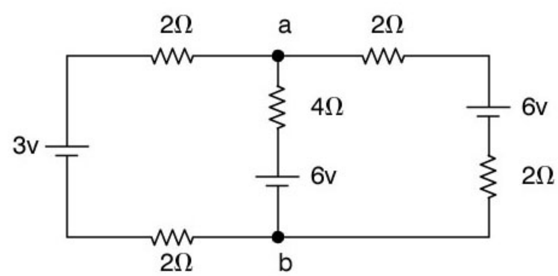
Set up the circuit drawn below.

- Measure and calculate the voltage drop across each resistor. Don't forget to measure the voltage that your batteries are actually supplying.

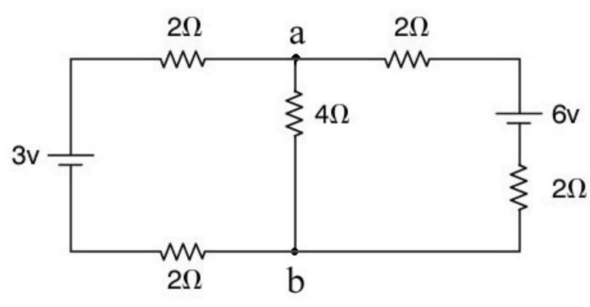


Problems (2)

27.4.1. (a) Calculate the current through each resistor in the circuit shown. (b) Calculate V_a-V_b.

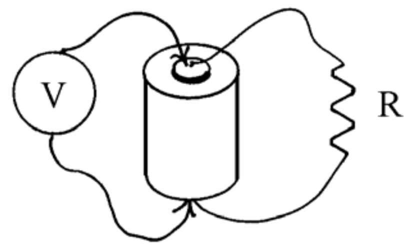


27.4.2. (a) Calculate the current through each resistor in the circuit shown. (b) Calculate V_a-V_b.

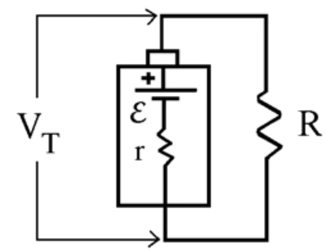


27.5. Real Batteries

Lab Demonstration



- Measure with a voltmeter (V) the terminal voltages of two common "1.5 volt" batteries, AAA and D cells. A good voltmeter will have a very high resistance and hence will not be a significant load for the batteries.
- Connect each battery in turn to resistors with R=100, 10, 3, and 1 ohm. Connect for only a short time (2-3 sec.) so as not to wear down the battery. In each case measure the terminal voltage. Qualitatively, what is happening and which battery is "best"?
- Assume each battery has an internal resistance r and derive an expression for the terminal voltage V_T in terms of the ideal EMF, $\mathcal{E}$ and r and R of the load resistor. Show that a plot of $\mathcal{E} / V_T$ versus R^{-1} should be linear with slope equal to r. Plot your data this way, and determine r for the AAA and D cells. What does battery physical size tell you about r? What makes a good battery?



Problems (3)

27.5.1. A battery of EMF 9 volts and internal resistance r is connected to an external resistance $R = 10\Omega$. (a) If the voltage across R is 8.82 volts, find r. (b) If the 10Ω resistor is replaced by a 1Ω resistor, what will be the voltage across this new resistor.

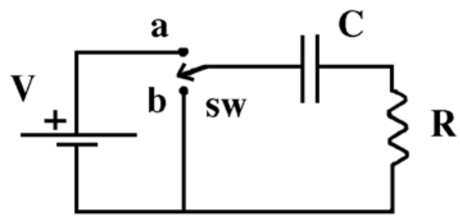
27.5.2. Repeat Problem 28.2.2 when the battery is a real battery with an internal resistance.

27.5.3. Repeat Problem 28.3.2 when the battery is a real battery with an internal resistance.

27.6. RC Circuits

Lab Demonstration

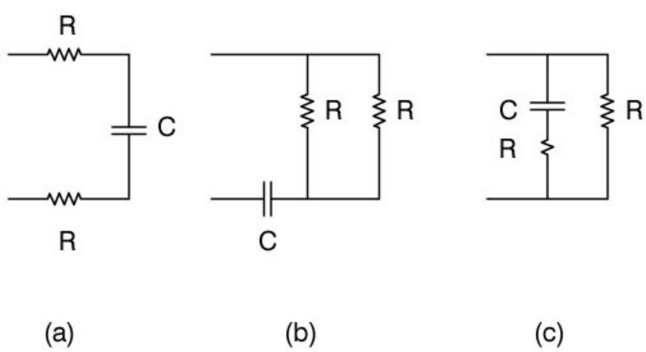
Set up the RC circuit drawn below. Use a battery for the voltage source to avoid grounding problems. Pick values of R and C so that RC is on the order of a couple of seconds. Use the data studio to detect both the voltage across the resistor V_R and across the capacitor V_C simultaneously.



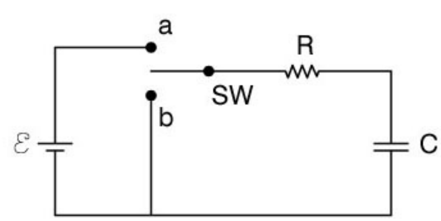
- Set the switch SW to position 'a' and record V_R and V_C as a function of time. Which voltage indicates current and which one indicates charge? Determine the time constant for both, compare them and compare to RC.
- Repeat for the switch moved to position b.

Problems (4)

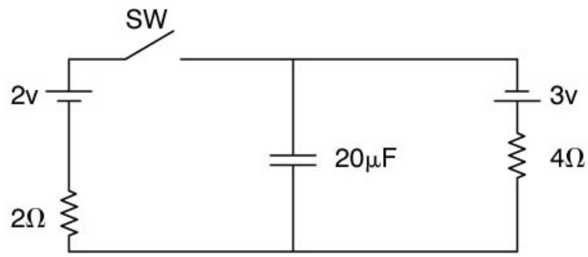
27.6.1. Find the time constant for the three circuits shown. In each case R=10,000 Ω and C=10 μF.



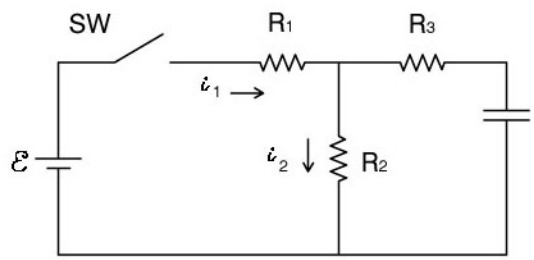
27.6.2. Consider the circuit shown in the figure. The capacitor is initially uncharged. At t=0, the switch SW is set to position a. (a) How many time constants must elapse for the capacitor to have 90% of its final, equilibrium charge? After the capacitor is fully charged, the switch is now set to position b. (b) How many time constants must elapse for the capacitor to lose 90% of its charge? (c) How much charge is left after twice this time? Thrice?



27.6.3. Consider the RC-circuit shown to the right. Initially switch S has been open for a long time. (a) What is the charge on the capacitor when the switch SW has been open for a long time? (b) Next the switch S is closed for a long time. What is the charge on the capacitor after the switch SW has been closed for a long time?



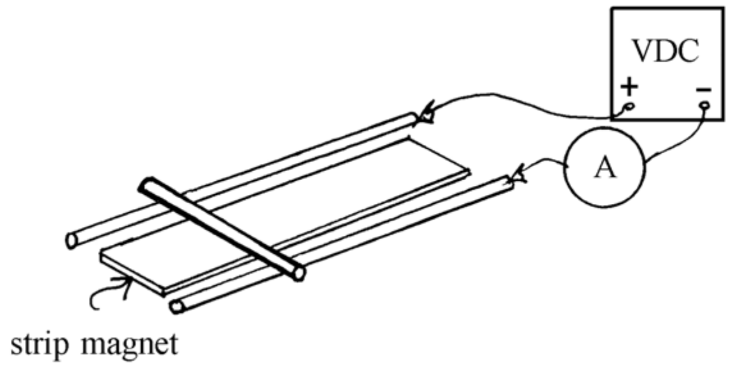
27.6.4. Consider the RC-circuit shown to the right. Here, $\mathcal{E}$=120 V, $R_1 = 4,200\Omega$, $R_2 = 4,000\Omega$, $R_3 = 1,000\Omega$, and $C = 4,700\mu F$. Initially the switch SW is open for a long time and the capacitor C is uncharged. The switch then is closed at t=0. (a) Find the values of i_1 and i_2 immediately after closing the switch, i.e., at t=0. (b) Find the values of i_1 and i_2 a long time after closing the switch.



28.1. Force on a Current Carrying Wire in a Magnetic Field

Lab Demonstration

Place a strip magnet on the table. If a strip magnet is not available, use a series of disk magnets all with the same pole up. In this configuration they will repel and flip so you will have to hold them down with tape. Lay two metal rods along each long side of the magnetic strip, parallel to each other. Tape the rods to the wooden blocks. Place a small rod on the parallel rods perpendicular to them. All three rods should be free of dirt, oxide, etc. (use steel wool to clean them). Connect a DC power supply to the parallel rods, with one terminal to each long rod (make sure the power supply is off at this time).

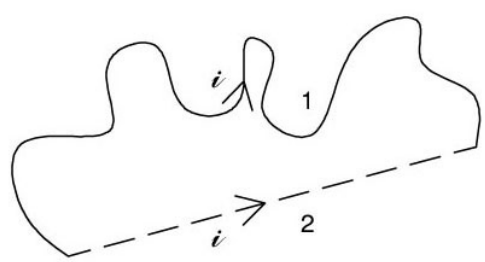


- Use the Hall probe to measure the magnetic field just above the strip magnet at the level of the small rod. By symmetry, what is the direction of the magnetic field?
- Set the current limit on the DC power supply as described by your instructor (before you connect the power supply to the circuit). Apply a voltage to the parallel rods. Reverse the voltage. What does the small rod do?
- Measure the current. Calculate the force on the small rod. Mass it. Calculate the acceleration (magnitude and direction). Measure the acceleration. (This will be rough, but better than no measurement.) Compare.

Problems (2)

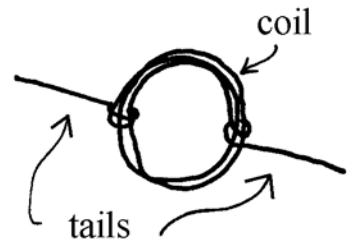
28.1.1. A 2.0 m straight wire is carrying a current of 10.0 A in a direction perpendicular to a 0.2 T magnetic field. (a) What is the magnitude of the force per meter on the wire? (b) What will be the magnitude of the force per meter on the wire if the angle between the current direction and the magnetic field is changed to 30^o?

28.1.2. One can show that the force on a current-carrying loop of arbitrary shape is zero when placed in a uniform magnetic field. (If you are curious as to how, try to work it out.) Use this result to show that the force on an arbitrarily shaped wire 1 carrying a current *i* and placed in a uniform magnetic field B is the same as the force on the wire 2 which is constructed by connecting the two end points of wire 1 and which carries the same current *i*.

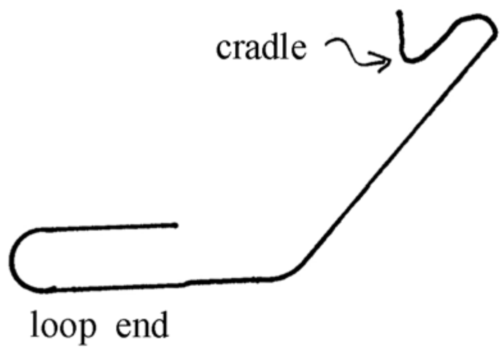


28.2 A DC Motor (Torque on a Magnetic Dipole)

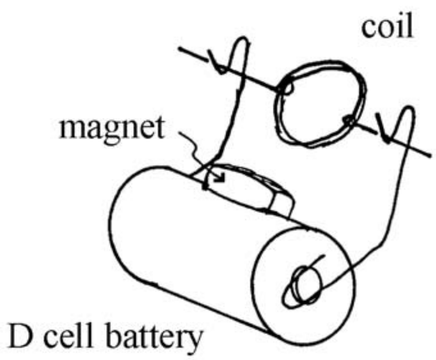
Lab Demonstration



- Starting about 3 inches from the end of a piece of magnet wire, wrap it several times around a D battery. Remove the battery. Cut the wire, leaving a 3-inch tail opposite the original starting point. Wrap the two tails around the coil so that the coil is held together and the two tails extend perpendicular to the coil. See illustration to the right.
- On one tail, use sandpaper to completely remove the insulation from the wire (do not sand the tabletops!). Leave about 1/4" of insulation on the end and where the wire meets the coil. On the other tail, lay the coil down flat and lightly sand off the insulation from the top half of the wire only. Again, leave 1/4" of full insulation on the end and where the wire meets the coil.
- Bend two paper clips into the following shape.



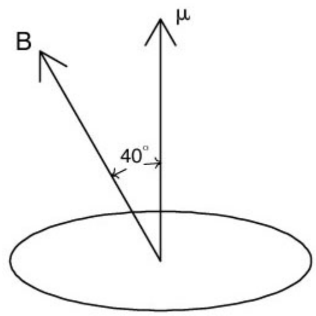
- Use a rubber band or masking tape to hold the loop ends of the paper clips (on the left in the above drawing) to the terminals of a "D" Cell battery:
- Stick a magnet on the side of the battery as shown.



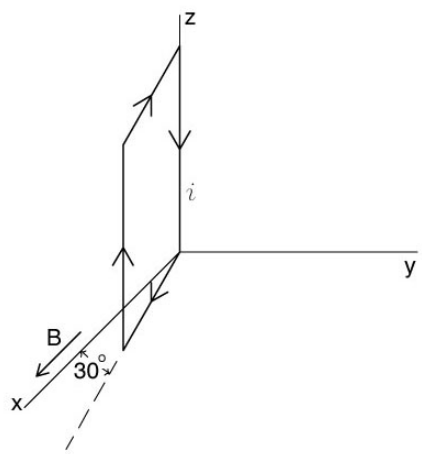
- Place the coil in the cradle formed by the right ends of the paper clips. You may have to give it a gentle push to get it started, but is should begin to spin rapidly.
- Try to make the best motor in class.
- Explain how the motor works.

Problems (4)

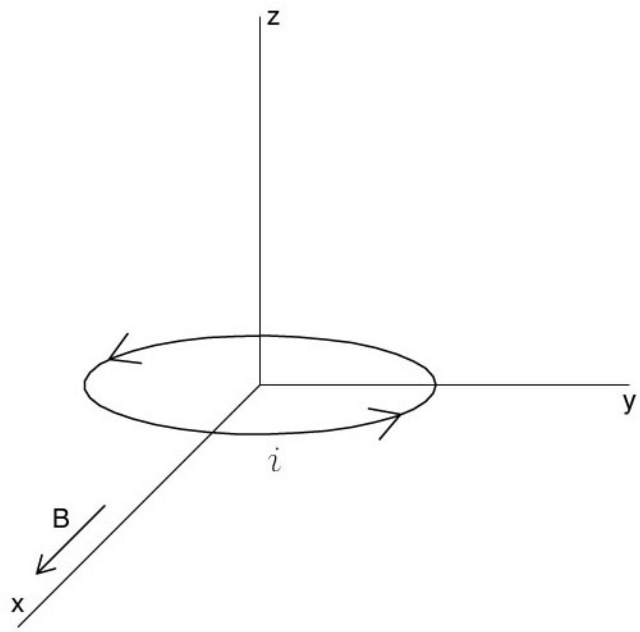
28.2.1. Drawn below is a 5 turn circular coil of radius 0.2 m with a current of 2.5 Amp immersed in a 0.01 T magnetic field. What is the magnitude of the torque on the coil?



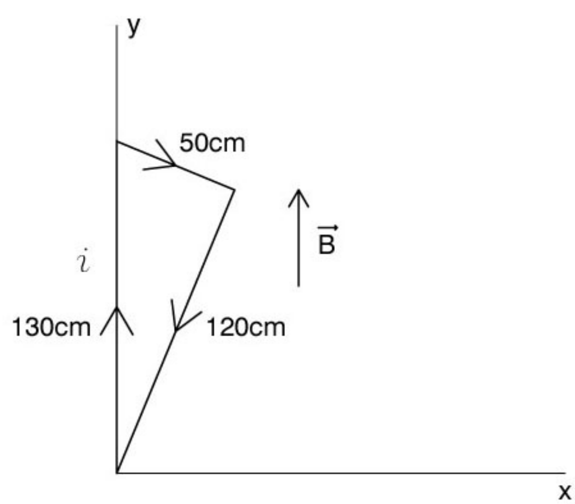
28.2.2. Drawn to the right is a rectangular, single turn loop of wire, 0.2 m by 0.3 m. The loop is on the perimeter of a door, which is free to rotate on hinges on the z-axis. The current in the loop is 3 Amp and the magnetic field is 0.4 T in the +x direction. (a) Find the magnitude of the magnetic moment of the loop. (b) Find the magnitude of the torque on the loop.



28.2.3. Drawn below is a circular current loop lying in the xy plane. It is free to move. A uniform magnetic field is directed along the +x axis. Describe the equilibrium orientation of the loop including the direction of the current.



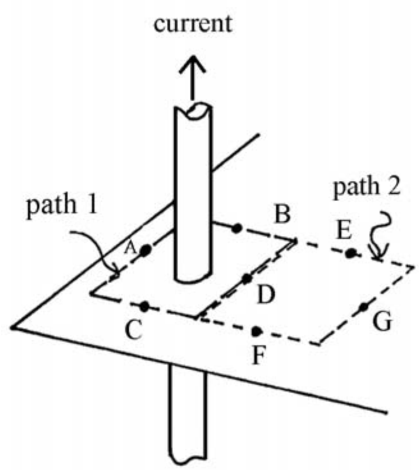
28.2.4. A single turn current loop, carrying a current of *i*=5.00 A, is in the shape of a right triangle with sides 50.0, 120 and 130 cm. (see figure). The loop is in a uniform magnetic field of magnitude 80 mT whose direction is parallel to the current in the 130 cm side of the loop. (a) Find the magnitude and direction of the magnetic dipole moment of the loop. (b) Find the magnitude of the torque acting on the loop. (c) Find the magnitude and direction of the magnetic force acting on the 130 cm side. (d) Find the magnitude and direction of the magnetic force acting on the 120 cm side.



29.1. Amperes' Law

Lab Demonstration

Put a large current into the square loop. Place some paper, on which you can draw, on the horizontal board. Draw two connected squares, 5 cm per side as drawn below. Now take time to understand what the probe measurement is telling you. Use the hall probe to measure the magnetic field (magnitude and direction) at the center of each side of each square (i.e., A, B, C, D, E, F and G as drawn). Measure only the component of the field parallel to the square side.



From these data you can approximate Ampere's integral, which is the left hand side of Ampere's Law

$$\oint \vec{B} \cdot \vec{dl} = \mu_o i \text{ (total inside)}$$

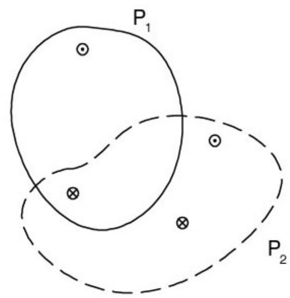
Note that $\vec{B} \cdot \vec{dl} = \pm B$ (parallel to side) dl. The + or - is determined by whether $\vec{dl}$ is parallel or antiparallel to $\vec{B}$ (parallel to side).

- Walk around the square loop which encloses the wire and determine ampere's integral as the sum of the four values of B (parallel to side) dl using B at the side center and dl=side length as an approximation. Compare this to $\mu_o i$ (total inside) and see how well Ampere's Law works.

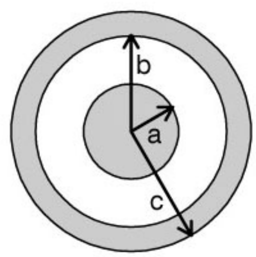
- Do this again for the square loop that does not enclose the wire. Be careful with signs. Verify Ampere's law.

Problems (3)

29.1.1. Each of the wires (perpendicular to the plane of the page) carries a current of 5 A. Compute $\oint \vec{B} \bullet d\vec{s}$ for the paths P_1 and P_2 shown in the figure.



29.1.2. The figure shows a cross section of a long conducting coaxial cable with its radii (a,b,c). Here a=0.40 cm, b=1.8 cm, and c=2.0 cm. Equal but opposite currents i =5 A are uniformly distributed in the two conductors. Find the magnetic field B(r) for various values of radial distance r. (a) r = 0.1 cm. (b) r = 1.6 cm. (c) r =1.9 cm. (d) r=25 cm.



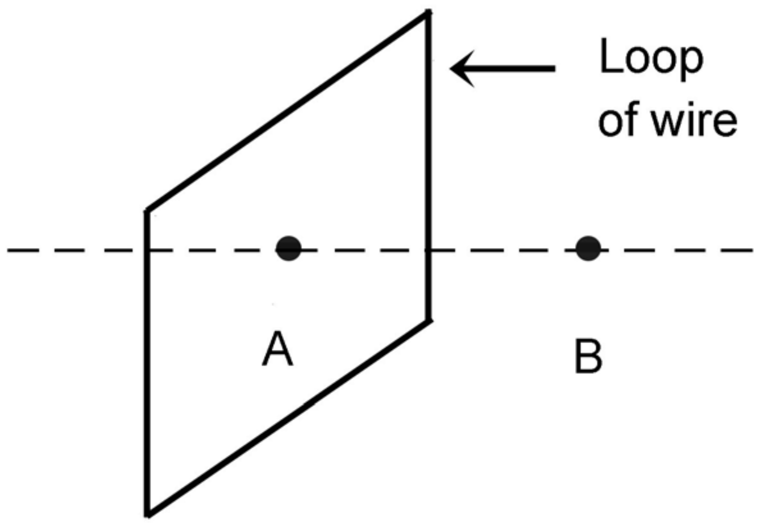
29.1.3. The current density inside a long, solid, cylindrical wire of radius R is in the direction of the central axis and varies linearly with radial distance r from the axis according to $J=J_0\, r/R$, where J_0 is a constant and its unit is A/m^2. Here R=4.0 cm and the wire carries a current of i =50 A. (a) Find the magnitude of the constant J_0. (b) Find the magnetic field B(r) at a distance r=3.0 cm from the central axis of the cylinder. (c) Find the magnetic field B(r) at a distance r=5.0 cm from the central axis of the cylinder.

29.2. Magnetic Field of a Current Carrying Loop

Lab Demonstration

Put a measured current into the square loop.

- Use the magnetic field sensor (the Hall probe) to measure the magnetic field at the loop's center.
- Measure the loop's dimensions and calculate the magnetic field at the center of the loop. Compare.
- Repeat the experiment and theory above for an arbitrary point on the perpendicular axis of the loop.



A = center of loop
B = arbitrary point on perpendicular axis

Problems (2)

29.2.1. A straight wire of length L =10 m carries a current of 2 A. Find the magnitude of the magnetic field at the points P_1 and P_2 at distances of (a) 5 m and (b) 0.1 m from the wire segment along a perpendicular bisector. (c) How much error would incur in each of the above cases if one considers the wire to be infinitely long?

29.2.2. A square loop of wire of edge length 0.3 m carries a current of 5 A. Find the magnitude of the magnetic field produced (a) at the center of the loop and (b) at a point on the axis of the loop and at a distance of 0.1 m from the center.

29.3. The Solenoid

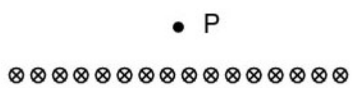
Lab Demonstration

Measure the number of turns per unit length for the air-cored solenoid. Also measure the total length and diameter. Compare and discuss whether it is an "infinite" solenoid.

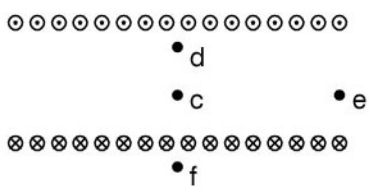
- Put a current of as much as 2 amps into the solenoid. Use the magnetic field detector (the Hall probe) to measure the field (magnitude and direction) near the center of the length of the solenoid, off the central axis, along the axis to the end and outside, but next to the solenoid. Compare to theory.
- How does the end compare to the center? Make a symmetry argument for the ratio of the field at the end and the center.
- How does the outside compare to the inside? Is the solenoid infinite?
- Make a graph of the axial field inside as a function of position.
- Now put a wood dowel in the solenoid. What is the field at the end?
- Now put an iron rod in the solenoid. What is the field at the end? Is this result useful? How can you use the rod to extend the reach of the solenoid?

Problems (2)

29.3.1. Drawn below is a large planar array of very long, parallel wires going into the plane of the paper, each carrying a current of 1.5 A. There are 100 wires per meter. Find the magnetic field a small distance above the array at the point P.



29.3.2. Below is a solenoid drawn in cross section parallel to its axis. The wires on top carry current out of the plane of the paper, those below into the plane. The magnetic field magnitude at position c inside the solenoid is B=0.230 T. (a) What is the direction of $\vec{B}$ at c? (b) What is the field (a vector) at position d, e, and f?



29.4. The Solenoid Continued

Lab Demonstration

For this lab, we will measure the relationship between the current through a solenoid and the B Field created by this current.

- You should have a wooden rod and at least one metallic rod (ideally we should have at least two types of metals).
- Now, with each of the 4 cores (air counts as one), measure the B Field while varying the current from 0 to 2 Amps. Measure at least in 0.5 Amp increments (but you can do smaller if you like).
- How can you determine the B Field at the center of the solenoid by measuring the B Field at one end? Comment on this in detail in your lab book.
- Don't forget to label the different curves you get, and explain why the curves are different.
- Consider the slope of the curve of the air core. What is this value? What should it be?

For the next part of this experiment, take one of the metallic cores and slowly strike a magnet along one end.

- Try to pick up paperclips (or something metallic). Why did this happen?
- Drop the rod from a couple of feet in the air onto the floor. Why does the rod become demagnetized?

30.1. Induction

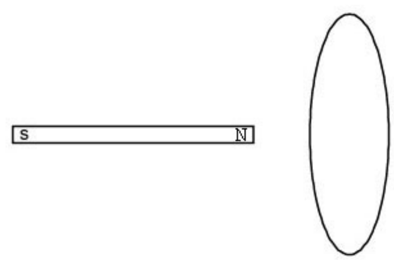
Lab Demonstration

Connect a wire loop to a galvanometer.

- Use a bar magnet and move one of the poles into the loop; leave it there. Describe the current flow as indicated by the galvanometer.
- Remove the magnet; what happens?
- Switch poles and repeat the experiment above.
- Vary the rates of movement. Vary the angles at which the magnet is in the center of the loop. Use more than one magnet. Deduce a law of induction. Does your law depend on the magnetic field or that rate at which it changes?

Problem (1)

30.1.1. A bar magnet moves with constant velocity along the axis of a conducting loop as shown. (a) Make a sketch of the magnetic flux Φ_B through the loop as a function of time. Indicate the time $t_{1/2}$ when the magnet is halfway through the loop. (b) Make a sketch of the current induced i through the loop as a function of time. Consider the current to be positive when it is counterclockwise viewed from the left. Indicate the time $t_{1/2}$ when the magnet is halfway through the loop.



30.2. Induction and Lenz's Law

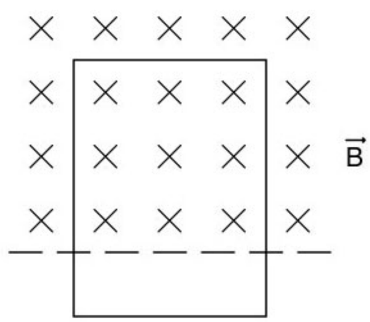
Lab Demonstration

(This is a quicky.)

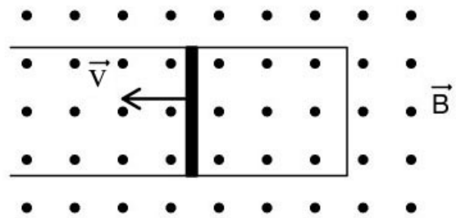
- Drop one of the rare-earth magnets down a vertical brass tube. What happens? Why?
- Place a thin piece of aluminum metal on top of a stiff piece of paper. Hold one of the rare-earth magnets under the paper below the aluminum. Note that there is, of course, no attraction of the aluminum to the magnet. Now move the magnet quickly, horizontally. What happens, why?
- Place the magnet on the thick sheet of aluminum, and let gravity slide it down. Compare this to letting the magnet slide down a thick book cover of the same inclination.

Problems (4)

30.2.1. A rectangular conducting loop is hung in a uniform magnetic field $\vec{B}$ directed into the page. The magnetic field only exists above the dotted line. The loop is then dropped. (a) Find the direction of the induced current during its fall. (b) Find the direction of the magnetic force on this current during the fall.

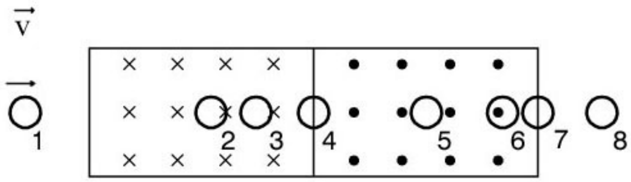


30.2.2. A metal rod is forced to move with constant velocity $\vec{v}$ along two parallel metal rails, connected with a strip of metal at one end. A uniform magnetic field $\vec{B}$ points out of the page. Find the (a) direction of the induced current in the rod and (b) the direction of the *magnetic* force on the rod.

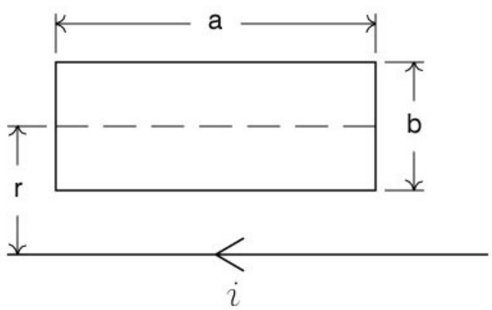


30.2.3. In the figure, a circular loop moves at constant velocity through regions where uniform magnetic fields of the same magnitude are directed into or out of the page. The induced EMF at locations, 2, 4, 6, 7, are (pick one):

a. clockwise,
b. counterclockwise,
c. zero.



30.2.4. A single turn rectangular loop of wire with length a=10 cm, width b = 5 cm and resistance $R = 20\Omega$ is placed near an infinitely long wire carrying current *i*=5 A, as shown in the figure. The distance from the long wire to the center of the loop is r= 20cm. (a) Find the magnitude of the magnetic flux through the loop. (a) Find the magnitude of the current in the loop as it moves *away* from the long wire with a constant speed v= 5 cm/s. Write down the direction of the current (clockwise or counterclockwise) induced in the loop.



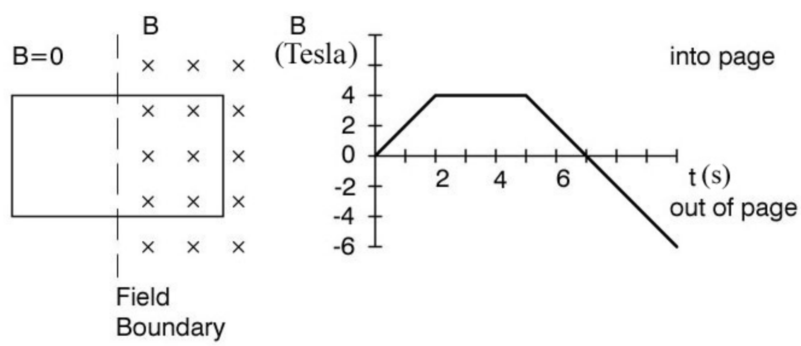
30.3. Electrical Generators

Lab Demonstration

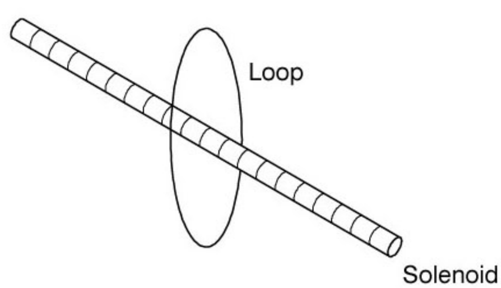
- Spin the crank of the hand generator with no electrical connection (i.e., no load). Note the torque you must apply.
- Now connect the generator to various loads of about 100 ohms, 10 ohms, and short-circuited (R_{load} ~ wires resistance). Note the qualitative torque you must apply. For what value of load is the torque the greatest and the least? Use conservation of energy to explain your observation.
- Is a large load a big resistance or a small resistance? Explain why the crank is harder to turn when the load is there. To do this use conservation of energy, conversion of mechanical to electric energy, and rotational work being torque times angle turned.
- Connect the hand generator to the oscilloscope function of the lab computer. This will give you an instantaneous picture of the output voltage as a function of time. Crank it at different rates and explain what you see.

Problems (3)

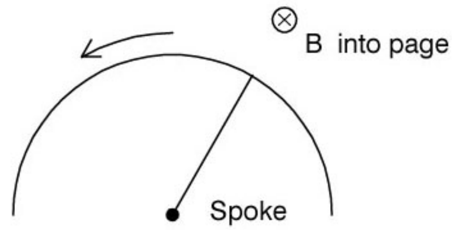
30.3.1. A rectangular loop of wire (one turn) with side lengths 0.20 m and 0.10 m is placed half way in a magnetic field as drawn below. The field as a function of time is also plotted below. Find the induced EMF at (a) t=1 s (b) t= 3 s (c) t=6 s. (d) At t=1 what is the force (a vector) on the loop if the resistance of the loop is 2 Ω?



30.3.2. A long solenoid of 2000 turns/meter and radius 0.05 m passes through a single turn loop with resistance of 1 Ω and radius of 0.15 m. The current in the solenoid is i(t)=(10 Amps) sin(400t), t in seconds. (a) Find an expression for the EMF induced in the loop. (b) If instead this current was in the loop, what do you expect, by symmetry, the EMF induced in the solenoid to be?



30.3.3. The horizontal component of the earth's magnetic field is $50\mu T$, North. A bicycle traveling west has wheels with spokes 0.25 m long. (a) Find the induced EMF across a spoke if the wheel is turning at 1 rev/sec. (b) Which end of the spoke is positive (see drawing)?



31.1. LC Oscillator

Lab Demonstration

Connect a capacitor to a switch where in one position the capacitor is in parallel with the voltage source, and in the other position it is in parallel with an inductor.

- Draw a graph of the voltage response.
- Measure and calculate the natural frequency and the period.
- Why does the graph of the experimental voltage differ from the theoretical? What could we do to make a "better" LC oscillator?

Problems (5)

The information given below is relevant for questions 1, 2, and 3. In a certain oscillating LC circuit, one of the plates of the capacitor (say, plate A) has maximum positive charge at t=0. The time period of oscillation is T.

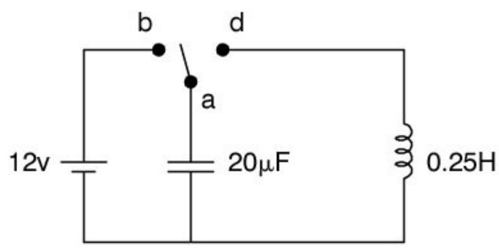
31.1.1. At what times $t > 0$ will the plate A again have maximum positive charge?
   a. T/2, 3T/2, 5T/2, 7T/2 ....
   b. T/4, 3T/4, 5T/4, 7T/4 ....
   c. T, 2T, 3T, 4T ....
   d. T/2, T, 3T/2, 2T ....
   e. T/4, 5T/4, 9T/4, 13T/4 ....

31.1.2. At what times $t > 0$ will the *other plate* of the capacitor have maximum positive charge?
   a. T/2, 3T/2, 5T/2, 7T/2 ....
   b. T/4, 3T/4, 5T/4, 7T/4 ....
   c. T, 2T, 3T, 4T ....
   d. T/2, T, 3T/2, 2T ....
   e. T/4, 5T/4, 9T/4, 13T/4 …

31.1.3. At what times $t > 0$ will the magnitude of the current through the inductor be a maximum?
   a. T/2, 3T/2, 5T/2, 7T/2 ....
   b. T/4, 3T/4, 5T/4, 7T/4 ....
   c. T, 2T, 3T, 4T ....
   d. T/2, T, 3T/2, 2T, …
   e. T/4, 5T/4, 9T/4, 13T/4,…

31.1.4. A 20 μF capacitor is initially charged by a 12 V battery by keeping the switch connected between the points a and b for a long time (see the adjacent figure). Then, at t=0, the switch is thrown from b to d so that points a and d are now connected and we have an oscillating LC circuit. Here L=0.25 H.

a. Find the maximum charge on the capacitor.
b. Find the maximum current in the inductor.
c. Compute the energy stored in the capacitor at t=1.5 ms.
d. Compute the energy stored in the inductor at t=1.5 ms.

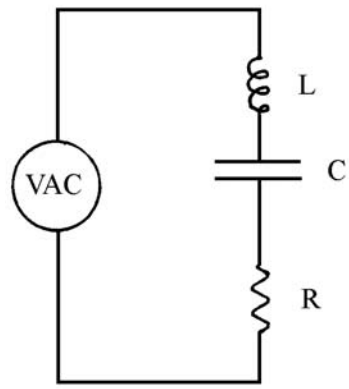


31.1.5. In an oscillating LC circuit, L=3.00 mH and C=2.70 μF. At t=0 the charge on the capacitor is 100 μC and the current is 1.00 A. The capacitor is charging.

a. What is the maximum charge on the capacitor?
b. What is the maximum current?
c. If the charge on the capacitor is given by q= Q cos(ωt + ϕ), what is the phase angle ϕ? Is it positive or negative?
d. What is the first time t >0 when the capacitor attains its maximum charge?

31.2. AC Circuit

Lab Demonstration

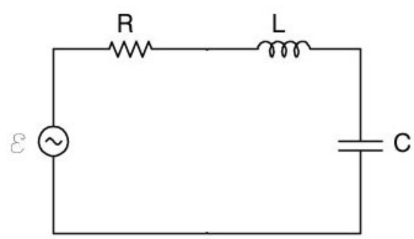


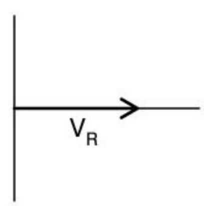
The "breadboard" for this experiment has an inductor with L=0.33 H (and a resistance of ~ 480Ω -- its a real inductor!). A capacitor with C=10nF and a resistor with R=1000 Ω. Connect these in series in the order L, C, and R. Connect the variable voltage output of the lab computer to the series combination. Turn on the output voltage and set the frequency near 1000Hz. Use an AC voltmeter to measure the voltage across the resistor as you increase the frequency. Dividing this voltage by the resistance gives you the current in the circuit (this is easy to do in your head because R=1000 Ω).

- Make a graph of I vs. f. What is the measured resonance frequency? Compare to theory. What is the current at resonance? Compare to theory.
- At resonance measure the voltages, V_L, V_C, V_R, across all three elements, L, C and R. Phasor (vector) add them and compare to the applied voltage. (Don't get faked out. Your voltmeter is probably measuring RMS, whereas an oscilliscope display--e.g., your voltage source from the computer--is showing you peak voltages.)
- Measure the voltage across the combination of L and C at resonance. Explain your result with phasors. If the inductor was ideal, i.e., if it had no resistance, what would $V_L + V_C$ equal?
- Both increase and decrease the frequency from resonance by a factor of 2 to 3. Measure V_L, V_C, V_R and show that these voltages, acting like phasors, add to the applied voltage.
- Use the oscilloscope function of the lab computer to measure the voltage across the entire LRC combination, and a second trace for the voltage across the resistor. This voltage tells you, with ohms law, the current in the circuit (why?). The dual sweep trace shows you the applied voltage and the current. Now vary the frequency from below resonance to above. Watch both the amplitude of the current and its phase relative to the applied voltage. Make sense of what you see.

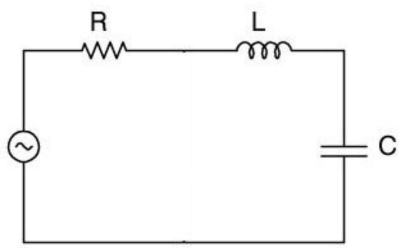
Problems (3)

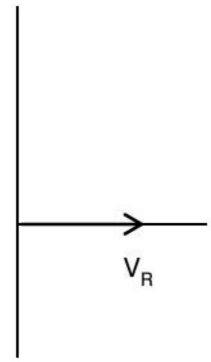
31.2.1. Consider the AC circuit shown in the figure containing $R = 40.0\Omega$, L=30.0 mH, and $C = 10.0\mu F$, and a generator whose EMF is given by $\mathcal{E} = \mathcal{E}_m \sin \omega_d t$. This generator has a *peak* voltage of 120.0 V. The frequency is f_d=200Hz. The current in the circuit can be written as i=I sin (ω t - ϕ). (a) Find the peak current I for this frequency. (b) Find the peak voltages across each element of the circuit. (c) Find the phase angle ϕ. (d) In the phasor diagram shown in the figure, first draw V_C and V_L *approximately to scale*. V_R is shown in the figure and this sets the scale of the figure. Next, complete the phasor diagram by drawing $\mathcal{E}_m$, and I, and showing ϕ.





31.2.2. Consider the AC circuit shown in the figure containing $R = 60.0\Omega$, L=50.0 mH, and C=80.0 μ F, and a generator whose EMF is given by $\mathcal{E} = \mathcal{E}_m \sin \omega_d t$. This generator has a RMS voltage of 120.0 V and the frequency f_d can be varied. (a) Find the RMS current at *resonance*. (b) At resonance, draw the RMS V_C and V_L *approximately to scale* in the phasor diagram shown in the figure (RMS V_R is shown in the figure and this sets the scale of the figure). (c) What is ϕ in this case?



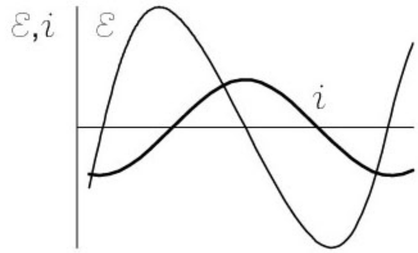


31.2.3. Current *i* and driving EMF $\mathcal{E}$ are shown in the figure for an AC circuit.

a. The phase constant ϕ in this case is:
   1. zero
   2. positive
   3. negative

b. The frequency of the generator f_d in this case is:
   1. equal to the natural frequency.
   2. more than the natural frequency.
   3. less than the natural frequency.

c. In this case
   1. $V_L > V_C$
   2. $V_L = V_C$
   3. $V_L < V_C$



32.1. Magnetic Materials

Lab Demonstration

- Try balancing a plastic rod that has either bismuth or copper sulfate located at the ends of the rod. Now place a magnet close to one end. What do you observe? What is the orientation of the rod relative to the magnetic field? Explain your observations.

33.1. Polarization in Nature

Lab Demonstration

Use a sheet polarizer to check the polarization of natural light sources. Hold the polarizer in front of your eye and rotate it back and forth through 90° as you look at:

- Room lights,
- Light reflected from the tile floor,
- Light reflected at a glancing angle from the black board,
- Light from the blue sky at various angles from the sun,
- Light from clouds.

What is an easy way to tell if advertised polarizing sunglasses are in fact polarizers and not just tinted glasses?

Problems (4)

33.1.1. What does polarization tell us about the nature of light?

33.1.2. What is the advantage of a pair of polarizing sunglasses over a tinted pair of sunglasses? How can you tell if a pair of sunglasses is polarizing or not?

33.1.3. How far above the horizon is the Moon when its image reflected in a calm Tuttle Creek lake is completely polarized?

33.1.4. The peak value of electric field for sunlight on Earth is about 1000 V/m. (a) Calculate the peak value of the magnetic field of sunlight on earth. (b) Which one is larger, the electric field or the magnetic field? (Pause for 10 seconds before you answer this question).

33.2. Polarized Light

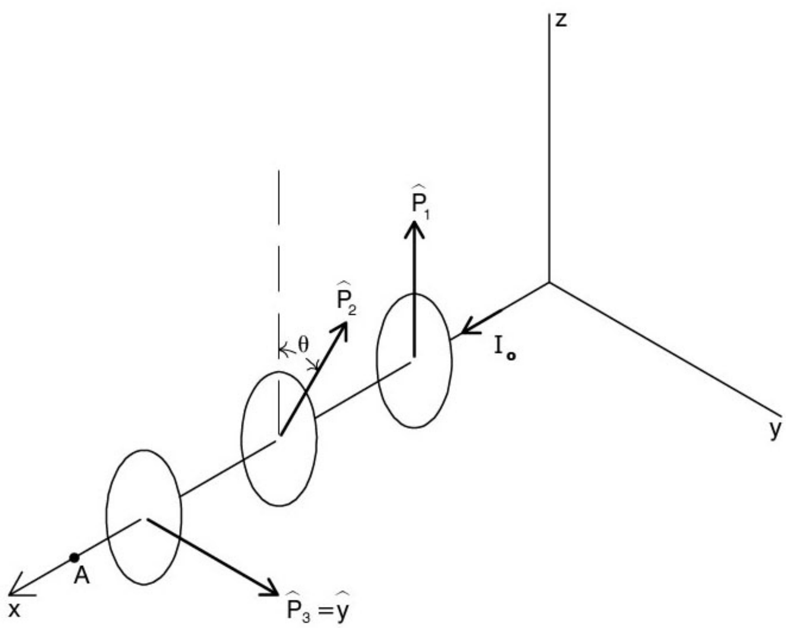
Lab Demonstration

- Look through two polarizers and rotate one relative to the other to qualitatively demonstrate the $\cos^2\theta$ functionality (the Law of Malus).
- Cross two polarizers, i.e., arrange them so that their optical axes are perpendicular and hence no light is transmitted. Now place a third polarizer between the two crossed polarizer and rotate its optical axis. How are the transmitted intensity and polarization related to the orientation of the third polarizer?

Problems (3)

33.2.1. Unpolarized light with an intensity of 100 units is incident on polarizer A with polarization axis tipped 30^o to the vertical. (a) What is the intensity and polarization of the light that passes through? (b) A second polarizer, polarizer B, is placed behind A so that the light from polarizer A is incident upon it. Polarizer B has its polarization axis parallel to the vertical. What is the polarization and intensity of the light after it passes through this second polarizer, polarizer B? (c) A third polarizer, polarizer C, is now placed between polarizers A and B at an angle θ from the vertical. How does the polarization of the light that finally comes out of polarizer B depend on θ?

33.2.2. Unpolarized light propagating along the x-axis with intensity I_0 passes through the following polarizer combinations. Find the resulting intensity and polarization direction as a function of θ at point A.

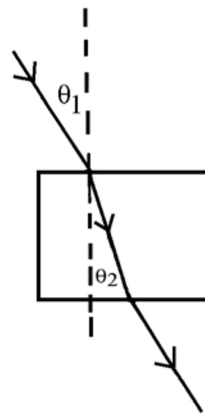


33.2.3. A beam of polarized light of intensity 43.0 W/m^2 is sent through a system of two polarizing sheets. *Relative to the polarization direction of that incident light*, the polarizing directions of the sheets are at angles θ for the first sheet and 90^o for the second sheet. If the intensity of the final, transmitted light is 8.6 W/m^2, what is the value of θ?

33.3. Refraction

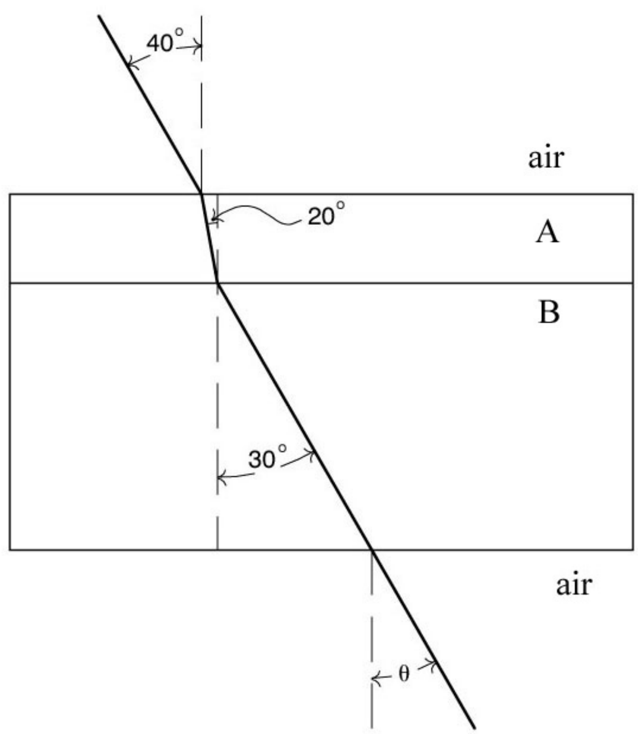
Lab Demonstration

Use the ray optics projector and shine rays at various angles (at least 3) from the normal. Measure the refracted angles, verify Snell's Law, and measure the refractive index of the material.



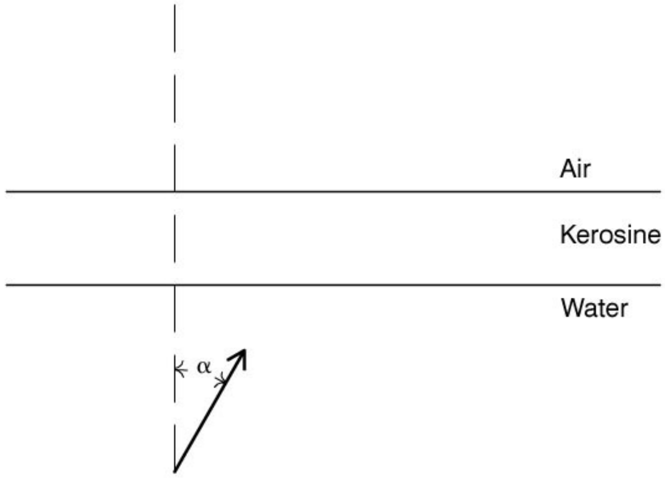
Problems (4)

33.3.1. For the drawing below: (a) Find the refractive indices of material A and B. (b) Find the angle θ.



33.3.2. The critical angle of a certain material (say, a piece of glass of unknown refractive index n) in air (refractive index of air is 1.0) is 40^0. What is the critical angle of the same glass if it is immersed in water (refractive index of water is 1.33)?

33.3.3. Consider a beam at an angle α from the vertical direction in water of index of refraction 1.33. A 5 mm layer of kerosene with n=1.30 is floating on top of the water. What is the minimum angle α necessary to achieve total internal reflection (a) at the water-kerosine and (b) at the kerosine-air interface?



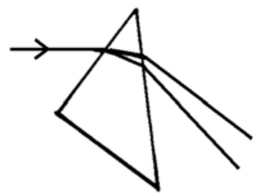
33.3.4. When green light in vacuum is incident at the Brewster's angle on a certain glass slab, the angle of refraction is 30^o. What is the index of refraction of the glass?

33.4. The Prism

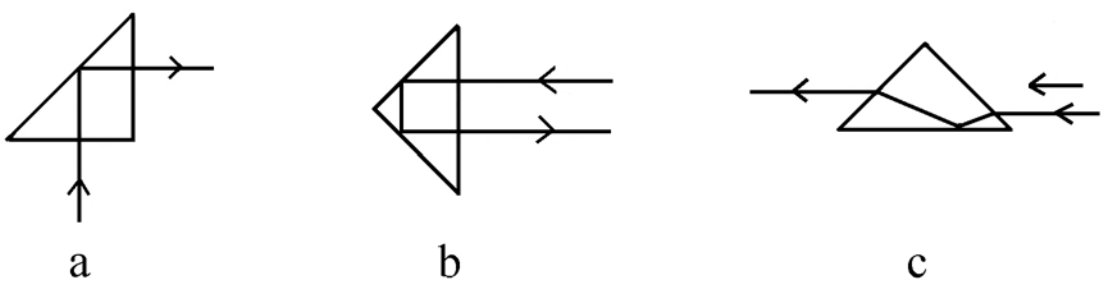
Lab Demonstration

A prism can be used to demonstrate a variety of interesting phenomena. Here we use a common 45°-45°-90° prism.

- Dispersion. Shine a white beam of light through one of the 45° corners as drawn. What is the order of increasing refraction of the colors. In other words, what color of light gets bent more by diffraction? Observe the beauty of the spectrum.

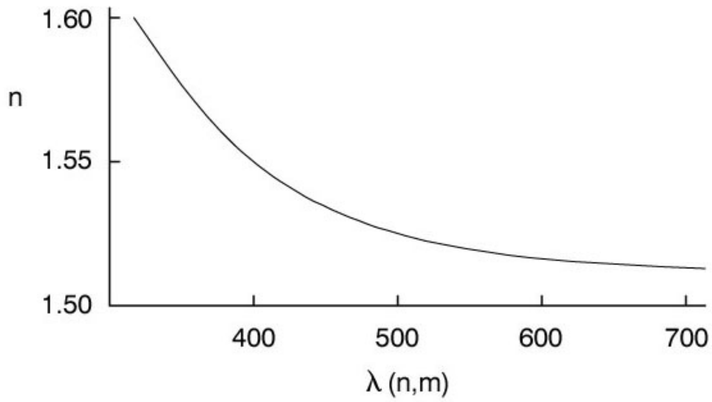


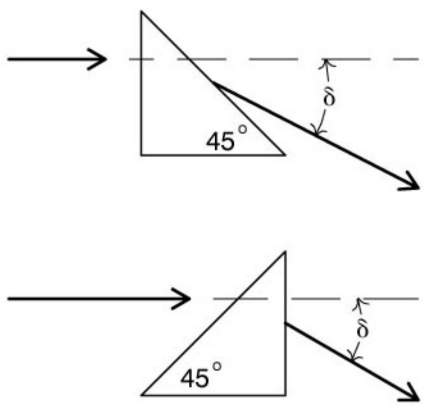
- Total Internal Reflection.
    a) 90° deviation. Shine light into one face toward the hypotenuses as drawn. Light is totally reflected from the clear glass hypotenuse. Look through it this way too.
    b) 180° deviation. Shine light into the hypotenuse toward the 90° corner. Look into this corner too. Move from side to side. Hold a printed page under your nose and look at this reflection through this corner. Where is the inversion?
    c) Dove prism. Look through the prism as drawn. Rotate the prism about an axis through the prism, parallel to the hypotenuse. What happens? Explain with ray diagram.



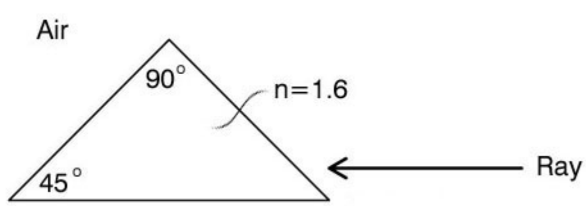
Problems (3)

33.4.1. Find the deviation angle δ for red light, λ =700 nm, and blue light λ =400 nm, for the two situations below. The prism refractive index is given in the graph.

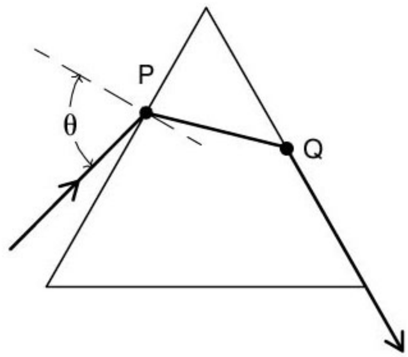




33.4.2. Complete the path of the incident ray in the diagram below.



33.4.3. Light enters an *equilateral* glass prism (n=1.56) at point P with incident angle θ and then refracts at point Q grazing along the face as shown in the figure.



a. Find the incident angle θ.
b. Mark the true answer below. If the incident angle θ is increased by 1^{o} from what is shown in the figure, then:
    1. Nothing new will happen at Q; light will still come out grazing along the face as shown in the figure.
    2. Light will not come out at Q; it will be totally internally reflected at Q.
    3. Light will emerge into air at Q.
c. Mark the true answer below. If the incident angle θ is decreased by 1^{o} from what is shown in the figure, then:
    1. Nothing new will happen at Q; light will still come out grazing along the face as shown in the figure.
    2. Light will not come out at Q; it will be totally internally reflected at Q.
    3. Light will emerge into air at Q.

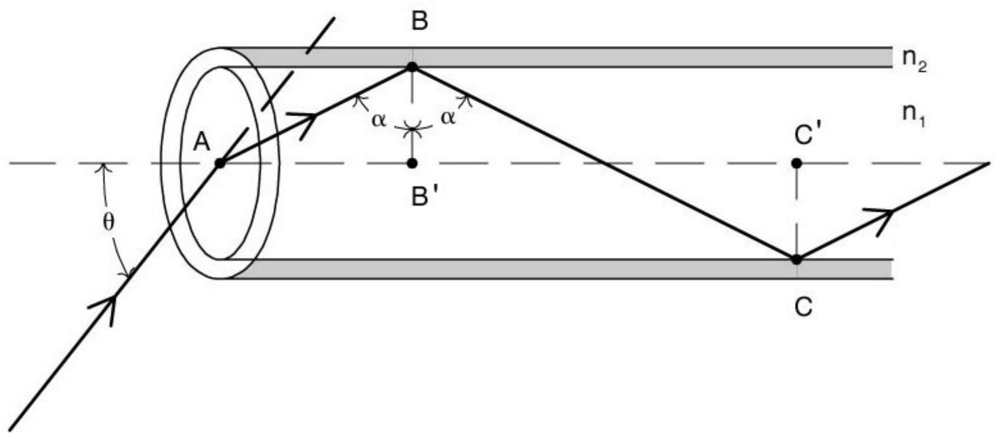
33.5. Fibers

Lab Demonstration

Mess around with the optical fibers.

Problems (1)

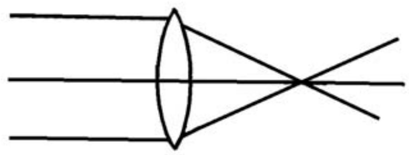
33.5.1. Consider an optical fiber of refractive index n_1 = 1.6 with a coating of index n_2 =1.4 shown in the figure below. The incident angle for a ray at point A is $\theta = 30^o$. The radius of the optical fiber is r=0.5 cm. (a) Find the critical angle for refraction at the point B. (b) It turns out that for the value of θ given above, the light ray will be totally reflected back into the fiber at point B. The next reflection will take place at point C. Find the distance of the path BC traveled by light between successive reflections. (c) Find how much time light takes to travel the distance BC. (d) Compare this (make a ratio) to the time it takes a light ray to travel along the fiber axis from B' to C'.



34.1. Ray Optics

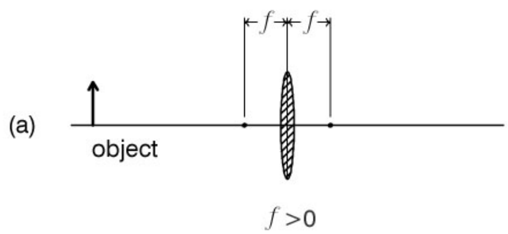
Lab Demonstration

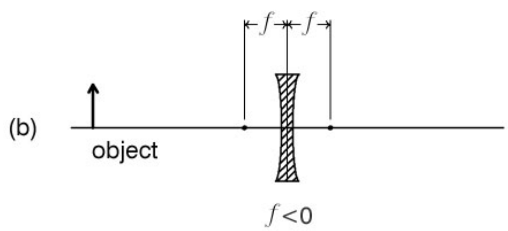
- Use the ray optics projector to create three parallel beams of light. Project these beams toward the lens and mirror cross sections to see how refraction and reflection can cause either convergence or divergence of rays hence focal points. Draw each case and label the focal point.

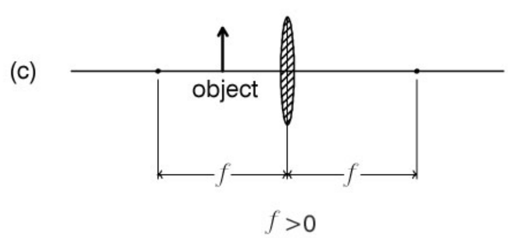


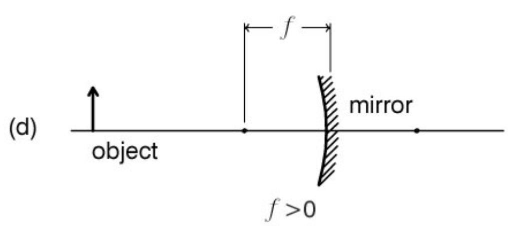
Problems (1)

34.1.1. Draw the three principal rays, find the image, and describe it as either real or virtual for the situations below.









34.2. Mirrors

Lab Demonstration

- Use the concave mirror to form a real image of a distant object. Draw a ray diagram to explain your observation.
- Hold the concave mirror close to your eye to form an image (real or virtual) of your eye (i.e., look into the mirror). Hold it far from your eye. What do you see? Why?
- Mess around with a convex mirror. Can it ever form a real, enlarged image?

Problems (2)

34.2.1. A concave shaving mirror has a focal length of 20.0 cm. It is positioned so that the upright image of a man's face is 2 times the size of the face. (a) How far is the mirror from the face? (b) What is the image distance? (c) Is the image real or virtual?

34.2.2. A small cup is positioned on the central axis of a spherical mirror. The magnification of the image of the cup is +0.250, and the distance between the mirror and its focal point is 2.00 cm. (a) What is the distance between the mirror and the image it produces? (b) Is the mirror concave or convex? (c) Is the image real or virtual?

34.3. Lenses

Lab Demonstration

Set up a luminous object, a lens, and an observation screen on the optical bench.

- Form an image of the object on the screen using a positive lens. Measure the image and object distances. Verify the thin lens formula. Draw a ray diagram and show consistency with both the calculation and the measurement. Measure the image and object size and compare to calculation and your ray diagram.
- Calculate the distance your lens should be placed from the luminous object to form a large, projected, real image on a distant wall. Try it and make it work.
- Now calculate the distance your lens should be placed from a screen to produce an image if the light source is far away. Try it and make it work.
- Mess around with a negative lens. Can you form a real image? Can you ever magnify (enlarge) with such a lens?

Problems (4)

34.3.1. Does the focal length of a lens depend on the fluid it is immersed in? What about the focal length of a spherical mirror?

34.3.2. Two converging lenses with the same focal length of 27.0 cm, are placed 16.5 cm apart. An object is placed 35.0 cm in front of lens 1. Where will the final image be formed?

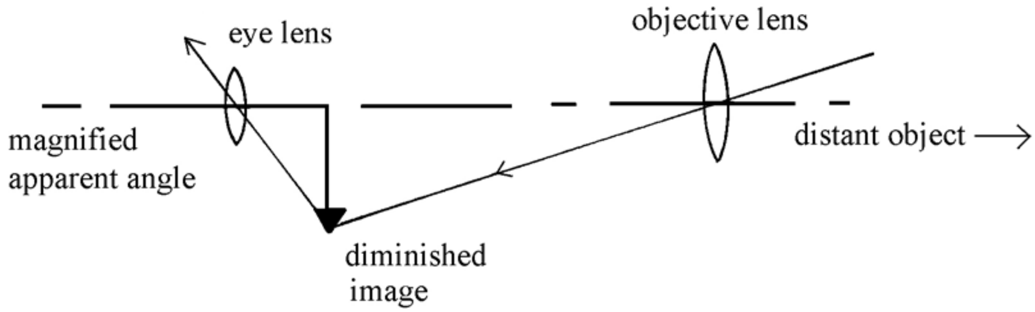
34.3.3. A converging lens with a focal length of 20 cm is located 10 cm to the left of a diverging lens having a focal length of 15 cm. (a) If an object is located 40 cm to the left of the converging lens, find the location of the final image. (b) What is the final magnification of the image? (c) Is the image upright or inverted?

34.3.4. A planoconvex lens forms an image of a nearby object. Does the image change if the lens is turned around?

34.4. The Telescope

Lab Demonstration

- Mount two lenses on the optical bench. Use f_o = 20 to 30 cm and f_{eye} = 3 to 5 cm. Place them approximately $f_o + f_{eye}$ apart. This is a telescope. Look through the eye lens (i.e., the eyepiece -- the one with f_{eye}) with the telescope pointed toward a distant object (many times f_o). Adjust slightly the distance between the objective lens (the one with f_o -- closest to the object) and the eye lens until the view is sharp (i.e., focus the telescope).



- Determine (approximately) the magnification of the telescope by viewing the image of the object with one eye through the telescope and the object directly with the other eye simultaneously. Relax, your mind will overlap these two images in your brain. Comparing sizes will allow a reasonable estimation of the magnification. Compare to calculation.
- With the telescope pointed toward a bright area (e.g., a window), hold a viewing screen (a piece of paper) behind the eye lens (about f_{eye} distance away) until a nice round circle of light forms. This is the exit pupil. Measure its diameter. Measure the diameter of the objective lens. Their ratio is the magnification. Compare to above.

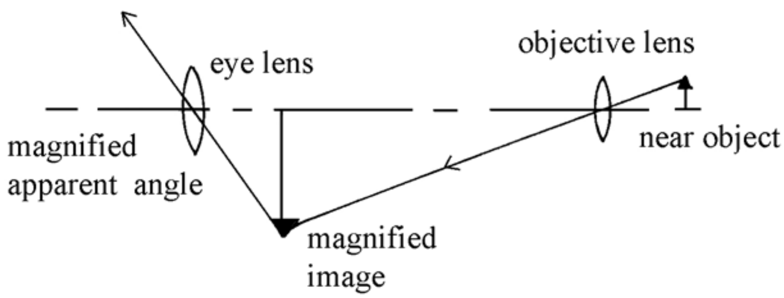
Problems (1)

34.4.1. If the angular magnification of an astronomical telescope is 40 and the diameter of the objective lens is 75 mm, what is the minimum diameter of the eyepiece needed to collect all the light entering the objective lens from a distant star located on the axis of the telescope?

34.5. The Microscope

Lab Demonstration

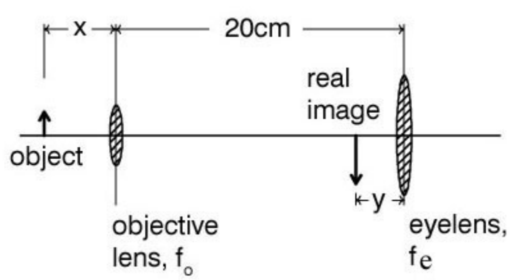
Mount two lenses on the optical bench. Use focal lengths for both of ca. 2 to 4 cm and place them 20 to 30 cm apart. Look through one lens and hold an object (e.g., some print) in front of the other, slightly more than one f away. Adjust the distance between the object and this objective lens carefully until you see an image while looking through the eye lens. You are focusing your microscope (compare to how one focuses a telescope).



- Using two eyes simultaneously, one looking through the microscope the other looking at the object, estimate your microscope's magnification. Using f_o, f_{eye} and the distance between the two lenses, calculate the magnification and compare.

Problems (1)

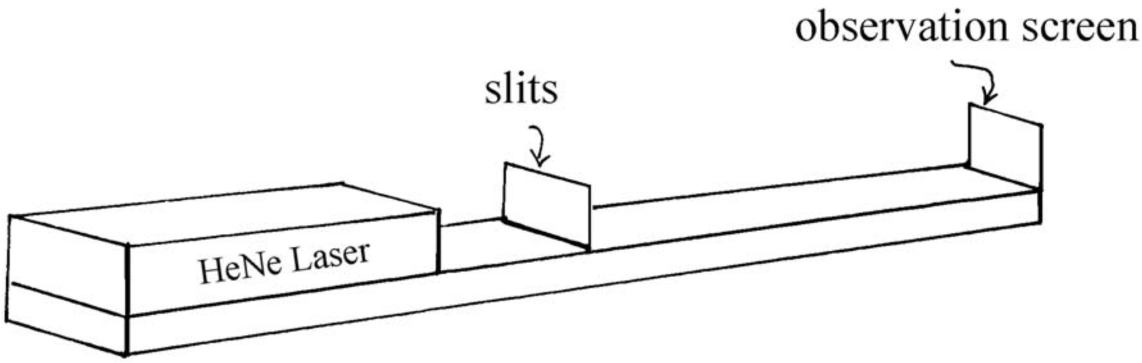
34.5.1. Drawn below is a lens arrangement for a microscope, f_e=5.0 cm and f_o=2.0 cm. The distance between the lenses is 20.0 cm. (a) the objective lens forms a real image of the object in front (to the left) of the eyelens. Where should this image be, relative to the eyelens, so that after light passes through the eyelens it can be viewed by a normal human eye, i.e. find the distance y. (b) What is the magnification of the eyelens? (c) Find x under the condition of part (a). (d) What is the magnification of the objective lens? (e) What is the total magnification of the microscope?



35.1. Young's Double Slit Experiment

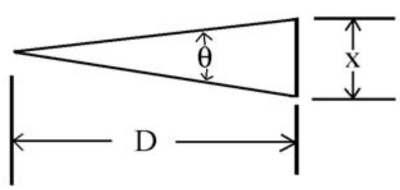
Lab Demonstration

Set up a laser to shine its beam toward the double slits. Adjust until the spot of the beam falls across both slits. Place an observation screen about 0.5 meter or more behind the slits (the larger the distance to the observation screen, the better your experimental results will be). Observe and describe the fringe pattern.



- Measure the distance between consecutive fringes and the distance between the double slit and the observation screen and calculate the angular spacing in radians.* Compare this to theory.
- Very delicately use a sharp edge (e.g., the edge of a piece of paper or a knife blade) and try to block just one of the slits. If you can do this, what do you see? Explain.

*Digression on small θ. You're big kids now and, when dealing with small angles, its time to wean yourself from trigonometry. For example in the diagram below, which is related to the fringe spacing problem above, what is the angle θ?



From a strictly trigonometric approach one can show

$$\theta = 2 \arctan (x/2D)$$

not particularly aesthetically pleasing. Instead, if I approximate the side x as an arc, I find

$$\theta = x / D$$

with θ in radians. This is clean, simple, and hence beautiful! I can also do the calculation in my head. But, you might protest, is it correct, i.e., accurate? It is for small θ, i.e., $\theta << 1$ radian $\simeq$ 57 deg. As an example let D=0.5m and x=1cm. We find

$$\theta = 2 \arctan (x/2D)=0.0199993 \text{ rad.} =1.14588 \text{ deg.}$$

$$\theta = x/D =0.0200000 \text{ rad.} = 1.14592 \text{ deg.}$$

These are essential equal, differing by only 4 parts in 100,000. Another way of saying this is that for $\theta << 1$ rad. $\simeq 57$ deg,

$\sin\theta \simeq \theta$

$\tan\theta \simeq \theta$

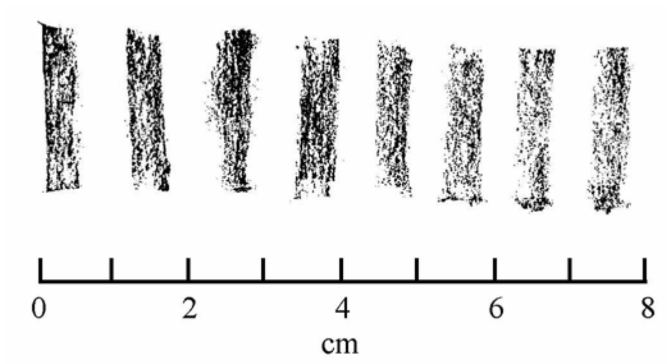
$\cos\theta \simeq 1$.

Thus arctan $\theta \simeq \theta$ and we have $\theta = 2$ arctan (x/2D)=2x/2D=x/D.

Problems (3)

35.1.1. In a double-slit arrangement the slits are separated by a distance equal to 1000 times the wavelength of the light passing through the slits. What is the distance between the second-order and third-order maxima on a screen placed 2.0 m from the slits?

35.1.2. Drawn below is a set of interference fringes observed on a screen 3.0 m away from a double slit arrangement. If the wavelength of light used is 633 nm, find the separation between the slits.



35.1.3. A thin flake of transparent plastic (n=1.6) is used to cover one slit of a double-slit interference arrangement. The central point on the viewing screen is now occupied by what had been the 8th bright fringe before the plastic was used. If the wavelength of the light used is 489 nm, what is the thickness of the plastic?

35.2. Thin Film Interference

Lab Demonstration

- Clean two microscope slides with chem-wipes. Press them together with your fingers and look at the reflection of the overhead lights in them. You should see interference fringes. What color are they and why? What happens when you press harder? Why?
- Suspend a soap film on a wire frame in a vertical plane and let it sit for a while (with preferably little air movement around it). Look for interference fringes. Record (draw) these fringes at various times after the initial suspension. What is the thickness of your film?
- Blow some soap bubbles. What gives bubbles their iridescent color?

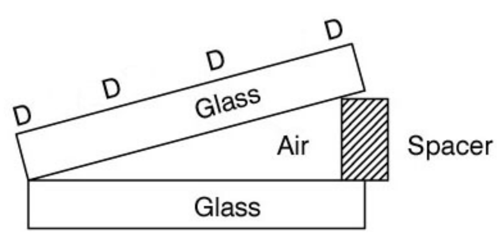
Problems (4)

35.2.1. What is the *minimum, non-zero thickness* of a soap film (n=1.34) that would appear black if illuminated normally with red light of wavelength 630 nm. Assume there is air on both sides of the soap film.

35.2.2. Antireflective coatings are used on lenses to eliminate various colors on reflection. What is the *minimum*, *non-zero* thickness for such a coating (n=1.4) applied to a glass lens (n=1.55) such that red light of wavelength 630 nm will be eliminated for light at normal incidence?

35.2.3. A thin layer of nickel is optically transparent and has a refractive index of 1.58. Professor Klabunde of KSU Chemistry makes thin layers of nickel on glass (n=1.50), which are 180 nm thick. Upon reflectance what color do these films of nickel appear to be, i.e., what wavelength(s) (measured in air) of *visible* light are reflected? Give both wavelength and color.

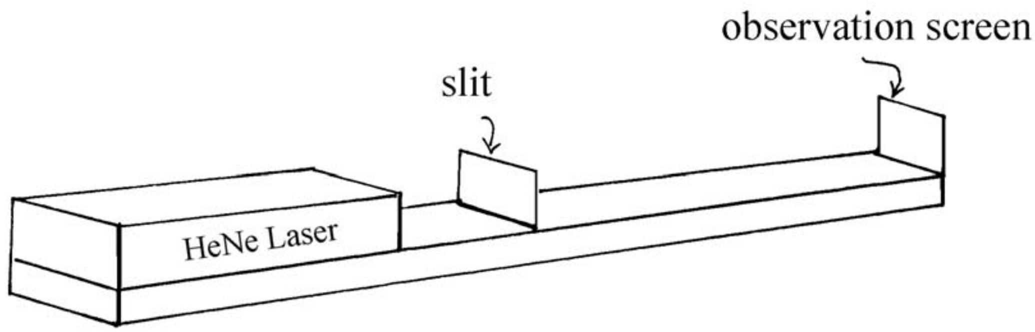
35.2.4. Two pieces of flat glass touch at one end. They are separated at the other end by a thin spacer as drawn. When illuminated with orange light of wavelength 600 nm, one observes interference fringes due to this wedge of air between the glass plates. A dark fringe appears where they touch and a total of four dark fringes (labeled D) are seen, the fourth being next to the spacer. How thick is the spacer?



36.1. Single Slit Diffraction

Lab Demonstration

Set up a laser to shine its beam on a single slit. Place an observation screen about 0.5 meter or more behind the slit. Observe, draw, and describe the pattern on the screen.



- Measure the width of the diffraction pattern and the distance between the slit and the screen and calculate the angular width in radians. Compare to theory.
- Try different wavelengths if available.
- Measure the width of a human hair with diffraction by holding a hair in the beam and measuring the diffraction pattern. Note that a hair is a "negative" (a reverse) of a slit. Then by Babinet's principle the diffraction patterns are very similar. Human hair should be on the order of 70 microns.
- Rest your arm on the table and let the laser beam pass between your thumb and index finger. Squeeze down on the beam and observe the diffraction pattern on a distance screen.

Problems (3)

36.1.1. A screen is placed 50.0 cm from a single slit, which is illuminated by red light of wavelength 700 nm. If the distance between the first and the third minima in the diffraction pattern is 3.00 mm, what is the width of the slit?

36.1.2. Why can you hear around corners but not see around them?

36.1.3. Which is more easily diffracted around buildings, AM or FM radio waves? Why?

36.2. Circular Aperture Diffraction

Lab Demonstration

Repeat 36.1 but for a circular aperture. Compare theory and experiment.

Problems (3)

36.2.1. (a) How small is the angular separation of two stars if their images are barely resolved by a telescope with lens diameter of 76 cm and focal length of 14 m? Assume λ =550 nm. (b) Find the distance between these barely resolved starts if each of them is 10 light years away from the earth.
(c) For the image of a single star in this telescope, find the *diameter* of the first dark ring in the diffraction pattern, as measured on a photographic plate at the focal plane.

36.2.2. In laser welding operations one desires to focus the laser to as small of a spot as possible to create the largest intensity (power per unit area). The size of the spot is determined by diffraction. Consider a CO_2 laser beam with λ =10.6 μ . The beam is 20 mm in diameter and uniformly illuminated across its diameter. What is the *diameter* of the central maximum spot if this beam is focused by a lens with focal length f=50 cm? What could one do to achieve a smaller spot size with this laser?

36.2.3. (a) Calculate and compare the theoretical minimum angles of resolution of an optical telescope (400 nm $\leq \lambda \leq$ 700 nm) of diameter 1.0 m to a radio telescope operating at λ =21 cm and diameter 50 m. Which telescope has a better resolving ability? (b) By placing two radio telescopes far apart and mixing their signals electronically, the effective size of the telescopes becomes equal to the distance between the two individual telescopes as far as resolving power is concerned (so-called "Long Baseline Interferometry"). Find the approximate distance between two radio telescopes operating at λ =21 cm necessary so the angular resolution is the same as the 1.0 m optical telescope.

36.3. Diffraction Grating

Lab Demonstration

- Shine a laser through a diffraction grating. Describe the diffracted spot pattern. Measure the angles for each diffraction order. Find the wavelength of the light using these data, the specified grating lines per unit length, and the diffraction grating formula. Compare to the known wavelength.
- Shine a white light beam through the grating. Observe the spectrum. Measure the angle and calculate the wavelength at the limit of visibility at the blue end of the spectrum.
- Shine a laser through a piece of woven material (e.g., a thin shirt). What do you see? What is the thread spacing?

Problems (2)

36.3.1. A Diffraction grating has 350 rulings per millimeter. If it is illuminated by light of wavelength 600 nm at normal incidence, how many maxima are there in the full diffraction pattern?

36.3.2. A diffraction grating has 300 rulings per mm. For m=1 what is angular separation of $\lambda = 400$ and 700 nm (i.e. between the two extremes of the visible spectrum).

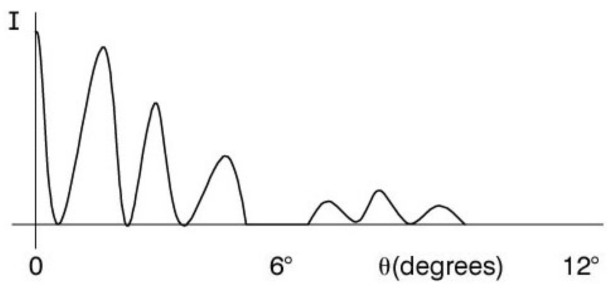
36.4. Diffraction

Lab Demonstration

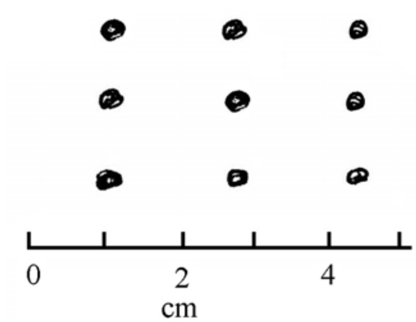
- Place a piece of window screen in front of the objective lens of a telescope. Look through the telescope at a bright, distant object. What do you see, that isn't there without the screen. Why?
- Look at a bright light through a piece of fine screen, cloth, or tissue. What do you see and why?

Problems (4)

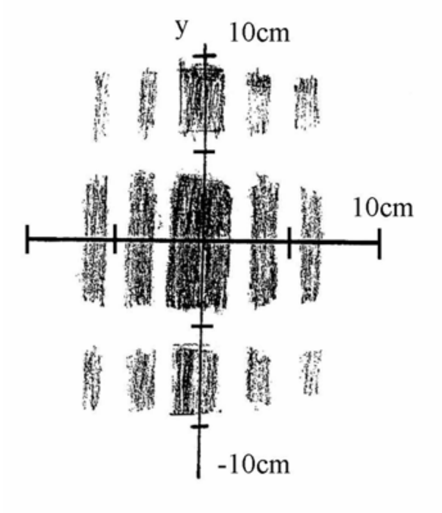
36.4.1. Light of wavelength 630 nm passes through a double slit. Consider the interference of light from the two slits and also the diffraction of the light through each slit. The intensity I versus angular position θ for this experiment is shown in the figure. (a) Calculate the slit width. (b) Calculate the slit separation.



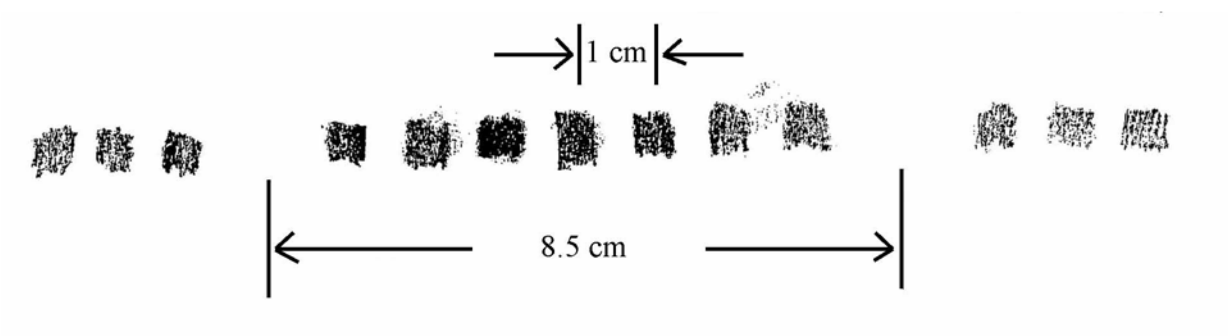
36.4.2. Drawn below is a diffraction pattern (an array of bright spots) obtained by shining a laser with light of wavelength 488 nm through a wire screen. The distance from the screen to the diffraction pattern is 2.0 m. What is the vertical spacing of the screen wires?



36.4.3. In a darkened room you observe the rectangular diffraction pattern shown here. The pattern is 5 meters from the tiny hole that made it. Find the approximate x and y dimensions of the hole, and describe its shape assuming λ = 600 nm.



36.4.4. Drawn below is a two-slit interference/diffraction pattern due to λ =600 nm light. This pattern is observed 5.0 m from the two slits. (a) What is the width of either slit given that the slits have an equal width? (b) What is the center-to-center separation of the slits? (c) A flood occurs in the lab! The apparatus is immersed in water with refractive index n=1.33. What happens, if anything, to the 1 cm fringe spacing?



37.1. Time Dilation

Lab Demonstration

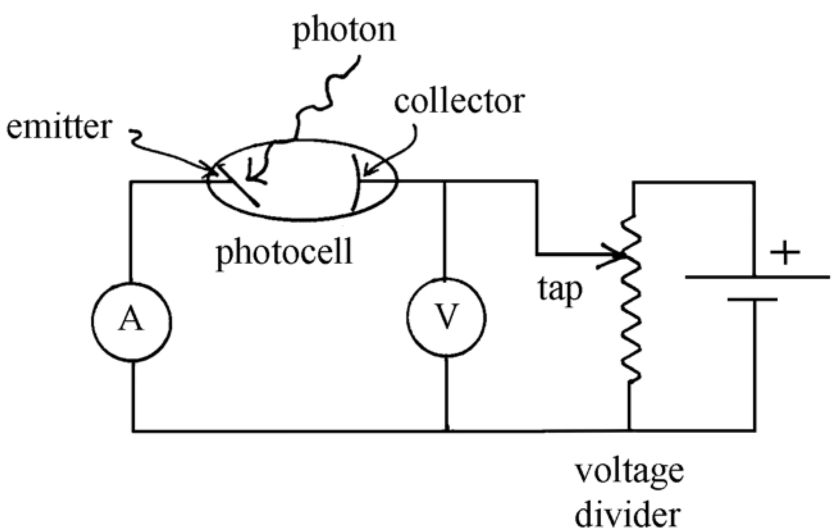
Run as fast as you can. While running note that everybody else's time seems to run slower than yours. When they observe you, what do they see? When you stop and compare times notice that they appear to have aged more than you. Is this because running is good demonstration and helps keep you young? By the way, did you feel more massive while you were running?

38.1. The Photoelectric Effect

Lab Demonstration

In this experiment you will shine light on the emitter of a photocell. If the photons of light have enough energy, electrons will be emitted from the emitter (one e^- per photon), pass through a vacuum in the photocell and be collected by the collector. Thus current will be measured with an ammeter. Depending on the energy per photon and the work function of the cathode material, the electrons will jump out of the cathode with a certain energy. This emission energy can be opposed by a voltage applied across the photocell with a bias such that the collecting electrode is negative (hence repels the electrons). The voltage which completely stops the electron flow (current) tells us the emission energy of the photo-electrons (recall $U = q\Delta V$ and electron volts).

- Turn on the mercury lamp and let it warm up. Avoid looking at the lamp since its UV light can hurt your eyes.
- Connect the circuit as drawn below.



- Set the filter wheel on the box to one of the wavelengths. This allows only that wavelength of the Hg lamp to pass to the photocell. Put the lamp right next to the filter. Increase the voltage until the current stops decreasing and levels of at some small, but probably not zero value. If the apparatus was purely dependent on the photoelectric effect, the large voltage would make the current zero, but the device is not perfect and a little, nonzero, "leakage" current is present. The critical measurement comes when you slowly decrease the voltage. The small current should remain constant for a while and then begin to change. This change is due to photoelectrons. Hence the voltage you want to measure is that when the current just begins to change. This is the stopping voltage. Record this stopping voltage. What is its significance?
- Repeat for the other two wavelength filters.
- Look at the photoelectric effect formula and find a way to plot stopping voltage and wavelength so that the graph is linear. From this graph find the work function and Planck's constant.

Problems (2)

38.1.1. The work function of cesium is 2.14 eV. (a) What is the cut off wavelength, i.e., the light wavelength above which photoelectrons are not emitted? (b) If light with wavelength of λ =420 nm shines on bare cesium metal, what will be the energy of the emitted photoelectrons? (c) If the intensity of the λ =420 nm light is increased, will the energy of the photoelectrons increase?

38.1.2. When light of wavelength 400 nm shines upon a lithium surface, electrons with an energy of 0.83 eV are emitted. (a) When the light intensity is doubled, what changes occur, if any, in the energy and the number of electrons emitted? (b) When the wavelength of light is changed to 450 nm, what is the energy of the emitted electrons?

39.1. Line Spectra

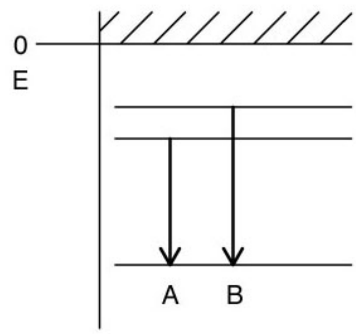
Lab Demonstration

Use the spectroscope to observe:

- Emission lines from the discharge tubes provided. Draw the line spectra observed, labeling each line with the wavelength as measured from the scale in the spectroscope.
- Pay special attention to hydrogen. Fit its lines to the Balmer series.
- Observe a white light spectrum. Place colored filters between the light and the spectrometer and explain your observations.
- Look at the spectra of the photodiodes provided. Emissions from photodiodes occur when electrons jump across an energy band gap. Calculate these band gap energies (in joules and eV) from your spectroscopic measurements.

Problems (2)

39.1.1. In the energy level diagram to the right which transition yields the "bluer" photon, A or B?



39.1.2. Drawn to the right is an energy level diagram for an atom. (a) What is the ionization energy from the ground state? (b) If the atom is in the ground state and is hit by a 5.0 eV neutron, how much energy is transferred from the neutron to the atom? (c) What is the wavelength of the photon that is emitted when the atom falls from the n=3 level to the n=2 level?