Formative Assessment Materials for Large-Enrollment Physics Lecture Classes

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Real-time In-class Formative Assessment

- ***The Problem:*** How can the instructor assess students' thinking during class and modify in-class instructional activities accordingly?

- ***Our Goal:*** Develop and test materials that both
  - provide a basis for in-class instructional activities, and
  - assist the instructor in monitoring student thinking, moment-to-moment…

…in the context of large-enrollment classes

Our Materials:

Carefully sequenced sets of multiple-choice questions

- Emphasize qualitative, conceptual items
- Make heavy use of multiple representations

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Carefully sequenced sets of multiple-choice questions

- Emphasize qualitative, conceptual items
- Make heavy use of multiple representations
- Allow rapid assessment of student learning
- Assist in structuring and guiding the presentations and instructional activities

Motivation

Research in physics education suggests that:

- Problem-solving activities with rapid feedback yield improved learning gains
- Eliciting and addressing common conceptual difficulties improves learning and retention

Active-Learning Pedagogy
(“*Interactive Engagement*”)

- problem-solving activities during class time
  - student group work
  - frequent question-and-answer exchanges

- “*guided-inquiry*” methodology: guide students with leading questions, through structured series of research-based problems

Goal: Guide students to “figure things out for themselves” as much as possible

Key Themes of Research-Based Instruction

- Emphasize qualitative, non-numerical questions to reduce unthoughtful “plug and chug.”
- Make extensive use of multiple representations to deepen understanding.

  (Graphs, diagrams, words, simulations, animations, etc.)
- Require students to *explain their reasoning* (verbally or in writing) to more clearly expose their thought processes.

Active Learning in Large Physics Classes

- **De-emphasis of lecturing**; Instead, ask students to respond to questions targeted at known difficulties.
- Use of classroom communication systems to obtain **instantaneous feedback** from entire class.
- Incorporate cooperative **group work** using both multiple-choice and free-response items

Goal: *Transform large-class learning environment into "office" learning environment (i.e., instructor + one or two students)*

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“Fully Interactive” Physics Lecture

DEM and K. Manivannan, Am. J. Phys. ***70,*** *639 (2002)*

- Use structured sequences of multiple-choice questions, focused on specific concept: small conceptual “step size”

- Use student response system to obtain instantaneous responses from all students simultaneously (e.g., “flash cards”)

[a variant of Mazur’s “Peer Instruction”]

Transforming the lecture-hall environment: The fully interactive physics lecture

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(Received 19 September 2001; accepted 29 January 2002)

Numerous reports suggest that learning gains in introductory university physics courses may be increased by "active-learning" instructional methods. These methods engender greater mental engagement and more extensive student–student and student–instructor interaction than does a typical lecture class. It is particularly challenging to transfer these methodologies to the large-enrollment lecture hall. We report on seven years of development and testing of a variant of Peer Instruction as pioneered by Mazur that aims at achieving virtually continuous instructor–student interaction through a "fully interactive" physics lecture. This method is most clearly distinguished by instructor–student dialogues that closely resemble one-on-one instruction. We present and analyze a detailed example of such classroom dialogues, and describe the format, procedures, and curricular materials required for creating the desired lecture-room environment. We also discuss a variety of assessment data that indicate strong gains in student learning, consistent with other researchers. We conclude that interactive-lecture methods in physics instruction are practical, effective, and amenable to widespread implementation.
[DOI: 10.1119/1.1463739]

I. INTRODUCTION

Numerous investigations in recent years have shown active-learning methods to be effective in increasing student learning of physics concepts. These methods aim at promoting substantially greater engagement of students during in-class activities than occurs, for instance, in a traditional physics lecture. A long-standing problem has been that of

The basic elements of an interactive lecture strategy have been described by Mazur.[1] In this paper we broaden and extend that discussion, explaining in detail how the lecture component in large-classroom instruction may be almost eliminated. Depending on the preferences of the instructor and the specific student population, this strategy may yield worthwhile learning outcomes. To carry out the rapid back-and-forth dialogue observed in one-on-one instruction in large-enrollment classes requires a variety of specific instruc-

Results of Assessment

- Learning gains on qualitative problems are well above national norms for students in traditional courses.
- Performance on quantitative problems is comparable to (or slightly better than) that of students in traditional courses.
- Typical of other research-based instructional methods

Features of the Interactive Lecture

- High frequency of questioning
- Easy questions used to maintain flow
- Many question variants are possible
- Instructor must be prepared to use diverse questioning strategies

High frequency of questioning

- Time per question can be as little as 15 seconds, as much as several minutes
  - similar to rhythm of one-on-one tutoring
- Maintain small conceptual “step size” between questions for high-precision feedback on student understanding.

Curriculum Requirements for Fully Interactive Lecture

- Many question sequences employing multiple representations, covering full range of topics
- Free-response worksheets adaptable for use in lecture hall
- Text reference (“Lecture Notes”) with strong focus on conceptual and qualitative questions

→ *Workbook for Introductory Physics (DEM and K. Manivannan, CD-ROM, Vol. II, preliminary edition, 2002)*

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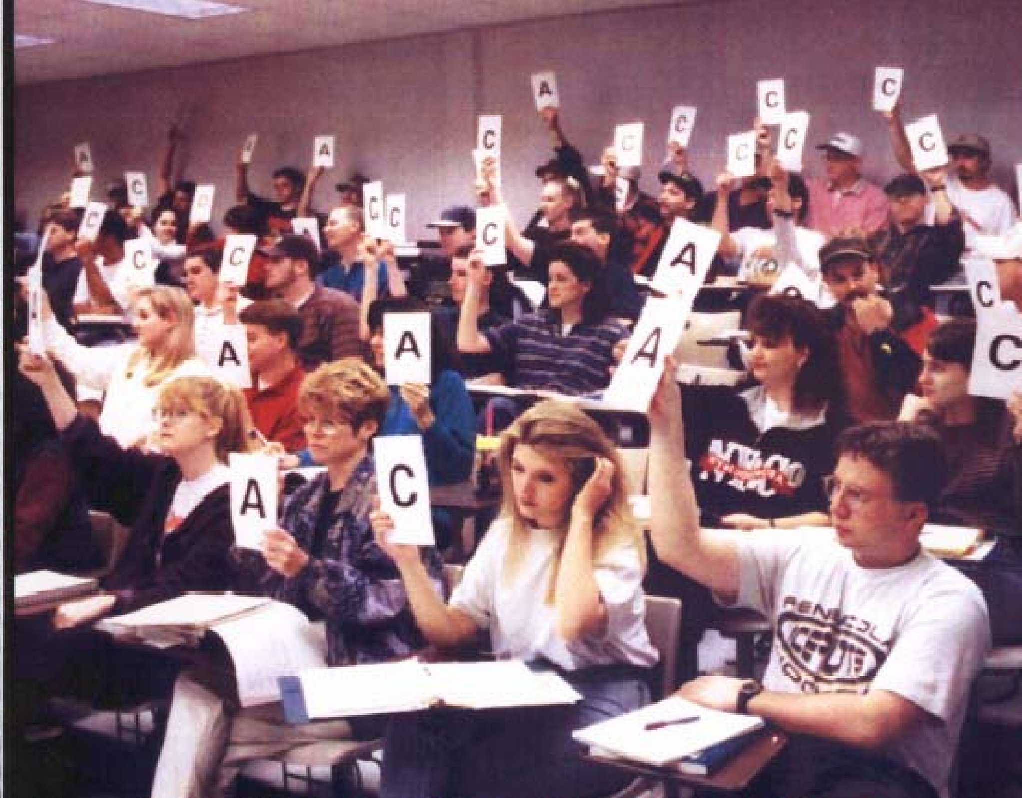
Workbook for Introductory Physics

Part II: Electricity and Magnetism, Optics, and Modern Physics

David E. Meltzer and Kandiah Manivannan



Iowa State University Physics Education Research Group

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Part 2: In-Class Questions and Worksheets, Chapters 1-8

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Part 7: Additional Material

Part 8: "How-to" Articles

Part 9: Flash-Card Masters

Part 10: Video of Class video

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Overall Tasks

- Develop question sequences for complete (two-semester) course
- Obtain feedback through in-class use to aid evaluation of assessment items
- Obtain interview data to validate items
- Do pre- and post-testing with standardized diagnostics to help monitor effectiveness

Design Strategies

- Not possible to pre-determine all possible discussion paths
- Knowledge of probable conceptual sticking points is important: *guided by research*
- Make use of standard question variants

Many question variants are possible

- Minor alterations to question can generate provocative change in context.
  - add/subtract/change system elements (force, resistance, etc.)
- Use standard questioning paradigms:
  - greater than, less than, equal to
  - increase, decrease, remain the same
  - left, right, up, down, in, out

Easy questions used to maintain flow

- Easy questions (> 90% correct responses) build confidence and encourage student participation.
- If discussion bogs down due to confusion, can jump start with easier questions.
- Goal is to maintain continuous and productive discussion with and among students.

Interactive Question Sequence

- Set of closely related questions addressing diverse aspects of single concept
- Progression from easy to hard questions
- Use multiple representations (diagrams, words, equations, graphs, etc.)
- Emphasis on qualitative, not quantitative questions, to reduce “equation-matching” behavior and promote deeper thinking

Chapter 1 Electrical Forces

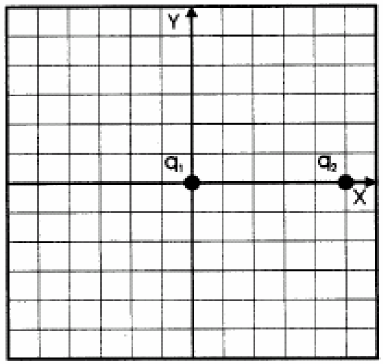
"Flash-Card" Questions

In-Class Questions

Prerequisite Concepts:

- **Positive and negative charges; Coulomb's law: $F = kq_1q_2/r^2$**
- **Protons (+) and electrons (–)**
- **Superposition principle: $F_{net}=F_1+F_2 + . . . + F_n$**
- **Vector addition: $F_{netx}=F_{1x} + F_{2x} + . . . F_{nx}$**
- **Newton's second law, $a = F/m$**

Questions #1–2 refer to the figure below. Charge q_1 is located at the origin, and charge q_2 is located on the positive x axis, five meters from the origin. There are no other charges anywhere nearby.



1. If q_1 is positive and q_2 is negative, what is the direction of the electrical force on q_1?

   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

2. If q_1 is positive and q_2 is positive, what is the direction of the electrical force on q_1?

   A. in the positive x direction
   B. in the negative x direction
   C. in the positive y direction
   D. in the negative y direction
   E. the force is not directed precisely along any of the coordinate axes, but at some angle
   F. there is no force in this case

3. In this figure, a proton is located at the origin, and an electron is located at the point (3m, 3m). What is the direction of the electrical force on the proton?

"Flash-Card" Questions

A.

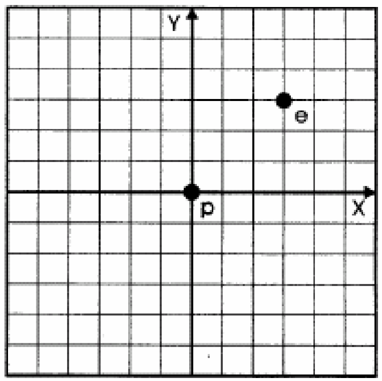
B.

C.

D.

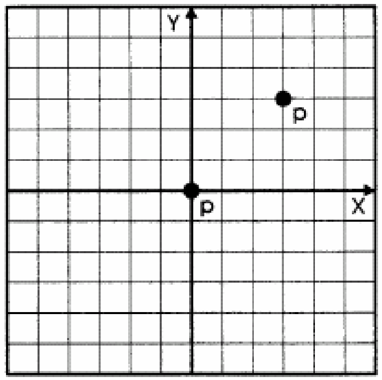
E.

F.



4. In this figure, a proton is located at the origin, and a proton is located at the point (3m, 3m). The vector representing the electrical force on the proton *at the origin* makes what angle with respect to the positive x axis?

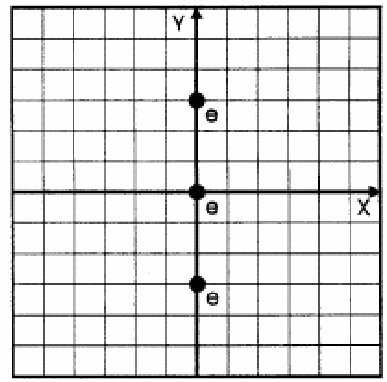
A. 0°
B. 45°
C. 90°
D. 135°
E. 225°
F. 270°



10. A 6-C charge and a 12-C charge are separated by 2 m; there are no other charges present. Compared to the electrical force on the 6-C charge, the electrical force on the 12-C charge is:

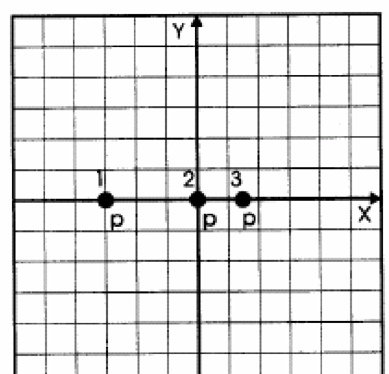
A. one-fourth as strong
B. one-half as strong
C. the same magnitude
D. two times as strong
E. four times as strong

11. In this figure, electrons are located on the y axis at y = 3 m, y = 0 m, and y = – 3 m. The direction of the net electrical force on the electron at the origin is:



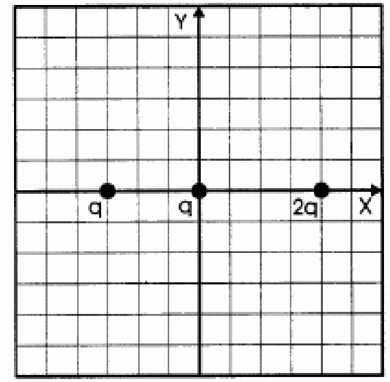
A. towards positive x
B. towards positive y
C. towards negative x
D. towards negative y
E. nowhere, since there is no net force on this electron

12. In this figure, protons are located on the x axis at x = – 3 m, x = 0 m, and x = 1.5 m. The direction of the net electrical force on the proton at the origin is:



A. towards positive x
B. towards positive y
C. towards negative x
D. towards negative y
E. nowhere, since there is no net force on this proton

13. In this figure, positive charges of magnitude q, q, and 2q are located on the x axis as shown. The direction of the net electrical force on the positive charge at the origin is:



A. towards positive x

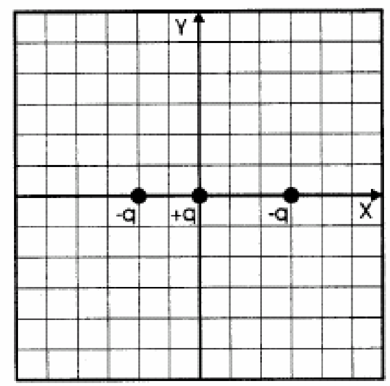
B. towards positive y

C. towards negative x

D. towards negative y

E. nowhere, since there is no net force on this proton

14. In this figure, particles with charges –q, +q, and –q are located on the x axis as shown. The direction of the net electrical force on the positive charge at the origin is:



A. towards positive x

B. towards positive y

C. towards negative x

D. towards negative y

E. nowhere, since there is no net force on this proton

15. A electron is fixed at the origin; there are no other charges present. If a negative charge is brought in and released at a nearby point, and allowed to move freely, then as it moves the magnitude of the force acting on this negative charge will:

A. always be zero

B. remain constant, but nonzero

C. always increase

D. always decrease, but never reach zero

E. sometimes increase and sometimes decrease

F. not enough information to decide

Examples of student response data

(Algebra-based general physics at Iowa State University)

Intended to assist instructors at other institutions in selection and planning in use of item sequences

Chapter 3 Electric Potential Energy

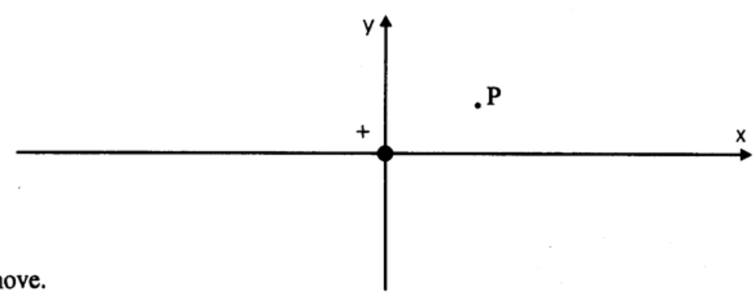
In-Class Questions

Prerequisite Concepts:

- **Positive and negative charge; Coulomb's law**
- **Definition of electric field**
- **Electric field of a parallel plate capacitor**
- **Kinetic energy and mechanical potential energy**
- **Definition of work; work/energy relationship**
- **Conservative forces/conservation of total energy**
- **Electrical force is conservative**

[Note: All gravitational forces may be ignored in this chapter]

1. *(Questions #1–6 refer to this figure.)* This figure shows a positive charge that is ***fixed in position*** at the origin. Suppose a positive charge q is placed at position P, and then released so that it (the charge q) is free to move. What will happen to this charge q?



A. It will not move.

B. It will move closer to the origin.

C. It will move farther away from the origin.

D. It will start moving closer to the origin, but then will reverse direction and start moving back out again.

E. It will start moving away from the origin, but then will reverse direction and start moving back in again.

2. As the charge q moves, what will happen to the magnitude of the electrical force acting on it?

A. The force will remain constant.

B. The force will increase in magnitude.

C. The force will decrease in magnitude, but never quite reach zero.

D. The force will decrease in magnitude, and at a certain point will reach zero.

E. The force will begin to decrease in magnitude, but then will start to increase again.

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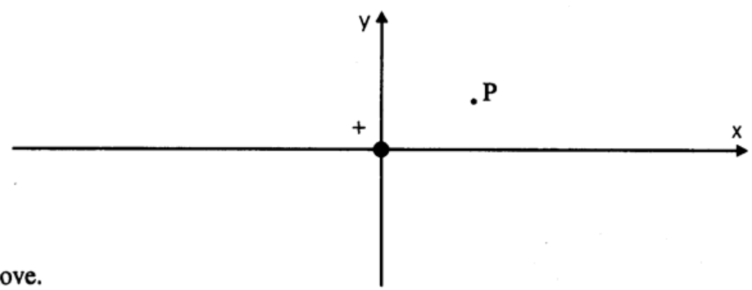


A. It will not move.
B. It will move closer to the origin.
C. It will move farther away from the origin.
D. It will start moving closer to the origin, but then will reverse direction and start moving back out again.
E. It will start moving away from the origin, but then will reverse direction and start moving back in again.

#1:

A: 0%
B: 7%
C: 93%
D: 0%
E: 0%

2. As the charge q moves, what will happen to the magnitude of the electrical force acting on it?

A. The force will remain constant.
B. The force will increase in magnitude.
C. The force will decrease in magnitude, but never quite reach zero.
D. The force will decrease in magnitude, and at a certain point will reach zero.
E. The force will begin to decrease in magnitude, but then will start to increase again.

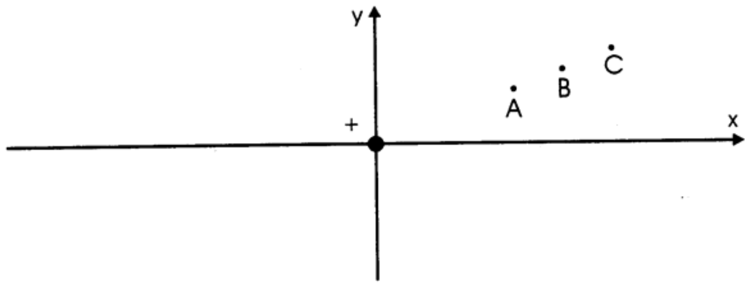
#2:

A: 10%
B: 8%
C: 77%
D: 2%
E: 5%

#7:

A: 2%
B: 3%
C: 3%
D: 83%
E: 9%

7. *(Questions #7–10 refer to this figure.)* In this figure (as in the previous one) a positive charge is fixed in position at the origin. Suppose a positive charge q is held at rest at position A, and then released and allowed to move freely. It passes through position B, and then moves on toward position C. Which of the following statements about charge q is true?



A. Its kinetic energy is the same at B and A, and its electric potential energy is the same at B and A.

B. Its kinetic energy is larger at B than at A, and its electric potential energy is larger at B than at A.

C. Its kinetic energy is smaller at B than at A, and its electric potential energy is smaller at B than at A.

D. Its kinetic energy is larger at B than at A, but its electric potential energy is smaller at B than at A.

E. Its kinetic energy is smaller at B than at A, but its electric potential energy is higher at B than at A.

#8:

A: 0%
B: 2%
C: 8%
D: 87%
E: 3%

8. This question again refers to the situation in Question #7. In comparing the energy of the charge q at positions C and B, which of the following statements is true?

A. Its kinetic energy is the same at C and B, and its electric potential energy is the same at C and B.

B. Its kinetic energy is larger at C than at B, and its electric potential energy is larger at C than at B.

C. Its kinetic energy is smaller at C than at B, and its electric potential energy is smaller at C than at B.

D. Its kinetic energy is larger at C than at B, but its electric potential energy is smaller at C than at B.

E. Its kinetic energy is smaller at C than at B, but its electric potential energy is higher at C than at B.

#9:

A: 0%
B: 13%
C: 7%
D: 53%
E: 22%

9. Again consider the setup shown in Question #7. Suppose now that a positively charged particle is shot from a gun that is located far away from the positive charge at the origin, but which is aimed directly at it. After leaving the gun the particle heads toward the origin, passing first through position C, then position B, and then position A. In comparing its energy at positions C and B, which of the following statements is true?

A. Its kinetic energy and electric potential energy are both the same at C and B.

B. Its kinetic energy and electric potential energy are both larger at C than at B.

C. Its kinetic energy and electric potential energy are both smaller at C than at B.

D. Its kinetic energy is larger at C than at B, but its electric potential energy is smaller at C than at B.

E. Its kinetic energy is smaller at C than at B, but its electric potential energy is higher at C than at B.

#10:

A: 67%
B: 20%
C: 9%
D: 2%
E: 0%

10. Consider the situation described in #9. Let us call the ***magnitude*** of the change in kinetic energy $|\Delta KE|$, and the ***magnitude*** of the change in electric potential energy $|\Delta PE|$. Which of these is true about the energy of the particle shot from the gun, as it travels from position C to position B?

A. $|\Delta KE| = |\Delta PE|$

B. $|\Delta KE| > |\Delta PE|$

C. $|\Delta KE| < |\Delta PE|$

D. Not enough information to answer.

Problem “Dissection” Technique

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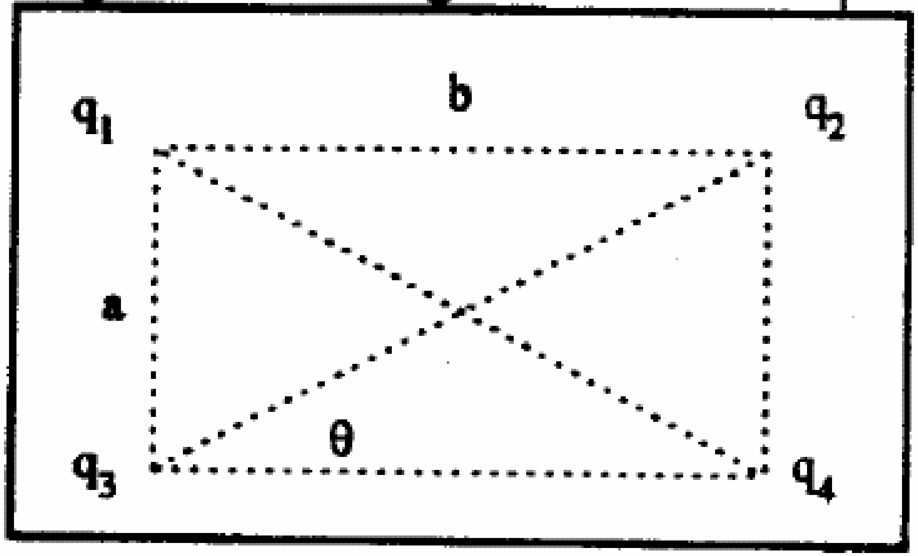
Example: Electrostatic Forces

Figure 1. Diagram used for problem dissection



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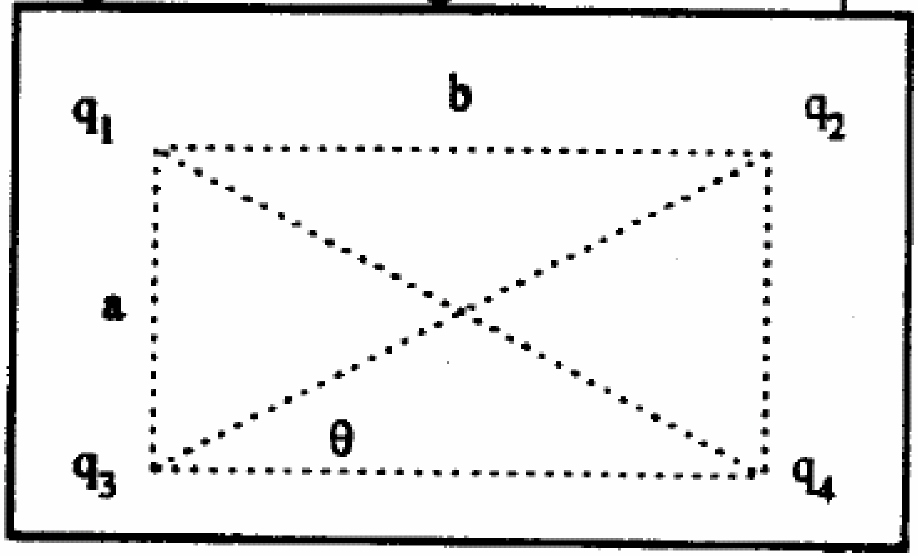

Four charges are arranged on a rectangle as shown in Fig. 1. ($q_1 = q_3 = +10.0\ \mu C$ and $q_2 = q_4 = -15.0\ \mu C$; a = 30 cm and b = 40 cm.) Find the magnitude and direction of the resultant electrostatic force on q_1.

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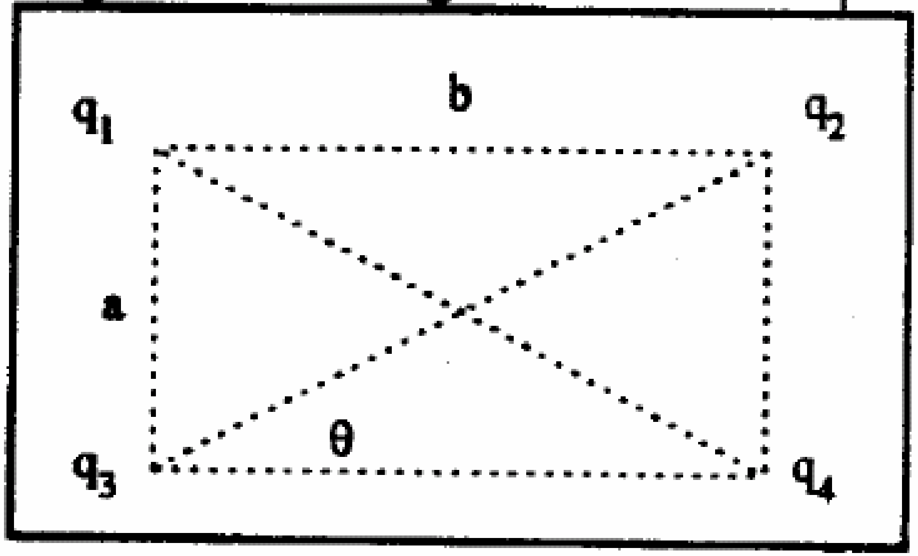

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Question #1: How many forces (due to electrical interactions) are acting on charge q_1?

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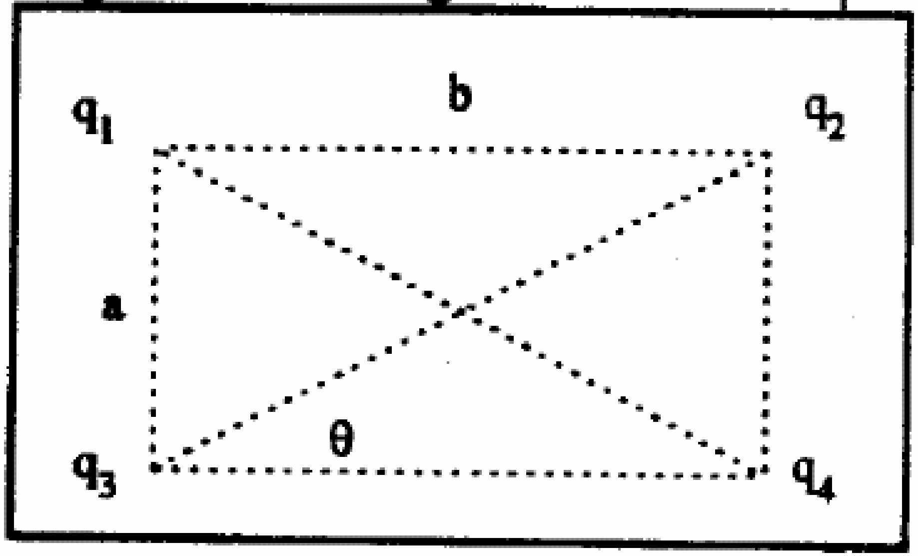

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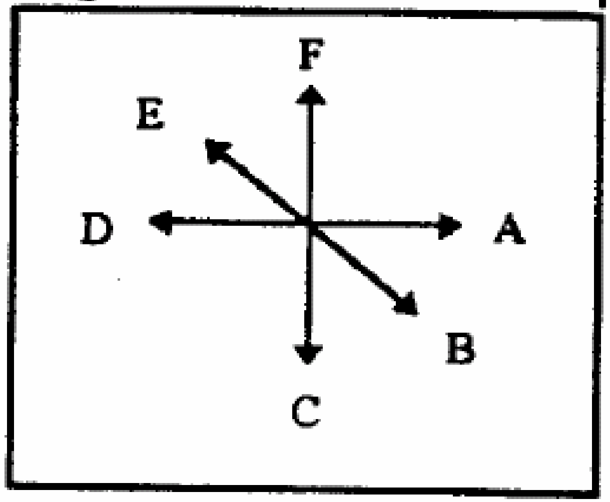
Question #1: How many forces (due to electrical interactions) are acting on charge q_1?

(A) 0 (B) 1 (C) 2 (D) 3 (E) 4 (F) Not sure/don't know

Figure 2. Direction options



For questions #2-4 refer to Fig. 2 and pick a direction from the choices A, B, C, D, E, and F.

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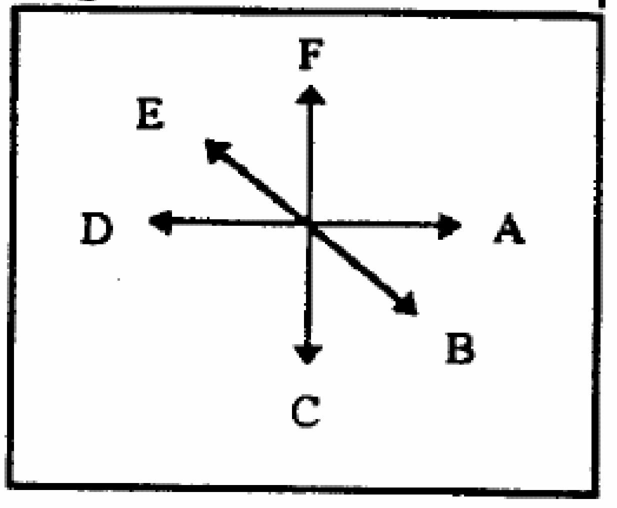

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Question #2: Direction of force on q_1 due to q_2

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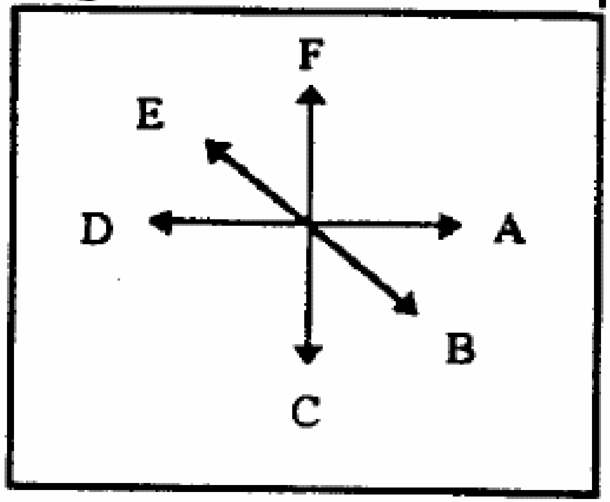

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Question #2: Direction of force on q_1 due to q_2

Question #3: Direction of force on q_1 due to q_3

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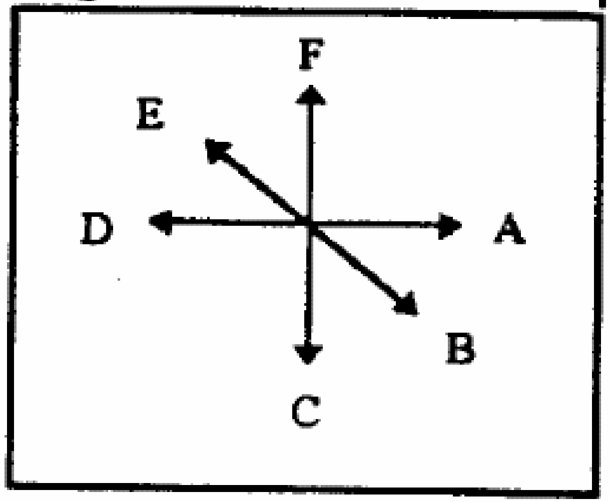

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Question #2: Direction of force on q_1 due to q_2

Question #3: Direction of force on q_1 due to q_3

Question #4: Direction of force on q_1 due to q_4

Let F_2, F_3, and F_4 be the *magnitudes* of the force on q_1 due to q_2, due to q_3, and due to q_4 respectively.

Question #5. F_2 is given by

(A) kq_1q_2/a^2

(B) kq_1q_2/b^2

(C) $kq_1q_2/(a^2 + b^2)$

(D) $kq_1q_2/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don’t know

Question #6. F_3 is given by

(A) kq_1q_3/a^2

(B) kq_1q_3/b^2

(C) $kq_1q_3/(a^2 + b^2)$

(D) $kq_1q_3/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don’t know

Let F_2, F_3, and F_4 be the *magnitudes* of the force on q_1 due to q_2, due to q_3, and due to q_4 respectively.

Question #5. F_2 is given by

(A) kq_1q_2/a^2

(B) kq_1q_2/b^2

(C) $kq_1q_2/(a^2 + b^2)$

(D) $kq_1q_2/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don’t know

Question #6. F_3 is given by

(A) kq_1q_3/a^2

(B) kq_1q_3/b^2

(C) $kq_1q_3/(a^2 + b^2)$

(D) $kq_1q_3/\sqrt{(a^2 + b^2)}$

(E) None of the above

(F) Not sure/Don’t know

(etc.)

Ongoing Curricular Development

(Projects starting 2003)

- "Formative Assessment Materials for Large-Enrollment Physics Lecture Classes"

    Funded through NSF's "Assessment of Student Achievement" program

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- "Active-Learning Curricular Materials for Fully Interactive Physics Lectures"

  Funded through NSF's "Course, Curriculum, and Laboratory Improvement – Adaptation and Implementation" program

Project Phases

- Complete the development of question sequences for Chaps. 10-14 of Volume II of *Workbook for Introductory Physics*
- Acquire baseline data by administering questions in class with electronic student response system
- Begin work on question sequences for initial chapters of Volume I of *Workbook*

Materials Development

- Carried out by DEM and Ngoc-Loan Nguyen (Iowa State U. graduate student)
- Created question sequences for electrodynamics, optics, modern physics, thermodynamics, and mechanical forces
- Acquired baseline data (at Iowa State University) for questions on electrostatics
- Currently carrying out editing and additional data acquisition

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