PHYSICS PROBLEMS:
Electricity, Magnetism, and Optics

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To the Reader

Physics students often complain that they understand the physics but cannot solve problems. While their professors might think that impossible, the dilemma is real to the student. This book is an attempt to bridge that very real gap.

Physics Problems: Electricity, Magnetism, and Optics is designed to engage you in a discussion of physics problems as if you were in a small discussion class. The style is conversational and the format should help you sort out your own strengths and weaknesses as you actually work on problems.

Successful problem-solvers have at one time or another learned to do three things:

(1) Make a serious attempt at solving a problem and thereby benefit from successes and failures which occur.
(2) Obtain feedback from a teacher, a fellow student, or a book that aids in identifying and eliminating errors.
(3) Criticize their own work, requiring that solutions make sense and that they be consistent with some general conceptual framework.

This book is intended to give you a great deal of practice in doing the first two and some of the third. The format will give you feedback in the form of answers to questions and will allow you to bypass sections that you don't need. The book assumes that you are or have been enrolled in a physics course, so it does not attempt to develop concepts as fully as a textbook would. In each chapter, a Programmed Study Section reviews the necessary physical concepts, emphasizing the high points of particular topics, the meaning of symbols, graphical analysis, mathematical techniques, and diagrams used to present these concepts.

Physic Problems: Electricity, Magnetism, and Optics covers topics normally included in the second semester of a physics course. A separate, self-contained book, *Physics Problems: Mechanics and Heat,* covers topics from the first half of a year-long course in physics. Each book is independent, so they can be used separately or together.

How to Use This Book

To make this book work best for you, you should be familiar with its flexible format. Each of the chapters has four sections:

- Sample Problems and Objectives
- Programmed Study Section
- Programmed Solutions to Sample Problems
- Self-Test

The Sample Problems and Objectives give a preview of the content in each chapter. First try to work the sample problems and then compare your solutions with the answers on the next page. If you can solve all the problems and if the objectives are familiar, you can probably skip the chapter or skim it quickly. Be sure you read the objectives. Even if the problems seem easy, the discussion often covers techniques that will help you solve more difficult types of problems.

If either the problems or the objectives cover unfamiliar material or if your comprehension is shaky, turn to the Programmed Study Section which follows. This section reviews the concepts and techniques basic to solving the problems in the chapter. The discussion is presented in numbered frames. Each frame will present some information and ask you a question or give you a problem to solve. By checking your answer with the one given below the dashed line, you can assure that you understand each part of the discussion. If your answer is different from the one given, be sure you understand why before you go on to the next frame. An explanation is often provided as well as the answer. These explanations should be considered carefully if you have given an incorrect response.

Even if you can correctly answer the sample problems, it may be useful to go through the Programmed Study Section comparing your technique with that given. The combination of techniques may be more effective than either one individually. There is more to be learned than just the answer to a specific problem.

The third section presents a step-by-step solution to each of the sample problems. This section is also programmed so that you actually work out the problem yourself, checking your progress at each step. If you still have difficulty, you may wish to reread the Programmed Study Section.

Finally, the problems in the Self-Test will allow you to test your ability to solve problems like those discussed in the chapter. See if you are able to handle the problems, checking the answers which follow.

If you want to review a particular type of problem or a problem in a certain area of physics, look up the topic in the Index. Turn to the appropriate chapter and read the sample problems. When you find the type of problem you're looking for, turn to the solution of that sample problem.

You will be able to write your answer in the spaces provided in each frame. However, room has not been left for all calculations and lengthy solutions, so you may wish to keep some scratch paper handy. This book will help most if you actually try to answer the questions in each frame. Cover the printed answer and then compare your answer with the one given.

This book is not, of course, a physics textbook; rather, it assumes that you are either taking or have taken a physics course. So the Programmed Study Sections only highlight those techniques and concepts necessary to problem-solving in that chapter. But if you want to read fuller explanations on a particular topic, the Cross-Reference Chart on page xiii will help you locate the appropriate pages in some of the major physics texts.

REFERENCES FOR SELECTED TEXTBOOKS IN INTRODUCTORY PHYSICS*

Atkins, Kenneth R., *Physics,* 2nd edition (New York: John Wiley & Sons, Inc., 1970).

Bueche, Frederick, *Introduction to Physics for Scientists and Engineers* (New York: McGraw-Hill Book Company, 1969).

Freeman, Ira M., *Physics: Principles and Insights* (New York: McGraw-Hill Book Company, 1973).

Gamow, George, and Cleveland, John, *Physics, Foundations and Frontiers* (New Jersey: Prentice-Hall, Incorporated, 1969).

Halliday, D., and Resnick, R., *Fundamentals of Physics* (New York: John Wiley & Sons, Inc., 1970).

Marion, Jerry B., *Physics and the Physical Universe* (New York: John Wiley & Sons, Inc., 1971).

Miller, Franklin Jr., *College Physics* (New York: Harcourt Brace Jovanovich, Inc., 1972).

Sears, Francis W., and Zemansky, M. W., *University Physics,* 2 pts, 4th edition (Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1970).

Weidner, Richard T., and Sells, Robert L., *Elementary Classical Physics,* 2nd revised edition, Vol. 1 and 2 (Boston: Allyn and Bacon, Inc., 1973).

*The mathematical level in *Physics Problems: Electricity, Magnetism, and Optics* is noncalculus; however, this book discusses many of the concepts and problems presented in textbooks which include calculus.

Chapter in this book	Atkins	Bueche	Freeman	Gamow & Cleveland	Halliday & Resnick	Marion	Miller	Sears & Zemansky	Weidner & Sells
1 Coulomb's Law	13	18	16	12	22	6	17	24	22
2 Electric Fields & Gauss's Law	14	18,19	16	12	23,24	8	18	25	23,24
3 Electric Potential	14	20	16	12	25	7,8	-	26	25
4 Magnetic Fields	16,17	24,25	18	14	29,30	9	21	30,31,32	29,30
5 Faraday's Law of Induction	-	26	19	14	31	-	21	33	31
6 Current Electricity	15	21,22	17	13	27,28	-	19,20	28,29	27,28
7 Electric Energy, Heat, and Power	15	21	17	13	27	-	19,20	28,29	27
8 Reflection and Refraction	-	31	14	15	36	-	24	38,39,40	36,37

Contents

CHAPTER ONE
Coulomb's Law

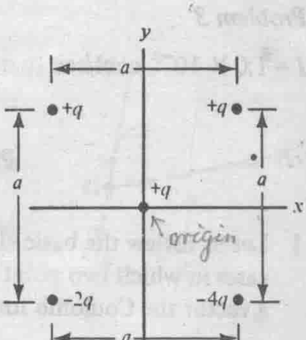
If the sample problems and objectives below identify your weak points, go directly to the programmed study section on page 2. If not, try the problems and compare your answers with those that follow. If you can do all the problems easily and if you are familiar with the objectives, you may wish to skip all or part of this chapter. The programmed study section covers techniques and concepts basic to solving the sample problems and fulfilling the objectives in this chapter. A programmed, step-by-step solution of each sample problem begins on page 5. A self-test is included at the end of the chapter.

SAMPLE PROBLEMS AND OBJECTIVES

Problem 1

Four charges are arranged as shown. Find the electrostatic force exerted on the charge at the origin.

$a = 1.0$ m, $q = 2.0 \times 10^{-6}$ coul



Objectives:
1. Reviewing the vector nature of electrostatic forces.
2. Reviewing right triangles.

Problem 2

Two positive charges separated by a distance of 0.1 m repel each other with a force of 18 nt. What is the charge on each if the total charge is 9.0×10^{-6} coul?

Objectives:
1. Solving problems algebraically prior to numerical substitution.
2. Solving quadratic equations.

Problem 3

The hydrogen atom can be pictured as an electron moving with constant speed in a circular orbit about a proton. The orbital radius is 5.3×10^{-11} m. This motion of the electron can be considered a current flow. What is the value of the electron current in coul/sec?

Objectives:
1. Using Coulomb's law in a "practical" case in which typical numerical values are discussed.
2. Reviewing the dynamics of circular motion.
3. Introducing the concept of electric current.

Answers to Sample Problems

See page 5 for programmed, step-by-step solutions to these problems.

Problem 1

$F_{total} = 4.21 \times 10^3$ nt at an angle of 14^0 to the right of the $-y$ axis.

Problem 2

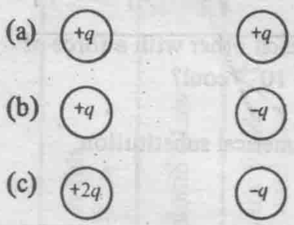
$q_1 = 5 \times 10^{-6}$ coul
$q_2 = 4 \times 10^{-6}$ coul

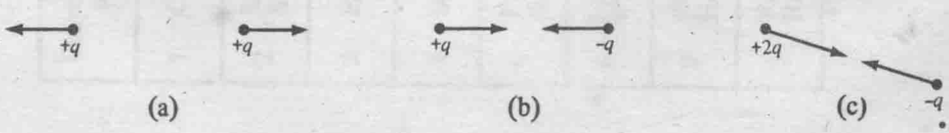
Problem 3

$I = 1.0 \times 10^{-3}$ coul/sec

PROGRAMMED STUDY SECTION

1 Let us review the basic elements of Coulomb's law. Below are shown three different cases in which two point charges interact with each other. In each case indicate by a vector the Coulomb force acting on each charge.



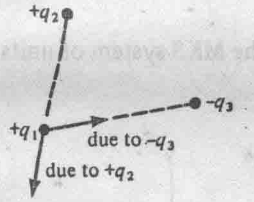


2 As in the examples of the first frame, like charges "repel" and unlike charges "attract." For the case of two charges interacting with each other the ____________ of the Coulomb force acting on each charge is the same. The ____________ of the Coulomb force on each is along the line joining the two charges with the direction determined by the types of charges involved.

---

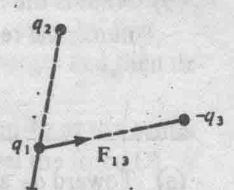
magnitude; direction

3 For the configuration of charges shown, indicate by vectors the electrostatic forces exerted on q_1 by q_2 and by $-q_3$. Indicate only the forces on q_1. All charges have the same magnitude.



4 Here we have labeled as $\mathbf{F}_{12}$ the electrostatic forces acting on q_1 by its interaction with q_2. $\mathbf{F}_{13}$ is similarly the force on q_1 by q_3. The electrostatic forces $\mathbf{F}_{12}$ and $\mathbf{F}_{13}$ are vector forces acting on q_1. To completely specify these vectors we need to know the magnitude and direction of each.

Will the directions (senses) of the forces in the diagram be as shown even if the magnitudes of the charges are altered?



Yes. The directions of the forces are determined by the signs (like or unlike) of the paired charges and their configuration (i.e., the line joining the pair). The directions are not determined by the magnitudes of the charges.

5 Although we have not selected a reference direction (i.e., coordinate system), we do know the directions of the electrostatic forces between q_1 and q_2 as well as between q_1 and q_3. In your own words, what is the direction of the electrostatic force exerted on one charge by a second charge?

Along the line joining the charges, being either repulsive or attractive depending on whether the charges are of the same or opposite sign

6 The quantity to be determined now is the magnitude of the electrostatic force. Write the scalar equation which gives the force on a charge q_1 due to another charge q_2. Assume the charges to be separated by a distance r_{12}.

$F_{12} =$ ____________________

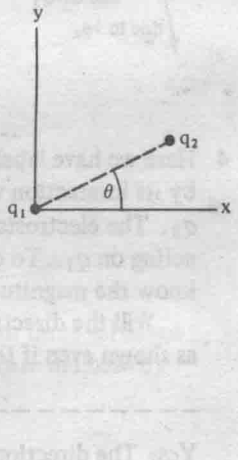
$$F_{12} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r_{12}^2}$$

This equation is known as Coulomb's law. Some specifics about the equation should be pointed out:

r_{12} is the distance from q_1 to q_2

$\frac{1}{4\pi\epsilon_0}$ is a constant equal to 9×10^9 nt-m^2/coul^2 in the MKS system of units

7 Two point charges $q_1 = 4.0 \times 10^{-6}$ coul and $q_2 = -8.0 \times 10^{-6}$ coul are separated by 4 m as shown.



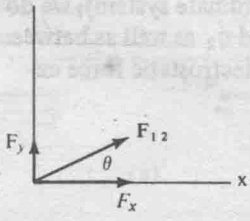
(a) What is the direction of the electrostatic force on q_1?
(b) What is the magnitude of the force on q_1? Obtain a numerical result.

(a) Toward q_2 along the line connecting q_1 and q_2

(b) $F_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2}$

$F_{12} = 18.0 \times 10^{-3}$ nt

8 Let θ in the problem be 30°. What are the x and y components of $\mathbf{F}_{12}$?



$F_x = F_{12} \cos\theta$
$F_x = 15.6 \times 10^{-3}$ nt
$F_y = F_{12} \sin\theta$
$F_y = 9.0 \times 10^{-3}$ nt

9 Describe fully the electrostatic force acting on q_2 due to q_1.

It is oppositely directed to $\mathbf{F}_{12}$ and of the same magnitude.

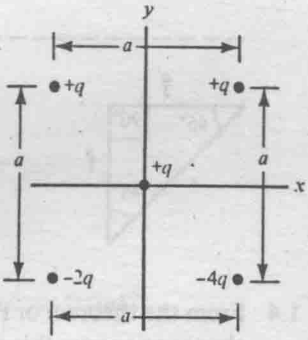
Note: When, as in frame 3, a charge is under the influence of more than one other charge, the total electrostatic force can be determined by finding the vector sum of all individual forces.

SOLUTIONS TO SAMPLE PROBLEMS

Problem 1

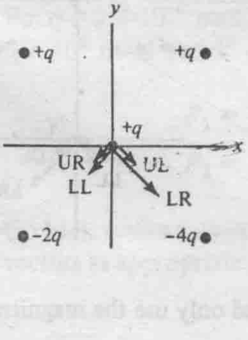
Four charges are arranged as shown. Find the electrostatic force exerted on the charge at the origin.

$a = 1.0$ m, $q = 2.0 \times 10^{-6}$ coul



1.1 The approach to this problem invokes the principle of superposition. Superposition means that we can calculate the total force on the charge at the center by first pairing the central charge q with each of the four surrounding charges and then determining the vector sum of the four forces.

Draw vectors on the diagram representing the forces acting on $+q$ at the center due to its separate interactions with the four other charges. Label the force UL (due to upper left charge), LR (due to lower right charge), LL (due to lower left charge), or LR (due to lower right charge).

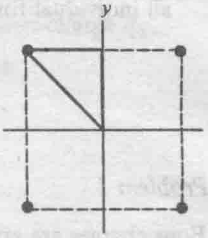


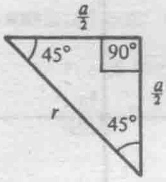
Coulomb's law can be used to calculate (for example) the force UL by ignoring the other three charges.

1.2 Now you know the directions of the four separate forces. Which forces have equal magnitudes? (Identify as UL, UR, LL, or LR.)

UL = UR

1.3 Prior to calculating the magnitude we need to do a bit of geometry. Here is a piece of the diagram from frame 1.1. Identify all the angles of this triangle as well as the length of the horizontal and vertical sides in terms of the given length a of the problem.





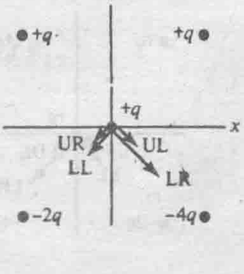
1.4 From the theorem of Pythagoras, what is the hypotenuse r of the triangle? (You may choose to answer this question using trigonometry. Try it!)

$$r = \sqrt{\frac{a^2}{4} + \frac{a^2}{4}} \qquad \text{or} \qquad \frac{a}{2} = r \sin 45°$$

$$r = \frac{a}{\sqrt{2}} \qquad\qquad \frac{a}{2} = (r)\left(\frac{1}{\sqrt{2}}\right)$$

$$r = \frac{a}{\sqrt{2}}$$

1.5 The separation between $+q$ at the center and each of the four charges is thus $a/\sqrt{2}$. From Coulomb's law then



(a) F_{UL} = ______________

(b) F_{LL} = ______________

(c) F_{UR} = ______________

(d) F_{LR} = ______________

Having determined the directions of all the forces we need only use the magnitude of the charges to compute the forces from Coulomb's law.

(a) $F_{UL} = \frac{1}{4\pi\epsilon_0} \frac{q^2}{a^2/2}$

(b) $F_{LL} = \frac{1}{4\pi\epsilon_0} \frac{2q^2}{a^2/2}$

(c) same as (a)

(d) $F_{LR} = \frac{1}{4\pi\epsilon_0} \frac{4q^2}{a^2/2}$

1.6 Using the answers from the previous frame, perform the following additions.

(a) $F_{UL} + F_{LR} =$ ______________

(b) $F_{UR} + F_{LL} =$ ______________

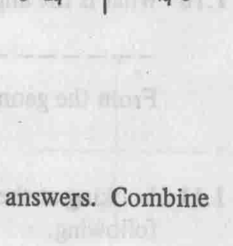
(a) $\frac{1}{4\pi\epsilon_0}\left(\frac{q^2}{a^2/2} + \frac{4q^2}{a^2/2}\right) = \frac{1}{4\pi\epsilon_0} + \frac{10q^2}{a^2}$

(b) $\frac{1}{4\pi\epsilon_0} \frac{6q^2}{a^2}$

1.7 Why was it appropriate to add the magnitudes in the previous frame?

Because $\mathbf{F}_{UL}$ and $\mathbf{F}_{LR}$ were in the same direction (i.e., they are colinear); likewise, $\mathbf{F}_{UR}$ and $\mathbf{F}_{LL}$.

1.8 Here the diagram is somewhat simpler as we now have added those pairs of forces which are colinear. (This is not drawn to scale.)



$$\mathbf{F}_1 = \mathbf{F}_{UL} + \mathbf{F}_{LR}$$
$$\mathbf{F}_2 = \mathbf{F}_{UR} + \mathbf{F}_{LL}$$

For $q = 2 \times 10^{-4}$ coul, $a = 1$ m, and $\frac{1}{4}\pi\epsilon_0 =$ 9×10^9 nt-m^2/coul^2

$F_1 =$ ____________ nt

$F_2 =$ ____________ nt

Go back to the answer of frame 1.5 and put the numbers in the answers. Combine vectors as appropriate.