TOPIC 4.2: ELECTRIC FIELDS

Students define the electric field strength, E, as a force per unit charge (in N/C). The electric force is given by $F_e = qE$, and lines of force are used to draw the field. The field between two parallel plates is described. Students examine problems involving both the gravitational and electric forces, and describe Millikan's experiment and the elementary charge.

The student will be able to:

S3P-4-14: Define the electric field qualitatively as the region of space around a charge where a positive test charge experiences a force.

S3P-4-15: Diagram electric fields using lines of force with respect to a positive test charge.

Include: single point charges (positive and negative), near two like charges, near two unlike charges, between a single charge and a charged plate, between two oppositely charged parallel plates

S3P-4-16: Define the electric field quantitatively as a force per unit charge ($E = F/q$) and solve problems using the unit field concept ($F = qE$).

S3P-4-17: Solve problems for the motion of charges between parallel plates where $F_{net} = F_e + F_g$.

S3P-4-18: Describe a simplified version of Millikan's experiment for the determination of the elementary charge (solve for charge when $F_e = F_g$).

S3P-4-19: Define the elementary charge and convert between elementary charges and coulombs.

Include: $q = Ne$

General Learning Outcome Connection

Students will…

Employ effective communication skills and utilize information technology to gather and share scientific and technological ideas and data (GLO C6)

Specific Learning Outcomes

S3P-4-14: Define the electric field qualitatively as the region of space around a charge where a positive test charge experiences a force.

S3P-4-15: Diagram electric fields using lines of force with respect to a positive test charge.

Include: single point charges (positive and negative), near two like charges, near two unlike charges, between a single charge and a charged plate, between two oppositely charged parallel plates

Suggestions for Instruction

Entry-Level Knowledge

Students are introduced to electrostatics in Senior 1 Science.

Notes to the Teacher

Describe the electric field as a force per unit charge, and compare to the concept of the gravitational field and mass. Emphasize that an electric field can result from either a negative or a positive charge. Distinguish carefully between the charge that establishes the field and the test charge that experiences the force. The direction of the field can be confusing as it is always described as if the test charge is positive. Therefore, the electric field vector and the electric force vector are *in the same direction* if the charge brought into the field is positive, and *in opposite directions* if the charge is negative. Note that a line of force indicates the direction the force would act on a positive test charge in the field. Note also that the number of lines per unit area represents the intensity of the field.

Demonstrate the electric fields around charged objects with grass seeds, "fuzzy fur," or fibre clippings. Fine pieces of fibre clippings can be suspended in mineral oil between a pair of electrodes and the pattern projected on the overhead.

Teacher Demonstration

Demonstrate electric fields with a Van der Graff machine and a collection of threads, streamers, or light strips of paper.

Senior Years Science Teachers' Handbook Activities

Students compare and contrast electric and gravitational fields. While gravitational fields always exert attractive forces on other masses, an electric field may exert repulsive forces as well. (See *Senior Years Science Teachers' Handbook*, Compare and Contrast Frame, page 10.24.)

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2c: Formulate operational definitions of major variables or concepts.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

SUGGESTED LEARNING RESOURCES

Lapp, D.R. (1996) "Field Lines Flying Fur." *The Physics Teacher* 34.4: 252.

Software

Exploring Electrodynamics;
Explorations 1-2: Electric Field

EM Field 6, Physics Academic Software Publishing Organization

Multimedia

Videodisc: *Video Encyclopedia of Physics Demonstrations*: Demo 17-10, Electric Field

General Learning Outcome Connection

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

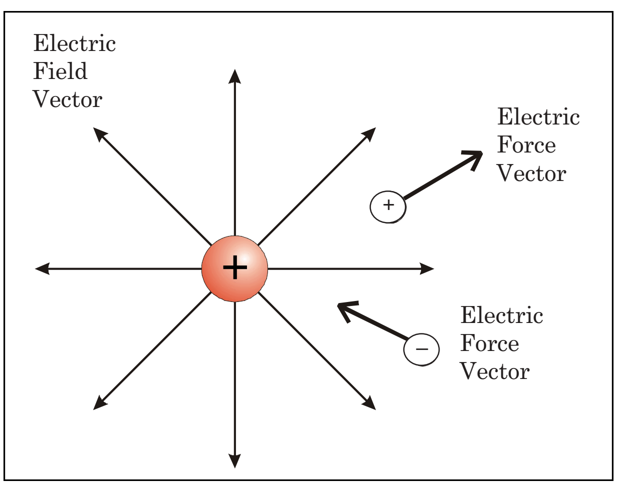
Specific Learning Outcome

S3P-4-16: Define the electric field quantitatively as a force per unit charge (E = F/q) and solve problems using the unit field concept (F = qE).

Suggestions for Instruction

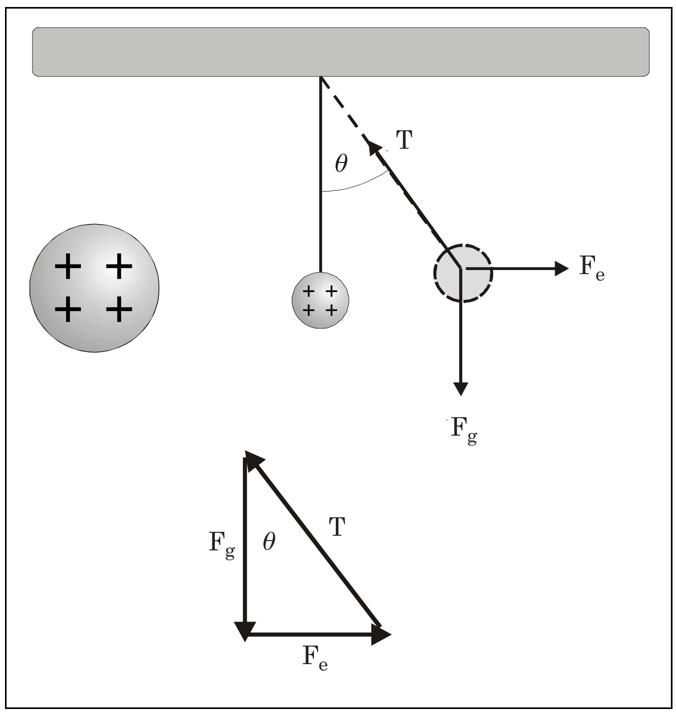
Notes to the Teacher

The electric force ($F_E = qE$) can be found in the same way as the weight of an object, given the gravitational field. Emphasize the unit concept (unit charge, unit mass). The electric field describes the number of newtons each coulomb of charge experiences at some point. Note carefully the direction of the electric force as it compares to the electric field. The direction of the electric field is always given as if it acts on positive test charges. Consequently, the electric field vector and the electric force vector are *in the same direction* if the charge brought into the field is positive. However, if the charge brought into the field is negative, then the electric field vector and the electric force vector are *in opposite directions*.



Illustrative Example

A charged pith ball is brought near a charged sphere. Calculate the electric field, using F_E/q, where $F_E = mg\tan\theta$, and θ is the angle of deflection of the pith ball.



Note: The scale in the illustrative example is exaggerated for simplicity.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2h: Analyze problems, using vectors.

Include: adding and subtracting vectors in straight lines and at right angles, vector components

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION

Senior Years Science Teachers' Handbook Activities

Journal Entry: Students compare and contrast the idea of a field (a force per unit "something") to the concept of a unit price in a grocery store.

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

Students solve problems with $F_E = qE$.

SUGGESTED LEARNING RESOURCES

Software

Exploring Electrodynamics; Explorations 1-2: Electric Field; Independent Exploration: Millikan Experiment; Core Activity 1: Electric Field and Force

Multimedia

Videodisc: *Physics at Work*: Side A/B, Frames 1853-60, Electric fields

Videodisc: *Video Encyclopedia of Physics Demonstrations*: Demo 17-10, Electric Field

Video: *Beyond the Mechanical Universe: From Electricity to Modern Physics:* #3: The Electric Field; #10: Vector Fields and Hydrodynamics

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SPECIFIC LEARNING OUTCOME

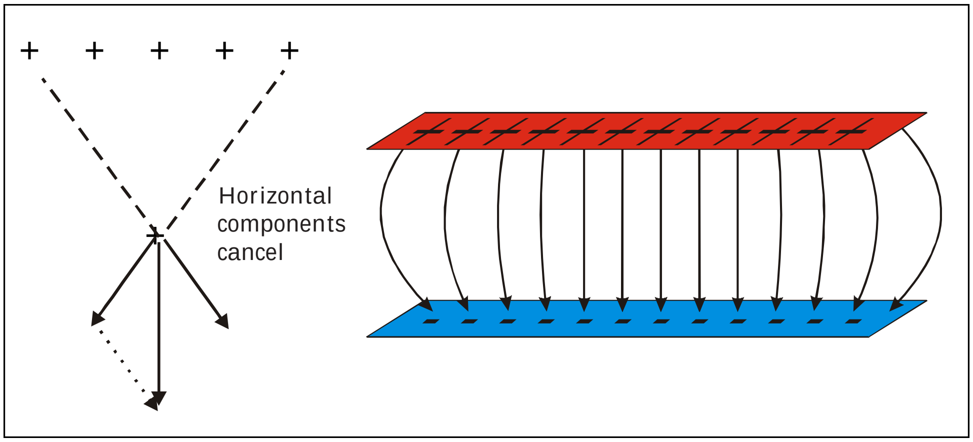
S3P-4-17: Solve problems for the motion of charges between parallel plates where $F_{net} = F_e + F_g$.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

Identify the constant field between parallel plates by first considering a line of charge and a single point charge placed nearby. The horizontal components of corresponding charges cancel and the vertical components add. For oppositely charged plates, the effect is enhanced. The field is constant and is directed from the positive to the negative plate. The edges of the field bulge slightly since there are no charges outside the plates to balance the horizontal effects of the nearby charges.

Since the electric field between parallel plates is constant, we may use all of the kinematic relations derived in 3.1.7 and Newton's Second Law to solve problems for charges that are moving between the plates. In Senior 3 Physics, students should only consider charges that are moving in a straight line between the plates. Problems can include solving for charge, electric field strength (E), electric force (F_E), mass, gravitation force (F_g), net force, acceleration, final velocity, or displacement.



SKILLS AND ATTITUDES OUTCOMES

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2h: Analyze problems, using vectors.

Include: adding and subtracting vectors in straight lines and at right angles, vector components

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION

Student Activities

Students predict the path of a particle in an electric field, using *Exploring Electrodynamics* Explorations 1 and 2.

Senior Years Science Teachers' Handbook Activities

See Compare and Contrast, *Senior Years Science Teachers' Handbook*, Building a Scientific Vocabulary, page 10.15.

SUGGESTIONS FOR ASSESSMENT

SUGGESTED LEARNING RESOURCES

Bonham, S. (1999) "Using Physlets to Teach Electrostatics." *The Physics Teacher* 37.5: 276.

Concept Overview, Attachment 19, *Success for All Learners: A Handbook on Differentiating Instruction*.

General Learning Outcome Connection

Students will…

Identify and appreciate contributions made by women and men from many societies and cultural backgrounds towards increasing our understanding of the world and in bringing about technological innovations (GLO A4)

Specific Learning Outcomes

S3P-4-18: Describe a simplified version of Millikan's experiment for the determination of the elementary charge (solve for charge when $F_e = F_g$).

S3P-4-19: Define the elementary charge and convert between elementary charges and coulombs.

Include: $q = Ne$

Suggestions for Instruction

Notes to the Teacher

Millikan's experiment can be diagrammed and described, or demonstrated using animations.

Define the elementary charge. Convert between elementary charges and coulombs. The coulomb is actually defined operationally by the force of attraction between two current-carrying wires. However, at this point, introduce the coulomb as a fixed number of elementary charges (1C = 6.25 x 10^{18} elementary charges). Therefore, in coulombs, one elementary charge is:

$$q = N \times e$$

$$1\text{ C} = 6.25 \times 10^{18}\ e$$

and

$$e = \frac{1}{6.25 \times 10^{18}}\text{ C}$$

$$e = 1.6 \times 10^{-19}\text{ C}$$

An elementary charge is the charge of an electron ($-e$) or a proton (+p).

Solve for the quantity of charge (q), electric force (F_e), mass, gravitational force (F_g), number and type (proton/electrons) of elementary charge (N) for Millikan-type problems.

In terms of Newton's Second Law, for a small sphere placed between the plates, we have:

$$F_{net} = F_{applied} + F_{friction}.$$

such that

$$F_{friction} = 0 \text{ (negligible) and}$$

$$F_{applied} = F_e + F_g$$

There are several cases to address for charges between parallel plates:

$F_e = -F_g$ (the sphere is stationary between the plates)

$F_e < F_g$ (opposite to F_g such that $a < g$)

$F_e > F_g$ (opposite to F_g such that $a > 0$ [upwards])

$F_e > 0$ (in the same direction as F_g such that $a > g$)

SKILLS AND ATTITUDES OUTCOME

S3P-0-1b: Describe the importance of peer review in the evaluation and acceptance of scientific theories, evidence, and knowledge claims.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

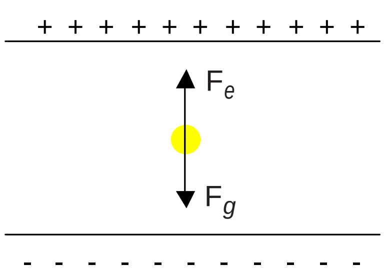
SUGGESTIONS FOR INSTRUCTION

Illustrative Example

A negatively charged 2.0 x 10^{-5} kg droplet of oil is placed between two oppositely charged plates. The oil drop is balanced when the electric field is adjusted to 4.2 x 10^{-7} N/C.

a) Diagram to indicate the charge on each plate.

b) How many elementary charges are on the oil drop?



m = 2.0 x 10^{-7} kg

E = 4.2 x 10^{5} N/C

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Written Test: Students solve for charge when $F_e = F_g$.

Visual Displays

Students diagram the different possibilities for charge, plates, forces, and acceleration.

SUGGESTED LEARNING RESOURCES

Software

Millikan Oil Drop Experiment: Vernier CBL system.

Multimedia

Video: *The Mechanical Universe: Introductory Physics*: #12: The Millikan Experiment

Videodisc: *Video Encyclopedia of Physics Demonstrations*: Demo 24-24: Millikan Oil Drop

Websites

Search for "Millikan applets" using the keywords: Millikan's experiment + applet

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Identify and appreciate contributions made by women and men from many societies and cultural backgrounds towards increasing our understanding of the world and in bringing about technological innovations (GLO A4)

SPECIFIC LEARNING OUTCOMES

S3P-4-18: Describe a simplified version of Millikan's experiment for the determination of the elementary charge (solve for charge when $F_e = F_g$).

S3P-4-19: Define the elementary charge and convert between elementary charges and coulombs.

Include: $q = Ne$

SUGGESTIONS FOR INSTRUCTION

Since the drop is balanced,

$F_e = F_g$

$qE = mg$

$$q = \frac{2.0 \times 10^{-7}\ (9.8)}{4.2 \times 10^{5}\ \text{N/C}}$$

$q = 4.7 \times 10^{-13}$ C

Since $q = Ne$,

$$N = \frac{4.7 \times 10^{-13}\ \text{C}}{1.6 \times 10^{-19}\ \text{C}}$$

Senior Years Science Teachers' Handbook **Activities**

Anticipation Guide: Students read Douglas Allchin's article "Flirting with Fraud: Millikan, Mendel and the Fringes of Integrity" in Appendix 4.4. Use the question, "Was Millikan's selective use of data 'good' science?" to address the Nature of Light outcome S3P-0-1b (scientific knowledge claims).

See Appendix 4.4: Student Article Analysis—Scientific Fraud?

Teaching Notes

SKILLS AND ATTITUDES OUTCOME

S3P-0-1b: Describe the importance of peer review in the evaluation and acceptance of scientific theories, evidence, and knowledge claims.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Understanding the Major Explanatory Stories of Science

Access the following URL for an article related to the integrity of earlier work in electric fields that could be suitable for a student article analysis:

<http://www1.umn.edu/ships/updates/fraud.htm>

The article, “Flirting with Fraud: Millikan, Mendel and the Fringes of Integrity” by Douglas Allchin, is also reprinted in Appendix 4.4.

NOTES