Information Bulletin

Physics 30

2009–2010 Diploma Examinations Program
Updated September 18, 2009

Alberta
Education

This document was written primarily for:

Students	✓
Teachers	✓ of Physics 30
Administrators	✓
Parents	
General Audience	
Others	

Distribution: This document is posted on the Alberta Education website at education.alberta.ca.

Contents

You can find diploma examination-related materials on the Alberta Education website at education.alberta.ca.

Teacher Involvement in the Diploma Examination Process

High-quality diploma examinations are the product of close collaboration between classroom teachers and Alberta Education. Classroom teachers from across Alberta are involved in many aspects of diploma-examination development, including the development of raw items; the building, reviewing, and administering of field tests; and the reviewing of diploma examinations.

Alberta Education values the involvement of the teachers and often asks school jurisdictions for the names of teachers who are interested in being involved. Teachers who are interested in developing raw items or building and/or reviewing field tests are encouraged to ask their principals to submit their names, through proper channels, to Learner Assessment. The list of teachers interested in these aspects of the development process remains open all year long, and teachers are welcome to have their names submitted at any time.

Other opportunities to be involved, such as field testing, have specific closing dates. General dates to be aware of include:

September 2009	Registration for field tests to be administered in December 2009 or January 2010
February 2010	Registration for field tests to be administered in May or June 2010

Periodically we send out information to those Physics 30 teachers who are on our contact list. If you would like to be added to this list, contact Laura Pankratz, the Physics 30 Examination Manager, at Laura.Pankratz@gov.ab.ca.

Formative Assessment Written-Response Items

In addition to the opportunities described above, teachers and their students can participate in the use of written-response items for formative assessment. These items are designed to assess Physics 30 outcomes mandated in the *Physics 20–30 Program of Study, 2007*. Any teacher interested in using these written-response items for formative assessment in the classroom should contact Laura Pankratz, the Physics 30 examination manager, at Laura.Pankratz@gov.ab.ca.

Course Objectives

Physics 30 is intended to further students' understanding and application of fundamental physics concepts and skills. The focus of the course is on understanding the physics principles behind the natural events that students experience and the technology that they use in their daily lives. The course encourages enthusiasm for the scientific enterprise and develops positive attitudes about physics as an interesting human activity with personal meaning. It develops knowledge, skills, and attitudes to help students become capable of and committed to setting goals, making informed choices, and acting in ways that will improve their own lives as well as life in their communities.

To develop the required knowledge, skills, and attitudes in Physics 30, students must have successfully completed Science 10 and Physics 20.

Performance Expectations

Curriculum Standards

Provincial curriculum standards help to communicate how well students need to perform in order to be judged as having achieved the objectives specified in the *Physics 20–30 Program of Studies, 2007*. The specific statements of standards are written primarily to apprise Physics 30 teachers of the extent to which students must know the Physics 30 content and be able to demonstrate the required skills in order to pass the examination.

Performance Standards

Acceptable Standard

Students who achieve the acceptable standard in Physics 30 will receive a final course mark of 50% or higher. Students achieving the acceptable standard have gained new skills and knowledge in physics but may encounter difficulties if they choose to enroll in post-secondary physics courses. These students are able to define basic physics terms: for example, scalar, vector, momentum, force, field, charging by conduction or by induction, refraction, diffraction, interference, the photoelectric effect, the Compton effect, matter-energy equivalence, nucleons, nucleus, decay, half-life, and stable energy states. These students are able to state and use formulas as they appear on the equation sheet: for example, momentum of a single object, linear momentum analysis, electric force, electric field, magnetic deflecting force, motor force, angle of refraction, index of refraction, focal length, magnification, photon energy, work function, mass (activity or percentage) remaining of a radioactive nuclide, photon energy, and energy change associated with photon emission or absorption. They can do this in situations where they need to sort through a limited amount of information. Their laboratory skills are limited to following explicit directions and to using laboratory data to verify known physics information. They are able to identify manipulated and responding variables but not relevant controlled variables. These students are able to relate graph shape to memorized relationships, but their analysis of graphs is limited to linear data. These students tend to use item-specific methods in their problem solving and rarely apply the major principles of physics in their solutions: for example, conservation laws, balanced or unbalanced forces, and type of motion. When explaining the connections between science, technology, and society, these students tend to use examples provided from textbooks. These students have difficulty connecting physics to real-life scenarios beyond the classroom.

Standard of Excellence

Students who achieve the standard of excellence in Physics 30 receive a final course mark of 80% or higher. They have demonstrated their ability and interest in both mathematics and physics, and feel confident about their scientific abilities. These students should encounter little difficulty in post-secondary physics programs and should be encouraged to pursue careers in which they will utilize their talents in physics. Students who achieve the standard of excellence show flexibility and creativity when solving problems, and minor changes in problem format do not cause them major difficulties. These students are capable of analyzing situations that involve two-dimensional vectors, charge motion initially perpendicular to an external electric field, charge motion perpendicular to an external magnetic field, and energy level values above or below given values based on photon characteristics, etc. They seek general methods to solve problems and are not afraid to use physics principles as a framework for their solutions. In the laboratory, students who achieve the standard of excellence can deal with data that are less than perfect or with instructions that are incomplete. These students are able to explicitly relate graph shape to mathematical models and to physics equations. They transfer knowledge from one area of physics to another and can express their answers in clear and concise terms. These students are able to apply cause and effect logic in a variety of situations: algebraically, experimentally, etc. In addition, these students can connect their understanding of physics to real-world situations that include technological applications and implications beyond the classroom setting.

Examination Specifications and Design

Each Physics 30 diploma examination is constructed as closely as possible to the following specifications. Adjustments in the emphasis may be necessary because the examination includes machine-scored scenarios or contexts that cover more than one general outcome. Questions on the diploma examination will require students to demonstrate knowledge of physics concepts and to apply skills in a context that supports making Science, Technology, and Society (STS) connections.

The design supports the integration of all Physics 30 general outcomes (GOs) as outlined in the *Physics 20–30 Program of Studies, 2007*. As a result, the examination is not necessarily arranged sequentially by units but is instead built around scenarios or contexts that support STS connections; a set of questions may assess students' ability to integrate several GOs.

General Outcomes

		Emphasis (Curricular Fit)
GO A	**Momentum and Impulse:** Students will explain how momentum is conserved when objects interact in an isolated system.	10–20%
GO B	**Forces and Fields:** Students will explain the behaviour of electric charges using the laws that govern electrical interactions. They will describe electrical phenomena using the electric field theory. They will explain how the properties of electric and magnetic fields are applied in numerous devices.	25–35%
GO C	**Electromagnetic Radiation:** Students will explain the nature and behaviour of electromagnetic radiation using the wave model. They will explain the photoelectric effect using the quantum model.	25–35%
GO D	**Atomic Physics:** Students will describe the electrical nature of the atom. They will describe the quantization of energy in atoms and nuclei. They will describe nuclear fission and fusion as powerful energy sources in nature. They will describe the ongoing development of models of the structure of matter.	20–30%

Scientific Process and Communication Skills

Students will

- formulate questions about observed relationships and plan investigations into questions, ideas, problems, and issues
- use a broad range of tools and techniques to record data and information
- analyze data and apply mathematical and conceptual models to develop and assess possible solutions
- apply the skills and conventions of science in communicating information and ideas, and in assessing results

Science, Technology, and Society Connections (STS)

Students will

- explain that technological problems often require multiple solutions that involve different designs, materials, and processes, and that have both intended and unintended consequences
- explain that concepts, models, and theories are often used in interpreting and explaining observations, and in predicting future observations
- explain that scientific knowledge may lead to the development of new technologies and that new technologies may lead to or facilitate scientific discovery
- explain that the goal of technology is to provide solutions to practical problems
- explain that scientific knowledge is subject to change as new evidence becomes apparent, and as laws and theories are tested and subsequently revised, reinforced, or rejected
- explain that scientific knowledge and theories develop through hypotheses, the collection of evidence, investigation, and the ability to provide explanations
- explain that the goal of science is knowledge about the natural world
- explain that the products of technology are devices, systems, and processes that meet given needs, and that the appropriateness, risks, and benefits of technologies need to be assessed for each potential application from a variety of perspectives, including sustainability

The Physics 30 Diploma Examination consists of 36 multiple-choice and 14 numerical-response items, of equal weight.

Machine-Scored Questions

The examination contains both multiple-choice and numerical-response questions.

Multiple-choice questions are of two types: *discrete* and *context-dependent*. A discrete question stands on its own without any additional directions or information. It may take the form of a question or an incomplete statement. A context-dependent question provides information that is separate from the question stem. Many of the multiple-choice questions are context dependent. A particular context may be used for more than one multiple-choice question as well as for more than one numerical-response question.

Numerical-response questions are of three types: calculation of numerical values; selection of numbered events, structures, or functions from a diagram/list; and determination of a sequence of events.

Scenarios Requiring Problem-Solving Skills

Each examination will have a two-question numerical-response scenario that explores problem-solving strategies. The scenario will present a contextual problem that requires two physics principles and several calculations to solve. There will be a context box describing a situation and a numbered list of the ten physics principles that are given on the data sheets. The first numerical-response question requires the student to provide the numbers of the two physics principles IN THE ORDER in which the principles are applied to support or justify the solution to the problem. If there are multiple valid methods, then there will be multiple correct answers, which will be indicated. The second numerical-response question will require the student to provide the final answer to the problem.

Answers for multiple-choice questions are recorded in the first section of the machine-scored answer sheet. Answers for numerical-response questions are recorded in the second section on the same side of the same machine-scored answer sheet.

Assessment of Skills and STS Connections

Physics 30 examination questions are designed to measure students' understanding of physics concepts mandated by the *Physics 20–30 Program of Study, 2007*. Some questions also measure students' understanding and use of skills associated with scientific inquiry, and some questions have been designed to measure students' understanding of the connections among science, technology, and society. As a result, many questions measure how well students can apply the skills and knowledge they have acquired in science to everyday life.

Examination Security

- The 2010 January and June Physics 30 Diploma Examinations are secured at the time of writing.

Maintaining Consistent Standards over Time on Diploma Examinations

A baseline examination will be established, and equating will be reestablished as a result of the standard setting associated with the change in the program of study.

Publications and Supporting Documents

The following documents are published by Alberta Education.

- *Physics 20-30 Program of Study, 2007* available on education.alberta.ca, by following this pathway:
  Teachers > Programs of Study > (Programs of Study) Science > Programs of Study > (Senior High) Physics 20-30
- *Physics 20 and 30 Classroom-Based Performance Standards* available on education.alberta.ca, by following this pathway:
  Administrators > Provincial Testing > Diploma Examinations > Diploma Examination Information Bulletins
- *Physics 30 Information Bulletin 2009–2010* available on education.alberta.ca, by following this pathway:
  Administrators > Provincial Testing > Diploma Examinations > Diploma Examination Information Bulletins
- *Physics 30 Data Booklet* available on education.alberta.ca, by following this pathway:
  Administrators > Provincial Testing > Diploma Examinations
- *Archived Physics 30 Information Bulletin 2008–2009* containing an illustrative Part B and multiple written-response questions available on education.alberta.ca, by following this pathway:
  Administrators > Provincial Testing > Diploma Examinations > Diploma Examination Information Bulletins
- *Calculator Policy* available on education.alberta.ca, by following this pathway:
  Administrators > Provincial Testing > Diploma Examinations > Diploma Examination Information Bulletins
- *Assessment Highlights* available on education.alberta.ca, by following this pathway:
  Teachers > (Additional Programs and Services) > Diploma Exams > Assessment Highlights
- *Released Items*, mailed to schools in paper form. The Released Items document can be used in conjunction with Table 7: Results for Multiple-Choice (MC) and Numerical-Response (NR) Items in the Diploma Examination Detailed Reports in order to compare released items with the corresponding item descriptions.

- *Diploma Examination Detailed Reports*, available on the Alberta Education Extranet

Learner Assessment supports online assessment with the testing platform QuestA+ at http://questaplus.Alberta.ca.

Reminders and Explanations

Nuclear Equations

The curriculum specifies that students should be able to write nuclear equations for alpha and beta decay. This now includes both beta positive and beta negative decay with the appropriate neutrino and antineutrino.

Quantitative Analysis of the Compton Effect

The Compton effect is the change in wavelength of the scattered electromagnetic radiation in a photon-electron collision. It is described by $\Delta\lambda = \frac{h}{mc}(1-\cos\theta)$.

Wave-particle Duality

Students will be expected to know and apply $p = \frac{h}{\lambda}$ and $E = pc$ to determine the particle-like characteristics of photons.

Students are expected to know the wave-like characteristics of matter but **not** apply $\lambda = \frac{h}{mv}$.

Positron

Students are expected to know and use the term *positron* to describe the antimatter particle corresponding to the electron.

Use of Rulers or Straight-Edges

Students should be encouraged to use a ruler or straight-edge when drawing the line of best fit.

Default Angle Units and Graphing Calculators

Students who use graphing calculators on Physics 30 field tests and diploma examinations often fail to realize that the units for angle measure default to radians when the calculator memory is reset. As a result, these students will provide incorrect answers to questions that involve trigonometric functions.

Constants

Students should use constants provided on the data sheet and recorded to three significant digits rather than constants stored in calculators. This is important in order to obtain correct numerical-response answers.

Numerical-Response Questions

Students should be familiar with the different formats of numerical-response items and the procedure for completely filling in the bubbles on the answer sheet.

Machine-Scored Items Illustrating New Program of Study Outcomes

1. Which of the following statements **best** describes an isolated system?

A. No external forces act on an isolated system.

B. Only gravitational forces act on an isolated system.

C. Momentum is always conserved in an isolated system.

D. Kinetic energy is always conserved in an isolated system.

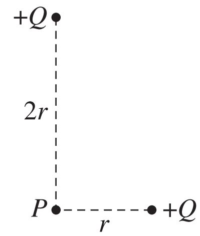
Statistical performance:

Percentage of students who selected choice	***A** =	76.5 %
	B =	1.8 %
	C =	12.9 %
	D =	8.8 %

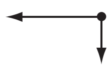
Commentary
The goal of this question is to explore the differences between what we do when we analyze a situation (choice C) and why we can do a particular analysis (choice A).

Use the following information to answer the next question.

Two identically charged objects are placed near a point, P, as shown below.

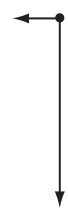


2. Which of the following free-body diagrams, drawn to scale, illustrates the electrostatic forces acting on a positive test charge placed at point P?

A. 

B. 

C. 

D. 

Statistical performance:

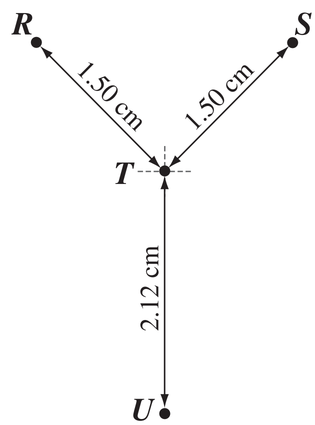
Percentage of students who selected choice	**A** =	33.6 %
	B =	19.4 %
	***C** =	40.1 %
	D =	6.9 %

Commentary

This question asks the students to select the free-body diagram for a particular situation in which they also need to recognize the $\frac{1}{r^2}$ property of an electrostatic force.

Use the following information to answer the next question.

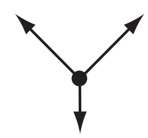
Four spheres are located near each other on a plane, as shown below. All four spheres have identical charges of $+2.00\mu\text{C}$.



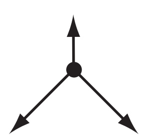
3. Which of the following free-body diagrams shows the forces acting on sphere *T*?

A.

B.



C.



D.

Statistical performance:

Percentage of students who selected choice **A** = 7.7%

B = 34.9%

***C** = 39.6%

D = 17.8%

Commentary

This question also explores free-body diagrams and vector addition. With the emphasis in the program of studies on free-body diagrams, it is expected that student performance will improve with time. Explore this idea further by changing the nature of all of the charges or by asking for net $\vec{E}$, net $\vec{F}$.

Use the following information to answer the next question.

Possible Sources of Electromagnetic Radiation

I A charged plastic sphere accelerates from the positive plate to the negative plate in a Millikan apparatus.

II Cathode rays travel at constant velocity in a vacuum.

III Gamma rays travel through a perpendicular magnetic field.

IV Beta positive particles travel perpendicular to a magnetic field.

4. Electromagnetic radiation is produced by

A. source I only

B. sources I and IV

C. source II only

D. sources I and III

Statistical performance:

Percentage of students who selected choice	**A** =	17.8 %
	***B** =	23.1 %
	C =	14.2 %
	D =	45.0 %

Commentary
This question asks students to apply the principle of accelerating charges producing electromagnetic radiation to various situations in which the students must decide whether acceleration occurs. This is a great opportunity to readdress circular motion and uniform motion, along with linear and centripetal acceleration.

Use of Written-Response Items for Formative and Summative Assessment

Written-response items measure communication skills more directly than do machine-scored items; however, there are many other valid assessment methods available to classroom teachers to assess their students. The rest of this document will explore the application of three types of written-response questions to assess outcomes mandated in the *Physics 20–30 Program of Study, 2007*.

Assessment of Communication Skills

Communication skills are assessed most directly in the written-response questions.

The term *communication skills* includes those processes by which information is expressed using appropriate conventions. These conventions include, but are not limited to, the following:

- scientific terminology
- words, sentences, paragraphs
- graphs, diagrams, tables
- mathematical formulas, mathematical and chemical equations
- significant digits, units of measurement, unit conversions

Physics Principles

The physics principles that a Physics 30 student should be familiar with are
—uniform motion (balanced forces)
—uniformly accelerated motion (unbalanced forces)
—circular motion (unbalanced forces)
—conservation of momentum
—conservation of energy
—conservation of mass-energy
—conservation of charge
—conservation of nucleons
—wave-particle duality

Directing Words

The directing words for Mathematics and Science have been combined. The complete list of directing words is available on the Alberta Education website at education.alberta.ca, via the pathway: Teachers > (Additional Programs and Services) Diploma Exams > Information Bulletins > Mathematics and Science Directing Words

Energy Versus Electric Field

In their written work, many students use the same symbol for energy as for electric field. Many of these students then substitute energy values into electric field formulas and vice versa. In their written work, students should be encouraged to use notation that differentiates between energy (E_p, E_k, E_M, $E_{electric}$) and electric field ($\vec{E}$ or $|\vec{E}|$).

Directions

Direction words such as “up” and “down” are ambiguous because they could apply to the real world or to a diagram on the page. Consequently, their use may limit the score a student response receives. The following convention describes directions relative to the page.

Direction	Description
↑	toward the top of the page
↓	toward the bottom of the page
→	to the right of the page
←	to the left of the page
×	into the page
•	out of the page

Reading the Whole Question Versus Answering the Bullets

The written-response items are designed, generally, to have a central idea given by the first one or two sentences following the question number. For students achieving at the *standard of excellence*, this is sufficient direction. These students are able to show connections and apply appropriate knowledge.

The bullets are provided to assist those students who are not at the standard of excellence. These students require more-specific direction. The bullets are **not** the question. Students who answer the bullets as separate questions only may be significantly limiting the maximum score they are likely to receive.

Two-Dimensional Vector Analysis

Students often inappropriately apply linear-analysis techniques in two-dimensional situations. Vector-addition diagrams containing arrowheads, vector labels, and angle labels would likely assist students in recognizing that 2-D analysis is necessary. Students using components need to remember that the direction of the components and the final resultant vector are important.

Role of Written-Response Questions

There are outcomes mandated in the *Physics 20–30 Program of Study, 2007* that are best assessed using open-ended, written-response style questions. The following three styles of question were designed to explore these outcomes.

Three Styles of Written-Response Questions

Skill-Based Question

The first style of question is a skill-based question. There are two types of skill-based question: graphing skills and two-dimensional vector analysis. For a graphing-skills question, the student's response is scored on a six-point scale (0, 1, 2, 3, 4, 5) for the graphing skills and on a six-point scale (0, 1, 2, 3, 4, 5) for the mathematical treatment and physics content. For a two-dimensional vector-analysis question, the student's response is scored on a six-point scale (0, 1, 2, 3, 4, 5) for the vector diagrams and on a six-point scale (0, 1, 2, 3, 4, 5) for the mathematical treatment and physics content.

The graphing-skills question from the January 2009 Diploma Examination begins on page 19. The graphing-skill scoring guides begin on page 14. Sample solutions begin on page 28.

A second example of a graphing skill-based question begins on page 42. The corresponding scoring guides begin on page 13. Sample solutions begin on page 44.

An example of a two-dimensional vector skill-based question is given on page 47. The corresponding scoring guides begin on page 15. Sample solutions begin on page 48.

Analytic Question

The second style of written-response question is an analytic question. Each question of this type requires the student to address two physics principles as listed on the data sheets. The student's response is scored on the physics principles cited and used (0, 1, 2, 3, 4), on the formulas cited and used (0, 1, 2, 3), on the substitutions shown (0, 1), and on the answer given (0, 1, 2).

The analytic question from the January 2009 Diploma Examination is given on page 21. The scoring guide is given on page 17. A sample solution is given on page 31.

A second example of an analytic question is given on page 51. The sample solution is given on page 52.

Open-Response Question

The third style of written-response question is an open-response question. The holistic scoring guide describes the characteristics of the student's answer that correspond to one of six values (0, 1, 2, 3, 4, or 5). The descriptor for each level addresses the level of knowledge and understanding demonstrated by the student, the completeness of the response, and the level to which the student communicates his or her understanding of the physics principles involved in solving the problem. Each scoring guide identifies the major concepts that a complete answer must address.

The open-ended question from the January 2009 Diploma Examination is given on page 22. The scoring guide is given on page 18. Sample solutions begin on page 31.

A second example of an open-ended question is given on page 53. The sample response is given on page 54. A third example begins on page 55.

Scoring Guide for Graphing-Skills Questions – Graph

Score	Description
5	All conventions for title, labels, scales, plotting of data, and line of best fit are followed* **Note:** one minor error may be present**
4	Two minor errors may be present **or** Four graphing conventions are present but enough of the graph is present and correct that the analysis could be done
3	Three of the conventions are present **or** A major error is present***
2	Two of the conventions are present
1	One of the conventions is present
0	The graph was started but nothing valid is present
NR	No response to the graphing portion of the question is present

*Graphing Conventions

Graphing conventions are as follows. Descriptions within [ ] denote calculator active response equivalents.

- The title is in the form "responding variable as a function of manipulated variable"
- The axes are labelled with the variable, including powers of 10 if required, and units [how the data are entered into the calculator is clearly communicated, including powers of 10 and units]
- The scales are such that the data, when plotted, cover a majority of the graph **and** interpolation or extrapolation of points based on the line of best fit is convenient [window settings are provided]
- All the data points are plotted [the sketch of the calculator window shows the locations of the data points relative to the line of best fit determined by the appropriate regression]
- The line of best fit, either a line or a curve, provides the best approximation of the trend of the data given the context of the data (i.e., students should be able to predict the shape of a graph based on physics knowledge and mathematical graphing) [The quality of the line of best fit is provided by stating the validity of the regression used based on the physics and logic of the situation or by comparing *r*-squared values for several different regression models]

**Minor Errors

- A data point that has been plotted incorrectly by a margin of more than one-half of a grid box
- Missing one set of units on one of the axes
- Reversing the order of the variables in the title
- The line of best fit is an appropriate trend but is not the best line of best fit

***Major Errors

- Reversed axes
- Dot-to-dot line of best fit
- Missing line of best fit
- Plotting inappropriate data

Scoring Guide for Graphing-Skills Questions – Mathematical Treatment

Score	Description
5	• All formulas are present • All substitutions are given and are consistent with the graphed data • The algebraic relationship between the slope, area, or intercept and the appropriate physics equation is explicitly communicated • The final answer is stated • Unit analysis is explicitly provided, if required **Note:** one minor error may be present*
4	• The response contains implicit treatment** **or** • The response contains explicit treatment with up to three minor errors or one major error***
3	• The response is incomplete but contains some valid progress toward answering the question (e.g., coordinates of relevant points are read correctly, including powers of 10 and units, and a valid substitution is shown)
2	• The coordinates of one relevant point are read • The reason a point is needed is addressed
1	• A valid start is present
0	• Only inappropriate mathematical treatment is present
NR	• No mathematical treatment is provided

***Implicit treatment means*
- Substituting appropriate values into a formula from the data sheets without stating the formula
- Starting with memorized, derived formulas not given on the equations sheet
- Substituting the value from one calculation into a second formula without communicating that the physics quantity in the two formulas is the same

*Minor Errors
- Misreading a data value by a margin of up to one-half of a grid while interpolating or extrapolating
- Stating the final answer with incorrect (but still respectful) units
- Stating the final answer with incorrect (but still respectful) significant digits
- Missing one of several different formulas

***Major Errors
- Using off-line points (most often, this is calculating the slope using data points that are not on a linear line of best fit)
- Using a single data point ratio as the slope
- Missing powers of 10 in interpolating or extrapolating

Scoring Guide for Two-Dimensional Vector Questions – Vector Diagrams

Score	Description
5	• The physics logic that provides the direction of the vectors is explicitly communicated* • A diagram showing the directions of the significant vectors is given (e.g., for a question dealing with forces, this is the free-body diagram; for a conservation of momentum question, this is a situational diagram) • A vector-addition diagram is given • All vector conventions are followed** • The solution is presented in an organized manner **Note:** One minor error may be present***
4	• The vector diagrams are present but have two minor errors. However, enough of the vector-addition diagram is present and correct to complete the analysis **or** • The situational diagram may be missing from an otherwise complete response **or** • A solution using components is given, but the relationship between the components and one of the vectors is missing
3	• The vector-addition diagram is given as a triangle (i.e., lines instead of arrows), but labels are present (i.e., the problem is solvable from the diagram given)
2	• A complete diagram showing the directions of the significant vectors is present (e.g., a free body diagram or a situational diagram) **or** • The vector addition diagram is given as a triangle with more than one label present **or** • Some vector addition is shown but not enough for the problem to be solved (e.g., the net vector is absent or labels are missing)
1	• There is a valid start present (e.g., a labelled situational diagram drawn as lines with some labels present)
0	• Nothing valid to vector addition is provided
NR	• No response to the vector diagram component of the question is provided

*Directional logic: where appropriate, the following (or equivalent) is required:
- A compass rosette is drawn and labelled
- Coordinate axes are drawn and labelled
- Like charges repel or unlike charges attract
- The direction of an electric field is the direction of the electrostatic force on a positive test charge
- The direction of a magnetic field is the direction of the magnetic force on the N-pole of a test magnet

**Vector conventions include
- Vectors are drawn as arrows pointing in the direction of the vector
- Arrows are labelled with the magnitude or name of the vector
- Angles are labelled at the vector's tail
- Scaling of vectors in the situational diagram or in the vector-addition diagram is not required

***Minor errors include
- Missing one arrowhead
- Missing one label

Scoring Guide for Two-Dimensional Vector Questions – Mathematical Treatment

Score	Description
5	• The physics principle related to the solution, if necessary, is explicitly communicated (e.g., conservation of momentum, work done equals change in energy, equilibrium means F_{net}= zero) • All formulas are present • All substitutions are shown • The final answer is stated with appropriate significant digits and appropriate units. Unit analysis is explicitly provided, if required One minor error may be present*
4	• A complete solution is present, but it contains two minor errors or one major error or omission**
3	• A valid method is begun and contains no errors **or** • The solution is complete, but there are significant errors or omissions
2	• A valid method is begun **or** • A linear analysis is present***
1	• A valid start is present. This may be one valid calculation
0	• Only inappropriate mathematical treatment is present
NR	• No response to the mathematical treatment is provided

*Minor errors include
- Stating the final answer with incorrect (but still respectful) units
- Stating the final answer with incorrect (but still respectful) significant digits
- Missing one formula

**Major omissions include
- Missing the physics principle
- Missing more than one formula
- Missing several substitutions
- Substituting a calculated value from one formula into another formula without explaining why this substitution is valid

*****Linear Analysis**
A response that contains a linear mathematical treatment of a two-dimensional situation could receive a maximum score of 2 for mathematical treatment if the Physics principle is stated, all formulas are shown, all substitutions are shown, and the answer is stated with appropriate significant digits and units.

Note: A student response calculated using a calculator in radian mode is valid until a numerical value does not make physics sense.

Analytic Scoring Guide

A1—Physics Principles

Score	Description
NOTE:	Extraneous principles not required to answer the question *may* result in a score reduction
4	Both relevant physics principles are stated and both are clearly related to the response. Physics principles for questions involving linear vector addition require explicit communication of vector nature; e.g., a situational diagram or a free body diagram (FBD) for forces and a vector-addition diagram
3	Both relevant physics principles are stated, but only one is clearly related to the response
2	Both relevant physics principles are stated but neither is clearly related to the response **or** One relevant physics principle is stated and is clearly related to the response
1	One relevant physics principle is stated
0	Only an unrelated physics principle is stated
NR	No physics principle is stated

A3—Substitutions

Score	Description
1	Substitutions are shown Significant digits are not required in intermediate steps A response with at most one implicit unit conversion may receive this score An incomplete or incorrect response may receive this score if all the values substituted are appropriate; for example, length measurements into length variables or energy measurements into energy variables
0	Substitutions are missing **or** The response contains one invalid substitution; for example, electric field strength for energy, speed for electric potential difference
NR	No substitutions are shown

A2—Formulas

Score	Description
NOTE:	Extraneous formulas not required to answer the question *may* result in a score reduction
3	All relevant formulas required for the complete solution are present and have been written as they appear on the equations sheet or in the information given with the question
2	Most relevant formulas are stated **or** Derived formulas are used as starting points
1	One relevant formula is stated
0	Only formulas not relevant to the solution are stated
NR	No formulas are stated

A4—Final Answer

Score	Description
2	The final answer to the complete problem is stated with the appropriate number of significant digits and with appropriate units A response in which an inappropriate substitution has been made may receive this score if the incorrect units are consistently carried forward
1	The value of the final answer is stated, but units or significant digits are incorrect **or** The response is incomplete (i.e., one of the physics principles is completely addressed or two parts (one part from each principle) are completed), but an intermediate value is stated with appropriate units (significant digits not required)
0	The response is too incomplete **or** The answer stated is unrelated to the solution shown
NR	No answer to any part of the solution is given

Holistic Scoring Guide

Major Concepts:	
Score	**Description**
5	• The response addresses, with appropriate knowledge, all the major concepts in the question • The student applies major physics principles in the response • The relationships between ideas contained in the response are explicit • The reader has no difficulty in following the strategy or solution presented by the student • Statements made in the response are supported explicitly **Note:** the response may contain minor errors or have minor omissions
4	• The response addresses, with appropriate knowledge, all the major concepts in the question • The student applies major physics principles in the response • The relationships between the ideas contained in the response are implied • The reader has some difficulty following the strategy or solution presented by the student • Statements made in the response are supported implicitly **Note:** the response may contain errors or have omissions *The response is mostly complete and mostly correct, and contains some application of physics principles*
3	• The response addresses, with some appropriate knowledge, more than half of the full scope of the question **or** The response addresses more than half of the full scope of the question with a mixture of knowledge and application • There are no relationships between the ideas contained in the response • The reader may have difficulty following the strategy or solution presented by the student
2	• The response addresses, with some appropriate knowledge, two of the five outcomes in the question
1	• The response addresses, with some appropriate knowledge, one of the five outcomes in the question
0	• The student provides a solution that is invalid for the question
NR	• There is no response to the question

The knowledge expectations are:

•
•
•

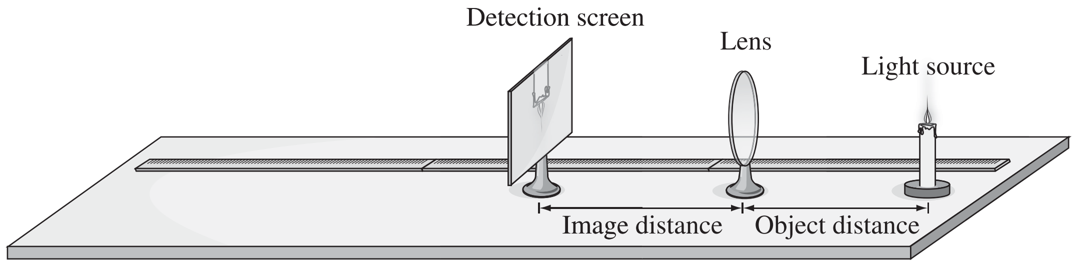
The application expectations are:

•
•

Written-Response Questions and Commentary on Student-Response Strengths and Weaknesses from the January 2009 Physics 30 Part A: Written Response

Use the following information to answer this graphing-skills question.

Some physics students do an experiment to find the focal length of a convex lens. They set up an optical bench and measure the image distance as a function of object distance.



Their observations and the start of their analyses are given below.

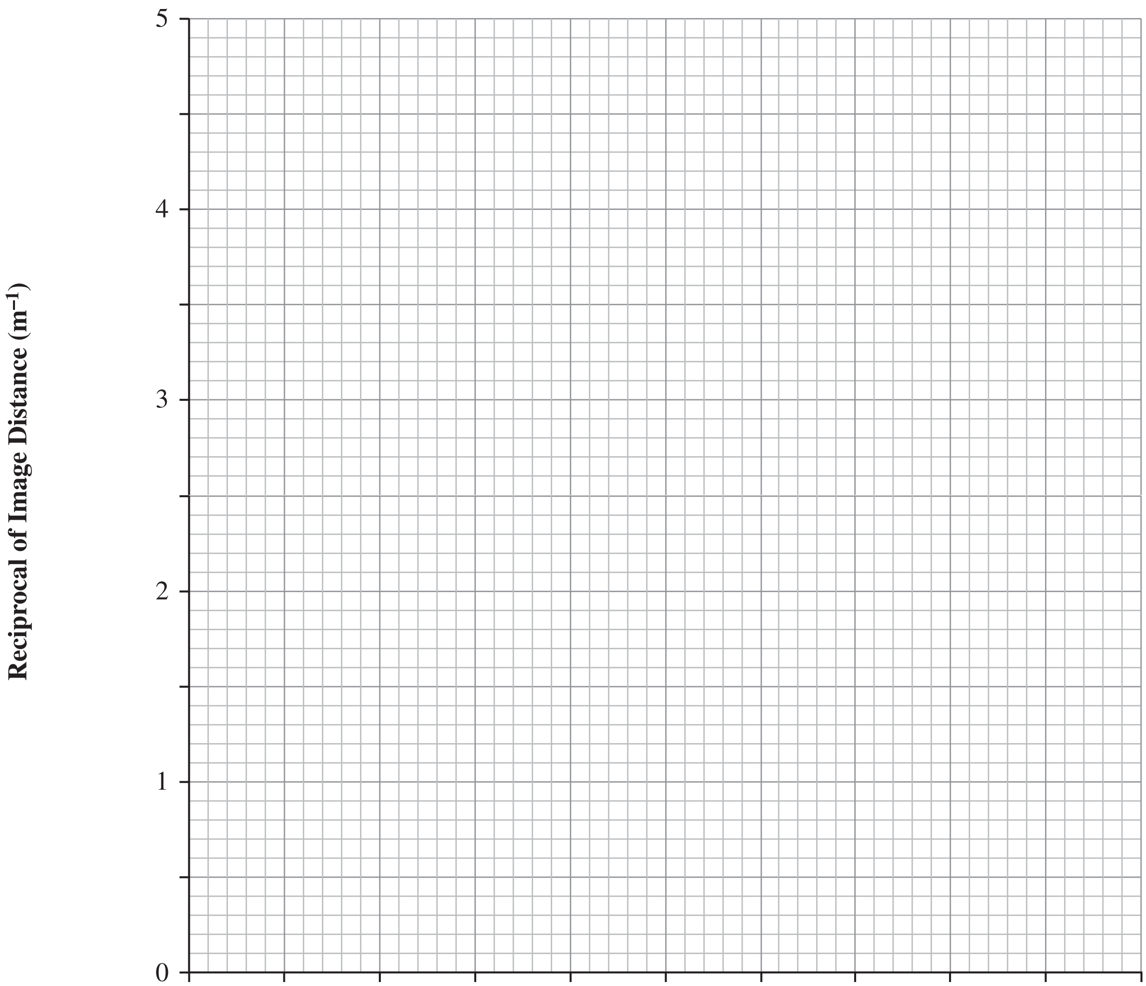
Observations		Analysis	
Object Distance (m)	**Image Distance (m)**	**Reciprocal of the Object Distance (m^{-1})**	**Reciprocal of the Image Distance (m^{-1})**
1.50	0.30	0.667	3.3
1.25	0.32	0.800	3.1
1.00	0.33	1.00	3.0
0.75	0.38	1.3	2.6
0.50	0.50	2.0	2.0

Written Response—10%

1. Using the *y*-intercept found from graphical analysis, **determine** the focal length of the lens. In your response, **provide** a graph of the reciprocal of the image distance as a function of the reciprocal of the object distance, **determine** the *y*-intercept of the graph, and **relate** the *y*-intercept algebraically to a physics equation. **State** all necessary physics concepts and formulas.

Marks will be awarded for your graph, for the physics that you use, and on the mathematical treatment that you provide.

(Title)

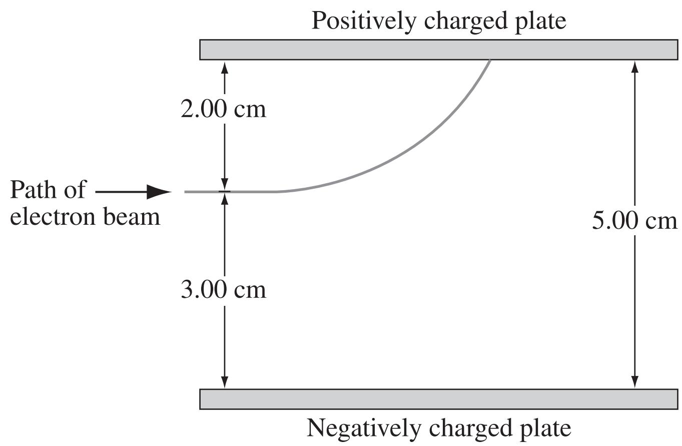


(Label)

Graphing Scoring Guides begin on	page 13
Sample Solutions for this question begin on	page 28
Commentary on Strengths and Weaknesses of Student Responses for this question is on	page 24

Use the following information to answer this analytic question.

Two horizontal plates are separated by a distance of 5.00 cm. A beam of electrons is directed, horizontally, into the region between the plates. The path of the beam is deflected as shown below. Electrons in the beam have a speed of 9.00×10^6 m/s as they enter the region between the parallel plates. The electric field strength in the region between the plates is 3.10×10^3 N/C.



Note: This diagram is **not** drawn to scale.

Written Response—10%

2. **Determine** the horizontal distance travelled by an electron in the beam in the region between the horizontal plates.

Marks will be awarded based on the relationships among the two physics principles* that you state, the formulas that you state, the substitutions that you show, and your final answer.

*** The physics principles are given on the tear-out data sheet included with this examination.**

Analytic Scoring Guide is on	page 17
Sample Solution for this question is on	page 30
Commentary on Strengths and Weaknesses of Student Responses for this question is on	page 25

Use the following information to answer the next question.

Selected Physics Apparatus

J.J. Thomson's cathode ray tube

Millikan's oil drop apparatus

Hertz/Millikan photoelectric apparatus

Michelson's rotating mirrors

Selected Physics Constants

$$c = 3.00 \times 10^{8} \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ J·s}$$

$$e = 1.60 \times 10^{-19} \text{ C}$$

$$\frac{q_e}{m_e} = 1.76 \times 10^{11} \text{ C/kg}$$

Written Response—15%

3. Using the concepts of experimental design, experimental observations, and methods of data analysis, **describe** how **one** of the selected physics apparatus given above was used to determine **one** of the selected physics constants. In your response,

- **match** one of the apparatus given above to the physics constant that could be determined using the results of the apparatus

- **outline** an experimental method that could be used to determine an accurate value of the physics constant you have identified. Your response must include
  - — a list of materials
  - — a procedure
  - — a labelled diagram
  - — an analysis in which you describe how the observations will be used to determine the physics constant

Marks will be awarded for the physics that you use to solve this problem and for the effective communication of your response.

Holistic Scoring Guide is on	page 18
Sample Solutions for this question begin on	page 31
Commentary on Strengths and Weaknesses of Student Responses for this question is on	page 27

Commentary on January 2009 Written-Response Question 1

Written-response question 1 provided the students with observations from an optics bench and the data corresponding to the initial analysis of the observations. The question provided detailed, step-by-step instructions directing the students toward a particular solution. The question also provided a 10 × 10 grid with labelled blanks for graph title and axis label. This question was unusual in that it provided the label with units and scale on the vertical axis.

This graphing-skills question was marked on two scales: No Response (NR) to 5 on the graph and NR to 5 on the mathematical treatment.

Students were expected to provide a scale on the horizontal axis that resulted in the plotted data covering more than half of the 10 × 10 grid and provided the ability to interpolate values on the line of best fit that were not data points. The two most common, valid scales that markers saw started at zero and went to 2.0 or 2.5. Because the question directed the students to the *y*-intercept, scales that did not begin at zero were invalid. Similarly, students who provided a scale from zero to 5, the same as the vertical scale, showed a weakness in their skills. The plotting of the points needed to be within one-half of a square of the ideal location. Students who chose poor scales often lost this mark, too, because their poor scale made accurate plotting more difficult. The students then needed to draw a line-of-best-fit in order to get a *y*-intercept. A student who provided a curve, a dot-to-dot line, or a line forced through the origin found this graphical analysis portion very challenging.

For the mathematical treatment, students were expected to read the value of the *y*-intercept, including units. Markers accepted any value, with units, consistent with the graph provided by the student. Students struggled with the meaning of the exponent –1. Many of them made it go away by re-writing the *y*-intercept as 0.25 m, thereby clearly revealing a lack of mathematical competency. To complete the question, the students were required to relate algebraically the *y*-intercept to a physics equation. The response to this portion of the question showed great variety: many students provided the appropriate lens equation but then used the data in the analysis portion of the table to calculate a value for the focal length; many students stated the *y*-intercept was the focal length without any support; many students stated the lens equation and described how, at infinity, one of the terms would go to zero so that the reciprocal of the focal length would be the reciprocal of the image distance; finally, many students applied the general equation of a line, $y = mx + b$, to the variables plotted and to the lens equation to derive that the "b" in the general equation corresponded to the "$1/f$" term of the rearranged lens equation. This final method was marked as being the most explicit algebraic relating of the *y*-intercept to a physics equation.

The skills question and scoring guide are designed such that the provincial average on this question, over time, will be in the 7.5 range. This question performed below this target. Teachers at marking recognized the value of laboratory activities in building the graphing competencies mandated by the program of studies.

The next question on the examination is the analytic question. The analytic question is designed to explore both the students' ability to calculate an answer (6 marks) **and** their ability to explain (4 marks), in terms of physics principles, why the calculations that they are doing are valid or appropriate for that situation. This is based on the program of studies mandate that students will explain their quantitative solutions.

Commentary on January 2009 Written-Response Question 2

Written-response question 2 provided the students with a parabolic trajectory followed by electrons travelling in a uniform electric field. The location of the entry point was an intentional choice because the markers were able to clearly see whether the response illustrated formula grabbing and substitutions, or appropriate analysis. The archived *Physics 30 2008-09 Information Bulletin* contains a very similar question and expected sample response.

Many students who provided responses to this question were able to complete the algebraic and mathematical analysis, yet provided no justification for why their calculations were valid. These students received scores of 6 out of 10.

Many more students provided disorganized, disjointed, and wide-ranging solutions and received scores below 4 out of 10.

The analysis of a two-dimensional trajectory rests on one of the fundamental mathematical ideas—that perpendicular vectors can be analyzed independently of each other. This is the idea behind all the rectilinear component analysis that students do. Unfortunately, most students do the component analysis as an algorithmic method to be followed rather than understanding why they need to do the calculations that way. This missing foundation was evident in the nature of the responses that the markers saw.

The scramble-to-an-answer method used by students to answer many machine-scored questions will not assist them on questions of this style: the expectation is that the student documents a complete solution; the final answer, in and of itself, is worth only 1 mark out of 10.

Another aspect of the scoring of this question that is of interest to teachers is the distinction between work that is inappropriate, and work that is irrelevant, and work that is not wrong … yet.

A response that contains statements (physics principles, formulas, or substitutions) that are inappropriate will lose marks on any of the 4 scoring scales, regardless of the level achieved by the response. For example, a response that cited, but did not clearly relate to the solution, both uniform motion in the horizontal direction, which was correct, and circular motion in the vertical direction, which is invalid, would likely receive a score of zero for the physics principles because the one correct statement gets one mark but the one invalid statement costs one mark. Similarly, describing the acceleration as caused by an electric force and then using $F = Bvq$ is invalid and would cost a mark.

Responses that contain formulas or substitutions that are irrelevant show work that is not wrong but that is not necessary to the solution. For example, students who did not cite conservation of momentum (that would be wrong) but who calculated momentum were not penalized for that calculation because it is completely unrelated to any valid approach to answering the question.

Finally, markers saw responses that were not wrong … yet. For example, many students cited conservation of energy and calculated the kinetic energy of an electron in the electron beam as it enters the electric field. If they stopped at this point the markers could give some marks as this calculation could lead, through a very convoluted path, to a correct final answer. However, if the students then used this energy in calculations in the vertical direction, they would be providing invalid physics, and at this point, the markers deducted a mark.

This analytic question style is new to physics in Alberta. The design is very predictable: the shortest path to the final answer will always involve two physics principles; there will always be a minimum of 4 required formulas, although a formula may be required twice, for example $p = mv$ or $E_k = \frac{1}{2}mv^2$ before and after a collision; and there will always be a single sentence that directs the students to the final answer without providing clues about the intermediate answer. It is expected that the physics principles will not be the same principle applied twice: for example, an examination question would not have vertically oriented parallel plates with a charged oil drop entering at the top because the principle of uniformly accelerated motion is required in both the vertical and horizontal directions.

The statement of the physics principles should be in a manner that makes sense to the student and should be done as part of the response so that the reader is confident that the student actually used the physics principle in their solution. This confidence can be shaken when the two principles are stated at the start of the response, because the relationship is not clear. Citing the two correct principles, drawing or numbering the principles, and referring to them in the solution clearly illustrates the relationship. An even clearer method is to cite the appropriate principle, provide the valid analysis, and then provide the other principle with its corresponding analysis.

The final written-response question is open-ended. These holistic questions are designed to have three recall-level and two application-level expectations. Students who are familiar with Learner Assessment's *Directing Words* are better able to answer the full scope of the question. The question is asked in the short paragraph beside the numeral three. The bullets provide direction to students who do not understand the question. The bullets are **not** the question.

Commentary on January 2009 Written-Response Question 3

Written-response question 3 on the January 2009 diploma examination was an experimental design question. Students were to match one of the given apparatus to one of the given constants and then provide an experimental method to determine that constant.

Almost all the students were able to match the constants. Most students were able to provide a summary of the historical significance of the experiment, and were able to relate a formula to the constant they had selected. What most students also did was completely miss the experimental design: set up equipment, control variables, manipulate something, make measurements, and repeat trials to get accurate data. The students demonstrated this by providing a set-up of apparatus that would not produce any measurements, let alone meaningful or appropriate measurements; by starting with known values of distances, electric potential differences, or energies, etc.; and by stating memorized, derived formulas specific to a situation other than the one they had outlined.

The students' actual experimental skills displayed on the January 2009 Part A are weak. This is a clear area of potential improvement across the province.

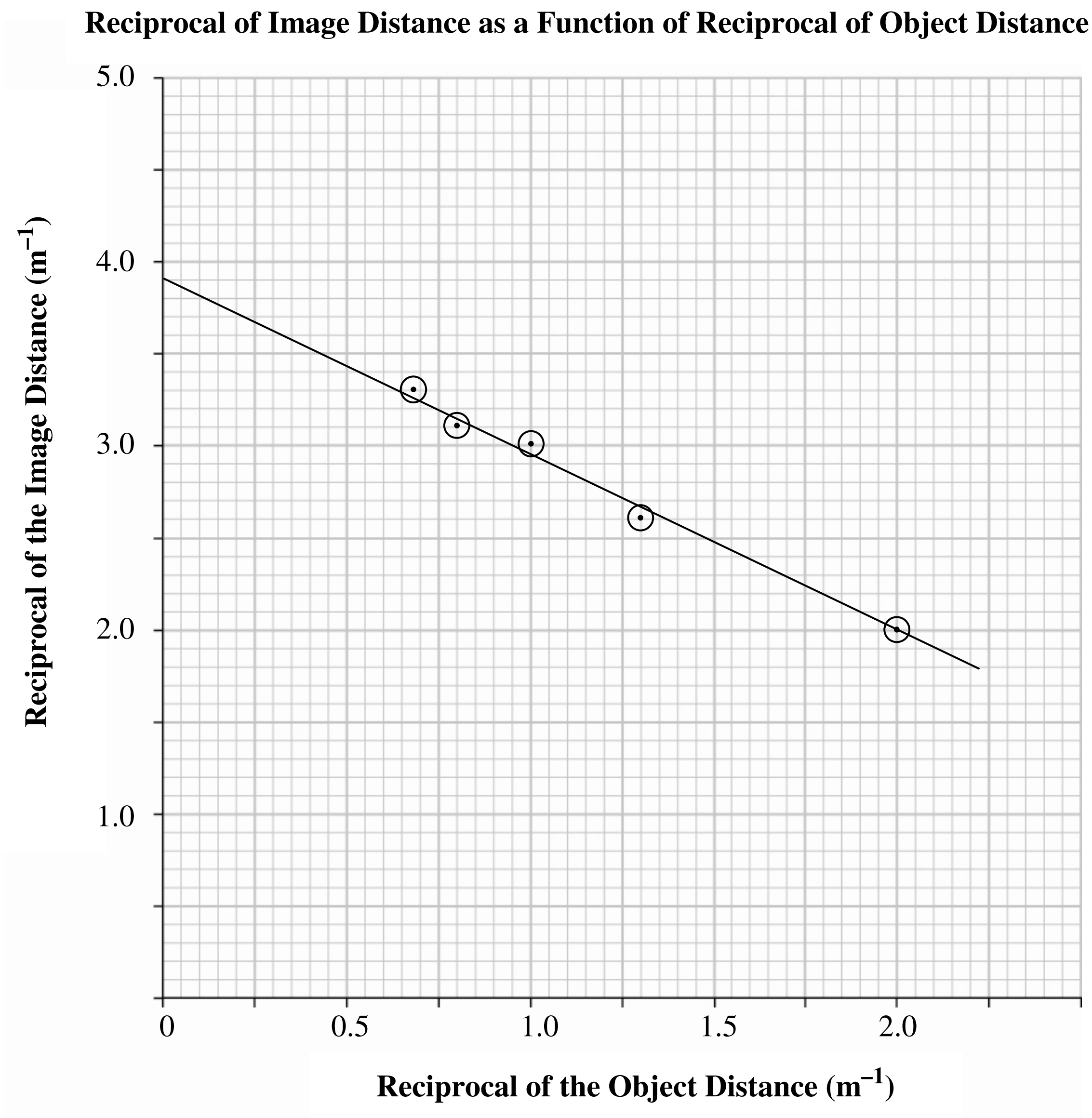
The **knowledge** expectations of this question are
- matching an experiment to its constant
- providing a diagram and list of materials consistent with either the experiment or constant
- identifying a measurement that needs to be made

The student shows **application** by
- explicitly relating cause and effect to the experiment design. (In the photoelectric effect this is changing the light source to generate multiple data values and produce the graph; in the mirrors, it is starting with the mirror at rest, verifying the path, slowly increasing the frequency of rotation until a maximum signal is again observed; in Millikan it is repeated trials to determine the difference between different charges so that this difference can be divided by a whole number multiple of a smallest value; in Thomson the cause and effect is to have the CR beam undeflected, add the perpendicular electric and magnetic fields, and adjust one of them until the beam is again undeflected).
- explicitly communicating the analysis of the observations to get the constant

Sample Solutions for the January 2009 Physics 30 Part A: Written Response

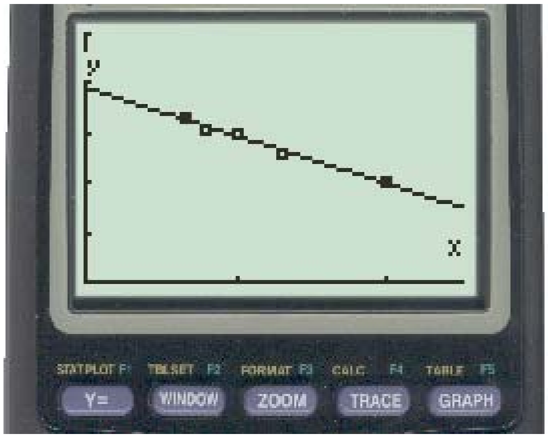
Written-Response Question 1

Method 1



Method 2

Calculator active solution:



Calculator active solution

store $\dfrac{1}{d_o}$ in L1, in units of m^{-1}

store $\dfrac{1}{d_i}$ in L2 in units of m^{-1}

perform the linear regression

$y = ax + b$ on L1, L2

to give $a = -0.967$

$b = 3.91$

Window settings on calculator

x:[0, 2.5]

y:[0, 5]

Determining the focal length using graphical analysis

The variable plotted on the y-axis is the reciprocal of the image distance, $\dfrac{1}{d_i}$

The variable plotted on the x-axis is the reciprocal of the object distance, $\dfrac{1}{d_o}$

The physics equation is $\dfrac{1}{f} = \dfrac{1}{d_o} + \dfrac{1}{d_i}$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{d_i} = -\frac{1}{d_o} + \frac{1}{f}$$

$$y = m\,x + b$$

Therefore, the $y-\text{intercept} = \dfrac{1}{f}$, which gives

$$f = \frac{1}{y\text{-intercept}} = \frac{1}{3.9\ \text{m}^{-1}} = 0.26\ \text{m}$$ (mark consistent with the student’s graph)

or using the calculator active solution

$$f = \frac{1}{y\text{-intercept}} = \frac{1}{3.91\ \text{m}^{-1}} = 0.26\ \text{m}$$ (2 S.D.’s as per data chart)

Sample Solution

Written-Response Question 2

Note: Alternate responses may receive full marks. Student responses that are internally consistent but not identical to this response may receive full marks.

Horizontal – uniform motion

Vertical = accelerated motion

$F_{\text{net}} = ma \neq 0$

$F_{\text{net}} = F_{\text{e(upward)}}$, Note: gravity is negligible (students don't need to tell us)

$$a = \frac{F_{\text{net}}}{m} = \frac{F_{\text{e}}}{m} = \frac{|\vec{E}|q}{m}$$

$$a = \frac{(3.10\times10^{3}\ \text{N/C})(1.60\times10^{-19}\ \text{C})}{9.11\times10^{-31}\ \text{kg}}$$

$$a = 5.44456\times10^{14}\ \text{m/s}^2$$

$$d = v_{\text{i}}t + \frac{1}{2}at^2\ ,\ v_{\text{i}} = 0$$

$$t = \sqrt{\frac{2d}{a}}$$

$$t = \sqrt{\frac{2(0.0200\ \text{m})}{5.44456\times10^{14}\ \text{m/s}^2}}$$

$$t = 8.537133\times10^{-9}\ \text{s}$$

$d = vt$

$d = (9.00\times10^{6}\ \text{m/s})(8.537133\times10^{-9}\ \text{s})$

$d = 0.07714199$ m

$d = 7.71$ cm

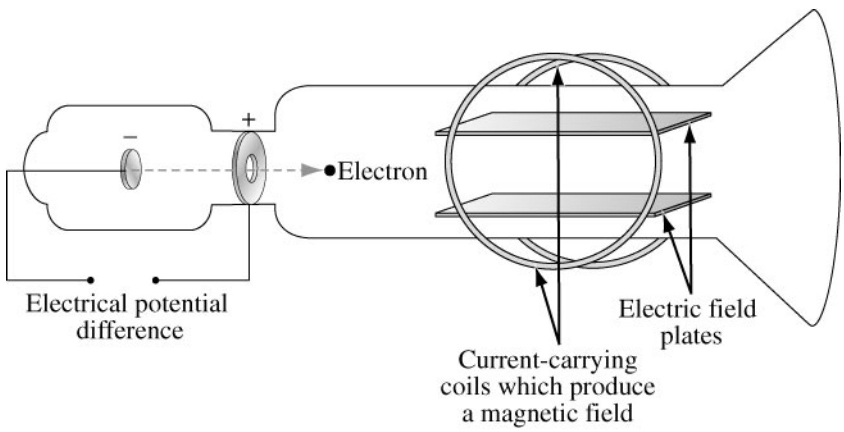
Written-Response Question 3

Sample Solution 1

J.J. Thomson's cathode ray tube was used to determine the charge-to-mass ratio of the electron.

Materials: —cathode ray tube with screen to show location of beam (or with low pressure gas to show path of beam)
—magnetic field coils
—electric field plates
—ruler for measuring radius and plate separation
—voltmeter for measuring electric potential difference

Set-up: —Cathode ray tube with perpendicular electric and magnetic fields



Method 1

1. Turn on the accelerating voltage to 50 volts (measure with voltmeter). This voltage gives an electron speed
2. Observe location of undeflected beam on screen at right end of CRT
3. Turn on the magnetic field and measure the radius of curvature of the electron beam.
4. Measure the plate separation.
5. Turn on the electric field between the plates on the right and increase the voltage until the beam is once again undeflected. Record this voltage
6. Repeat steps 3 and 5 for various magnetic field strengths.

Observations:

Trial	Accelerating electric potential V_1 (V)	Radius of curvature (m)	Voltage to cause undeflected path V_2 (V)	

Analysis:

$$v = \sqrt{\frac{2V_1 q}{m}}$$

The circular motion gives:

$$a = \frac{F}{m} \text{ where } F = Bvq \text{ and } a = \frac{v^2}{r}$$

Combining these gives

$\dfrac{q}{m} = \dfrac{v}{Br}$ (we have measured r and we have calculated v but we need B)

The undeflected motion gives

$$F_e = F_m$$

$$\frac{V_2}{d} q = Bvq$$

$B = \dfrac{V_2}{dv}$ (we have measured V_2 and d and we have an expression for v)

This expression can be substituted into the charge-to-mass equation.

Method 2:

Procedure:

1. Turn on accelerating voltage to 50 volts (measure with voltmeter).
2. Observe the location of the undeflected beam.
3. Turn on magnetic field and set it to one Tesla. (Unless the student identifies a magnetic field meter, this statement is equivalent to "a known value" for a variable, and drops the maximum score to 4)
4. Measure the radius of curvature of the electron beam.
5. Turn on balancing electric field and increase the voltage until the electron beam travels in a straight line. Record the voltage.
6. Reduce the magnetic field to 0.90 T and record the radius.
7. Repeat step 5 five times, reducing the magnetic field by 0.10 T each time.

Observations		**Analysis**
Magnetic field (T)	**Radius (m)**	***q/m* (C/kg)**
1.00		
0.90		
0.80		
0.70		
0.60		
0.50		

Analysis: Calculate velocity of electrons in cathode ray.
Since the electron travels straight through

$$F_e = F_m$$

$$\left|\vec{E}\right|q = \left|\vec{B}\right|qv$$

$$v = \frac{\left|\vec{E}\right|}{\left|\vec{B}\right|}$$

Calculate q/m

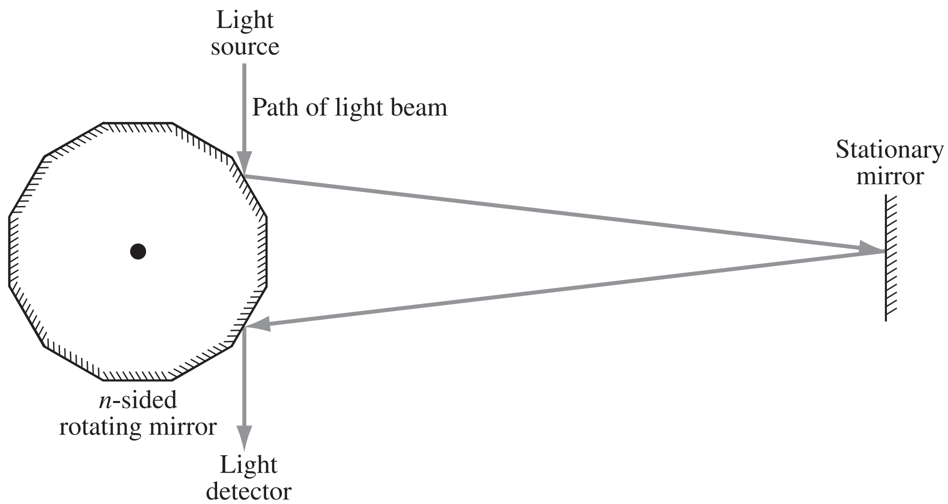
$$F_c = F_m$$

$$\frac{mv^2}{r} = \left|\vec{B}\right|qv$$

$$\frac{q}{m} = \frac{v}{\left|\vec{B}\right|r}$$

Sample Solution 2

Purpose: Michelson's rotating mirror was used to determine the speed of light, *c*.



Procedure:

1. With *n*-sided mirror stationary, set up source, plane mirror, and detector so that the detector detects the light.
2. Record number of sides, *n*. Measure distance from polygonal mirror to plane mirror, *D*.
3. Begin spinning. Increase spinning to maximum detected signal and past. Slow down to get maximum signal.
4. Record this frequency, *f*.

Analysis:

$$v = \frac{d}{t}$$

$$d = 2D$$

$$t = \frac{1}{n} \times \frac{1}{f}$$

$$v = 2nfD$$

Materials:

—light source
—plane mirror
—mirror
—multisided regular mirrored polygon with *n* sides
—tachometer to measure revolutions per second
—metre stick/measuring tape
—light detector

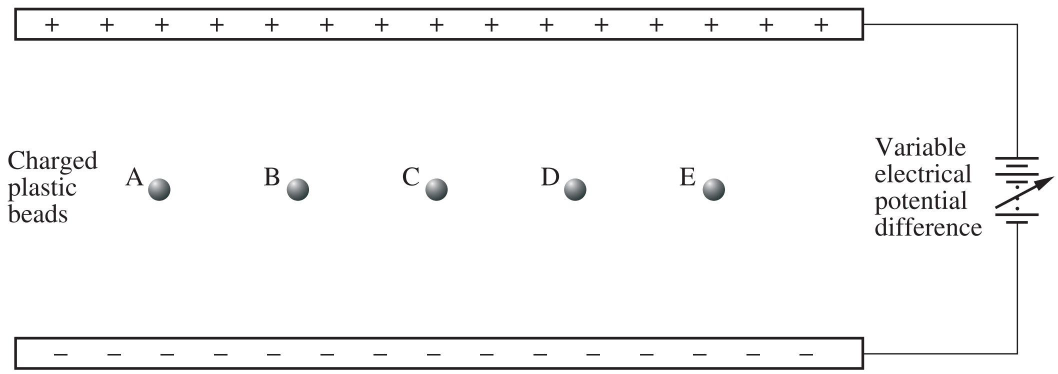
Sample Solution 3

Purpose: Millikan's oil-drop apparatus was used to determine the elementary charge, *e*.

Materials:
—parallel plates
—metre stick
—voltmeter
—variable voltage source
—beads
—X-ray source to charge beads

Procedure:

1. Obtain two parallel plates and set up plates as a Millikan oil-drop-like experiment



2. Measure plate separation, d
3. Measure m of plastic bead
4. Irradiate beads to give them a charge
5. Adjust voltage to have bead $\vec{v} = 0$ or $\vec{a} = 0$, record
6. Repeat various times
7. Calculate q, group similar "q" and average, then take the smallest difference between groups of q to determine e

Analysis:

$\vec{F}_{\text{net}} = 0$ for uniform motion

$$\left|\vec{F}_{\text{net}}\right| = \left|\vec{F}_{\text{e}}\right| - \left|\vec{F}_{\text{g}}\right|$$

$$\left|\vec{F}_{\text{e}}\right| = \left|\vec{F}_{\text{g}}\right|$$

$$\left|\vec{E}\right| q = mg$$

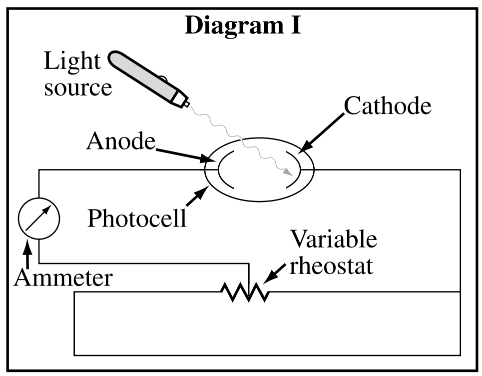
$$q = \frac{mgd}{V}$$

Sample Solution 4

Purpose: Hertz/Millikan photoelectric apparatus was used to determine Planck's constant, *h*.

Materials:
—photoelectric cell
—variable voltage supply
—ammeter
—visible EMR generator

Set-up: Set up the photoelectric cell with a wire connecting the anode and cathode. Place an ammeter in series as well as a variable voltage supply.

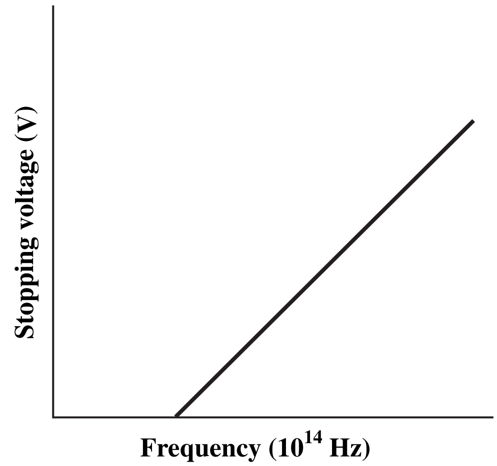


Procedure:
1. Shine 700 nm light (red) onto the photoelectric surface. Increase the stopping voltage until the current reads zero and record the voltage.
2. Repeat the previous step, decreasing the wavelength by 50 nm increments until you reach 400 nm.

Data

Observations		Analysis	
Wavelength	**Stopping Voltage**	**Frequency**	$V_{stop}q$

Analysis: Plot $V_{\text{stop}}q$ vs frequency on a graph.



By conservation of energy

$$E_{\text{i}} = E_{\text{f}}$$

$$E_{\text{photon}} = W + E_{\text{k electron}}$$

$$hf = W + V_{\text{stop}}q$$

$$V_{\text{stop}}q = hf - W$$

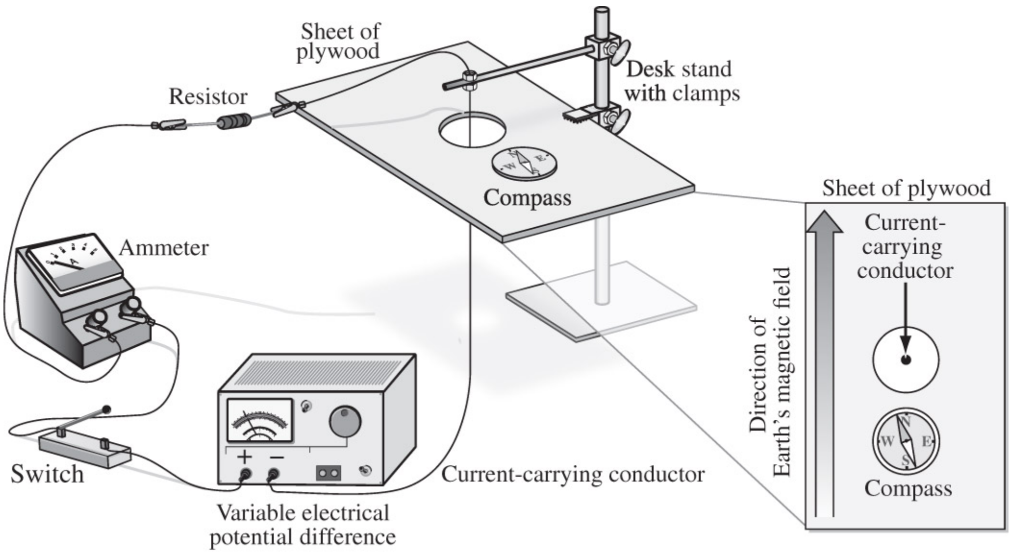
$$y = mx + b$$

$$\text{slope} = h$$

Examples of Formative Assessment Written-Response Questions

Use the following information to answer this graphing-skills question.

A group of students conduct an investigation to determine the horizontal component of Earth's magnetic field, B_{Earth}. Their apparatus is shown below.



The compass is placed on the plywood so that the compass needle points toward the conductor and toward the north, N, symbol on the compass. The switch is closed, and the variable electrical potential difference source is set to a non-zero voltage. The current is measured using the ammeter, and the angle of deflection of the compass needle is measured using a protractor. Several trials are conducted with increased voltages. The students' observations are recorded in the chart below.

As part of the analysis, the students draw a vector-addition diagram, which is given below.

Data Table

Observations		**Analysis**	
Current (A)	**Angle θ (º)**	**Induced Magnetic Field (10^{-5} T)**	**Tangent of Angle (no units)**
1.0	7	0.7	0.12
2.0	15	1.3	0.27
3.0	22	2.0	0.40
4.0	28	2.6	0.53
5.0	34	3.3	0.67

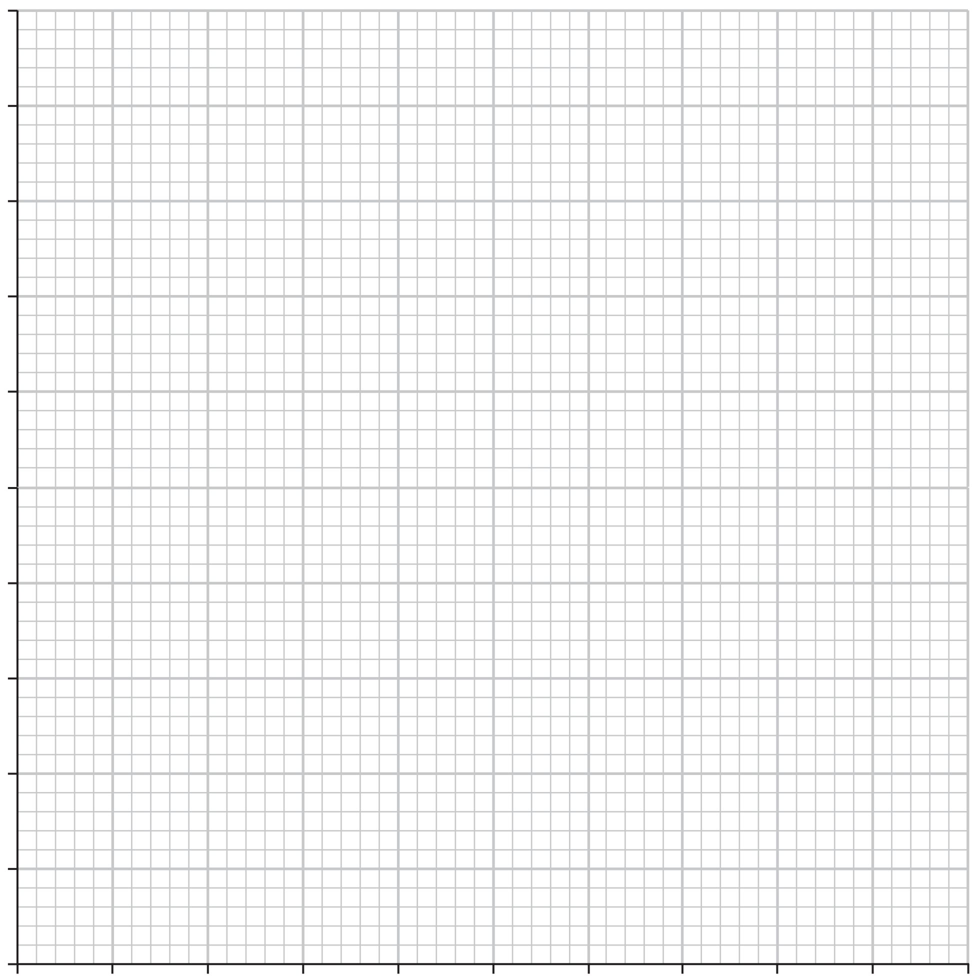
Written Response—10 marks

1. Using graphical analysis, **determine** the experimental value of Earth's magnetic field strength. In your response, **provide** a graph of the tangent of the angle as a function of the induced magnetic field, **determine** the slope of your graph, and **relate** the slope algebraically to a physics equation. State all necessary physics concepts and formulas.

Marks will be awarded for your graph and the mathematical treatment of the physics you used to solve this problem.

______________________________ (Title)

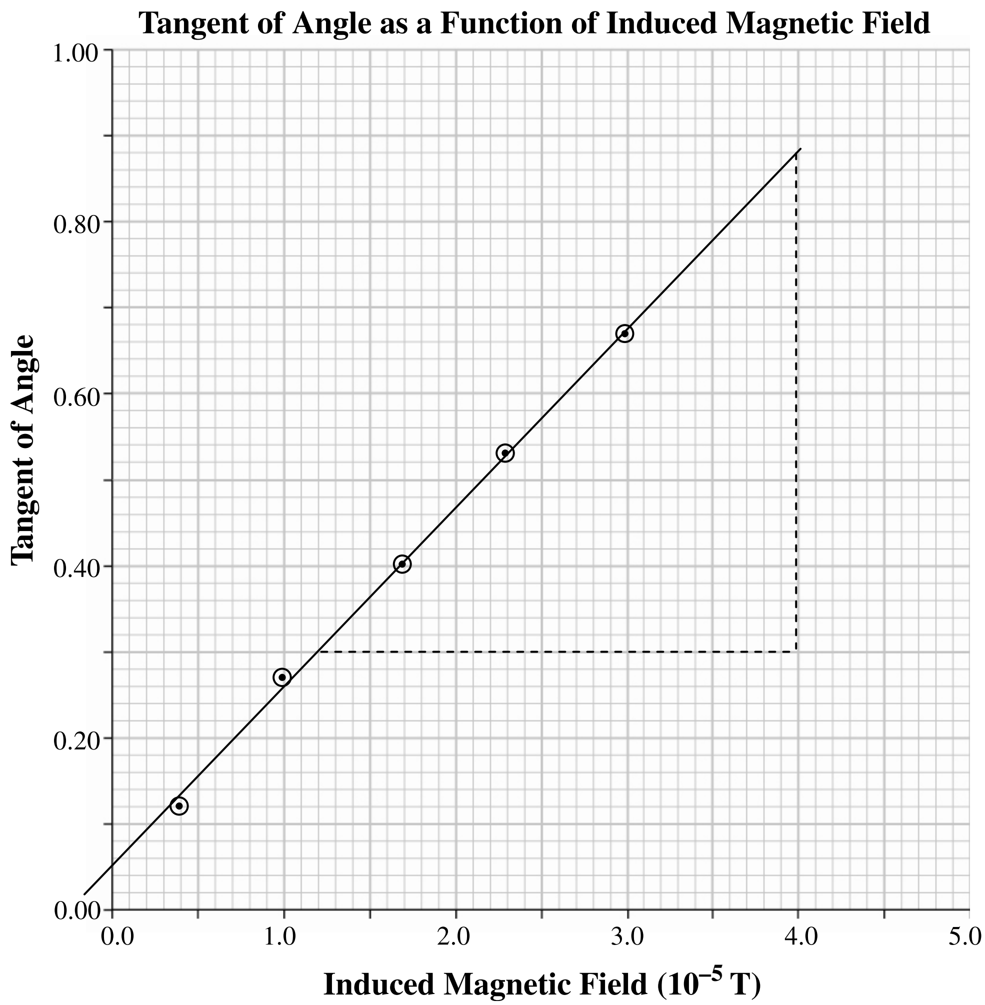
____________________ (Label)



____________________ (Label)

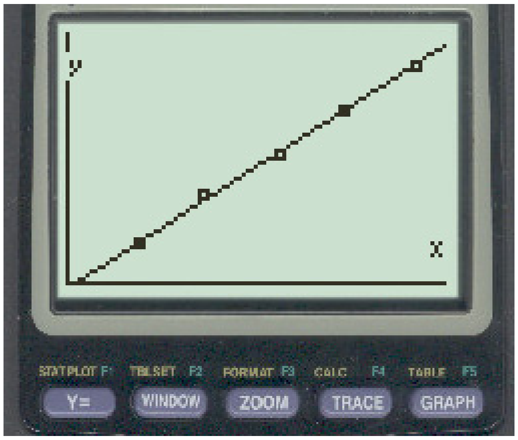
Sample Response

Note: Alternate responses, including calculator active responses, may receive full marks. Student responses that are internally consistent but not identical to this response may receive full marks.



$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{0.88 - 0.30}{4.30\times10^{-5}\ \text{T} - 1.50\times10^{-5}\ \text{T}} = 2.0714\times10^{4}\ \text{T}^{-1}$$

Calculator active solution:

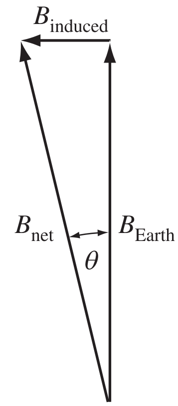


Calculator active solution
store B in L1, in units of T
store tangent of angle in L2, (no units)

perform the linear regression
$y = ax + b$ on L1, L2
to give $a = 20903.5$
$b = -0.0159$

Window settings on calculator
x:[0, 3.56×10^{-5}]
y:[0, 0.7635]

Determining the magnetic field strength of the current-carrying solenoid



The variable plotted on the y-axis is tangent of angle (no units)
The variable plotted on the x-axis is Induced Magnetic Field, B

By inspection of the graph and the Net vector diagram

From the graph

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

$$\text{slope} = \frac{\Delta\tan\theta}{\Delta B_{\text{induced}}}$$

From the Net vector diagram

$$\tan\theta = \frac{\text{rise}}{\text{run}}$$

$$\tan\theta = \frac{B_{\text{induced}}}{B_{\text{Earth}}}$$

$$B_{\text{Earth}} = \frac{B_{\text{induced}}}{\tan\theta}$$

$$\therefore \quad B_{\text{Earth}} = \frac{\frac{\tan\theta}{\text{slope}}}{\tan\theta}$$

The equation of a line, $y = mx + b$, for the graph of $\tan\theta$ as a function of B_{induced} is

$\tan\theta$ = (slope)(B_{induced}) + y-intercept

$$\therefore \quad B_{\text{induced}} = \frac{\tan\theta}{\text{slope}}$$

$$B_{\text{Earth}} = \frac{1}{\text{slope}}$$

Therefore, $B_{\text{Earth}} = \dfrac{1}{\text{slope}}$, which gives

$$B_{\text{Earth}} = \frac{1}{\text{slope}} = \frac{1}{2.09035\times10^{4}\ \text{T}^{-1}} = 4.7839\times10^{-5}\ \text{T} = 4.8\times10^{-5}\ \text{T} \quad (2\ \text{s.d.})$$

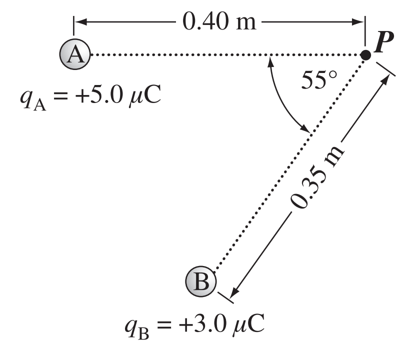
(mark consistent with the student's graph)

or using the calculator active solution

$$B_{\text{Earth}} = \frac{1}{\text{slope}} = \frac{1}{2.0714\times10^{4}\ \text{T}^{-1}} = 4.8277\times10^{-5}\ \text{T} = 4.8\times10^{-5}\ \text{T} \quad (2\ \text{s.d.})$$

Use the following information to answer this two-dimensional vector-skills question.

Two point charges are located near point *P*, as shown below.



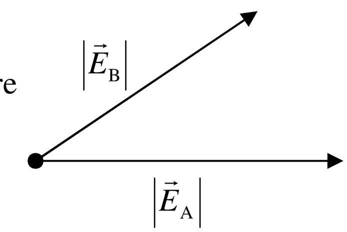
Written Response—10 marks

2. **Determine** the net electric field at point *P* that is caused by the two point charges. As part of your response, **sketch** arrows showing the electric field at *P* due to q_A and the electric field at *P* due to q_B, **explain** how you determined the direction of these arrows. **Sketch** a vector-addition diagram consistent with the vector-analysis method you are choosing. **State** all necessary physics concepts and formulas.

Marks will be awarded based on your vector diagrams, the physics that you use, and the mathematical treatment you provide.

Sample Solution

The electric field contributions from q_A and q_B are



The direction of the electric field is radially away from a positive source charge.

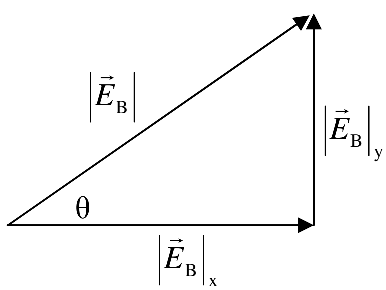
Calculating the electric field magnitudes due to each of charges A and B, at point P

$$|\vec{E}_A| = \frac{kq_A}{r^2} = \frac{(8.99\times10^9\ \frac{\text{N}\bullet\text{m}^2}{\text{C}^2})(5.0\times10^{-6}\text{C})}{(0.40\ \text{m})^2} = 2.81\times10^5\ \frac{\text{N}}{\text{C}}$$

and

$$|\vec{E}_B| = \frac{kq_B}{r^2} = \frac{(8.99\times10^9\ \frac{\text{N}\bullet\text{m}^2}{\text{C}^2})(3.0\times10^{-6}\text{C})}{(0.35\ \text{m})^2} = 2.20\times10^5\ \frac{\text{N}}{\text{C}}$$

Component diagram for charge B



Finding the components of $|\vec{E}_B|$ at point P

$$|\vec{E}_B|_x = |\vec{E}_B|\cos\theta = (2.20\times10^5\ \tfrac{\text{N}}{\text{C}})\cos 55^\circ = 1.26\times10^5\ \tfrac{\text{N}}{\text{C}}$$

$$|\vec{E}_B|_y = |\vec{E}_B|\sin\theta = (2.20\times10^5\ \tfrac{\text{N}}{\text{C}})\sin 55^\circ = 1.80\times10^5\ \tfrac{\text{N}}{\text{C}}$$

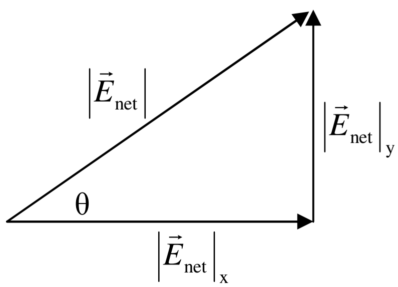
Adding the *x* components of the electric field vectors

$$\begin{aligned}|\vec{E}_{net}|_x &= |\vec{E}_A|_x + |\vec{E}_B|_x \\ &= 2.81\times10^5\ \tfrac{\text{N}}{\text{C}} + 1.26\times10^5\ \tfrac{\text{N}}{\text{C}} \\ &= 4.07\times10^5\ \tfrac{\text{N}}{\text{C}}\end{aligned}$$

Adding the *y* components of the electric field vectors

$$\left|\vec{E}_{\text{net}}\right|_{\text{y}} = \left|\vec{E}_{\text{A}}\right|_{\text{y}} + \left|\vec{E}_{\text{B}}\right|_{\text{y}}$$
$$= 0 + 1.80\times10^{5}\,\tfrac{\text{N}}{\text{C}}$$
$$= 1.80\times10^{5}\,\tfrac{\text{N}}{\text{C}}$$

Net vector-addition diagram



Finding the net electric field vector at point P

$$c^2 = a^2 + b^2$$

$$\left|\vec{E}_{\text{net}}\right|^2 = \left|\vec{E}_{\text{A}}\right|^2 + \left|\vec{E}_{\text{B}}\right|^2$$

$$\left|\vec{E}_{\text{net}}\right| = \sqrt{\left|\vec{E}_{\text{Net}}\right|_{\text{x}}^{2} + \left|\vec{E}_{\text{Net}}\right|_{\text{y}}^{2}}$$

$$\left|\vec{E}_{\text{net}}\right| = \sqrt{(4.07\times10^{5}\,\tfrac{\text{N}}{\text{C}})^2 + (1.80\times10^{5}\,\tfrac{\text{N}}{\text{C}})^2}$$

$$\left|\vec{E}_{\text{net}}\right| = 4.5\times10^{5}\,\tfrac{\text{N}}{\text{C}}$$

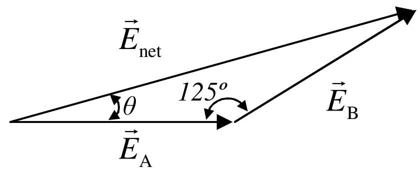
$$\tan\theta = \frac{\textit{opposite}}{\textit{adjacent}} = \frac{\left|\vec{E}_{\text{net}}\right|_{\text{y}}}{\left|\vec{E}_{\text{net}}\right|_{\text{x}}}$$

$$\theta = \tan^{-1}\left(\frac{1.80\times10^{5}\,\tfrac{\text{N}}{\text{C}}}{4.07\times10^{5}\,\tfrac{\text{N}}{\text{C}}}\right) = 24^{\text{o}}$$

The net electric field at point *P* is 4.5×10^5 N/C at 24° as labelled in diagram
or 24° from positive *x*-axis (requires an *x*-axis to have been labelled)
or 24° north of east (requires compass rosette)

Method 2: Cosine and Sine Laws (Note: this method is clearly outside the *Physics 20-30 Program of Studies*, 2007)

Net vector addition diagram



$$c^2 = a^2 + b^2 - 2ab\cos C$$

$$\left|\vec{E}_{\text{net}}\right|^2 = \left|\vec{E}_{\text{A}}\right|^2 + \left|\vec{E}_{\text{B}}\right|^2 - 2\left|\vec{E}_{\text{A}}\right|\left|\vec{E}_{\text{B}}\right|\cos 125°$$

$$\left|\vec{E}_{\text{net}}\right|^2 = (2.81\times10^5\text{ N/C})^2 + (2.20\times10^5\text{ N/C})^2 - 2(2.81\times10^5\text{ N/C})(2.20\times10^5\text{ N/C})\cos 125°$$

$$\left|\vec{E}_{\text{net}}\right|^2 = 1.98\times10^{11}\text{ N}^2/\text{C}^2$$

$$\left|\vec{E}_{\text{net}}\right| = 4.4\times10^5\text{ N/C}$$

To get the angle:

$$\frac{a}{\sin A} = \frac{b}{\sin B}$$

$$\frac{\vec{E}_{\text{B}}}{\sin\theta} = \frac{\vec{E}_{\text{net}}}{\sin 125°}$$

$$\sin\theta = \frac{(4.45\times10^5\text{ N/C})(\sin 125°)}{2.20\times10^5\text{ N/C}}$$

$$\theta = 24°$$

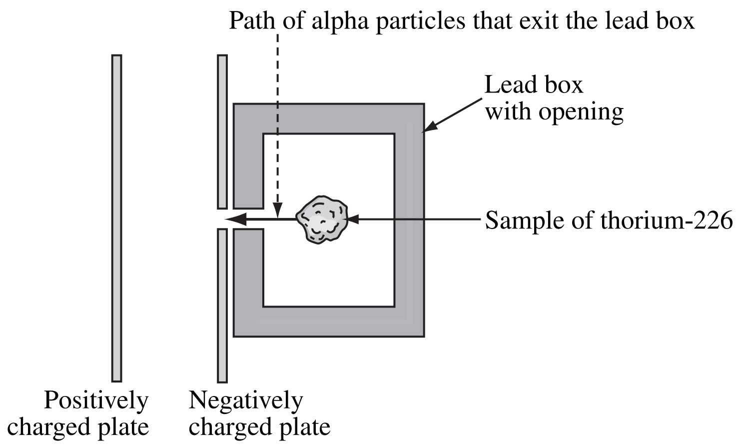
The net electric field at point P is 4.5×10^5 N/C at 24° as labelled in diagram
or 24° from positive x-axis (requires an x-axis to have been labelled)

or 24° north of east (requires compass rosette)

Use the following information to answer this analytic question.

A sample of thorium-226 is stored in a lead box, as shown below. Thorium-226 undergoes alpha decay. The lead box has a small opening on the left side to allow a stream of alpha particles to escape.

Top-Down View of Apparatus



In the sample, a nucleus of thorium-226 is at rest when it undergoes alpha decay. The daughter nucleus produced, radium-222, has a mass of 3.67×10^{-25} kg and moves to the right at 3.10×10^{5} m/s immediately after the decay. The thorium-226 nucleus, the radium-222 nucleus, and the alpha particle form an isolated system.

To the left of the lead box are two parallel plates, one positively charged and the other negatively charged, that together produce a uniform electric field. The parallel plates are 2.00 cm apart. The escaping alpha particles are stopped by the electric force just before they reach the positively charged plate. The complete apparatus is in a vacuum.

Written Response—10 marks

3. **Determine** the magnitude of the electric force acting on an alpha particle.

Marks will be awarded based on the relationships among the two physics principles* that you state, the formulas that you state, the substitutions that you show, and your final answer.

*** The physics principles are given on the tear-out data sheet included with this examination.**

Sample Solution

By conservation of momentum

$$
\begin{aligned}
\vec{p}_{\mathrm{i}} &= \vec{p}_{\mathrm{f}} \\
0 &= \vec{p}_{\mathrm{alpha}} + \vec{p}_{\mathrm{radium}} \\
\left|\vec{p}_{\mathrm{alpha}}\right| &= \left|\vec{p}_{\mathrm{radium}}\right| \\
m_{\alpha}v_{\alpha} &= m_{\mathrm{Ra}}v_{\mathrm{Ra}} \\
v_{\alpha} &= \frac{m_{\mathrm{Ra}}v_{\mathrm{Ra}}}{m_{\alpha}} \\
&= \frac{(3.67\times10^{-25}\ \mathrm{kg})(3.10\times10^{5}\ \mathrm{m/s})}{(6.65\times10^{-27}\ \mathrm{kg})} \\
&= 1.7108\times10^{7}\ \mathrm{m/s}
\end{aligned}
$$

Unbalanced force causes uniform acceleration

$$
\begin{aligned}
a &= \frac{\vec{F}_{\mathrm{net}}}{m} \\
a &= \frac{v_{\mathrm{f}}^{2}-v_{\mathrm{i}}^{2}}{2d}\text{, where } v_{\mathrm{f}}=0 \\
F &= m\left(\frac{v_{\mathrm{f}}^{2}-v_{\mathrm{i}}^{2}}{2d}\right) \\
F &= (6.65\times10^{-27}\ \mathrm{kg})\left(\frac{-(1.7108\times10^{7}\ \mathrm{m/s})^{2}}{2(0.020\ \mathrm{m})}\right) \\
F &= -4.8658659\times10^{-11}\ \mathrm{N}
\end{aligned}
$$

The negative sign indicates that the force acts to decelerate the charge. The magnitude of the force is

$$F = 4.87\times10^{-11}\ \mathrm{N}$$

or work-energy theorem (or conservation of energy)

$$
\begin{aligned}
W &= \Delta E_{\mathrm{k}} \\
|F||d|\cos\theta &= \frac{1}{2}mv_{\mathrm{f}}^{2}-\frac{1}{2}mv_{\mathrm{i}}^{2}
\end{aligned}
$$

where $v_{\mathrm{f}} = 0$, and θ is 180º

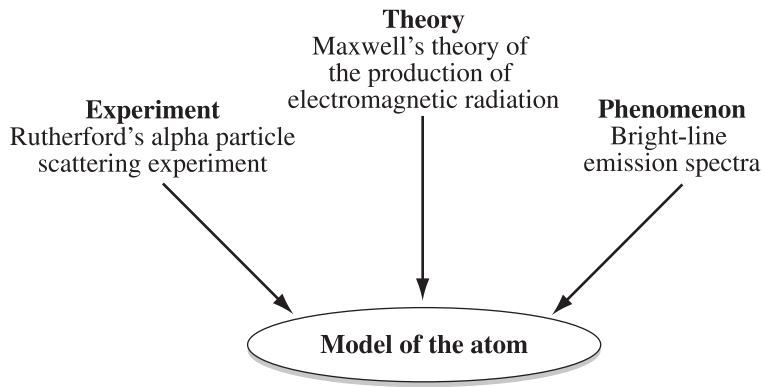
$$
\begin{aligned}
F &= \frac{-\frac{1}{2}mv_{\mathrm{i}}^{2}}{d\cos\theta} \\
&= \left(\frac{-(6.65\times10^{-27}\ \mathrm{kg})(1.7108\times10^{7}\ \mathrm{m/s})^{2}}{2(0.020\ \mathrm{m})\cos180^{\circ}}\right) \\
&= -4.86586\times10^{-11}\ \mathrm{N}
\end{aligned}
$$

The negative sign indicates that the force acts to decelerate the charge. The magnitude of the force is

$$F = 4.87\times10^{-11}\ \mathrm{N}$$

Use the following information to answer this holistic question.

Scientific theories evolve to explain experimental results, other theories, and physical phenomena. An experiment, a theory, and phenomenon that contributed to the evolution of the model of the atom are given below.



Written Response—5 marks

4. Using the concepts of the alpha particle scattering experiment, electromagnetic radiation production, and bright-line emission spectra, analyze a portion of the evolution of the model of the atom. In your response,

- **describe** Rutherford's alpha particle scattering experiment
- **describe** how electromagnetic radiation is produced
- **summarize** the phenomenon of bright-line emission spectra
- **explain** how **two** of the experiment, theory, or phenomenon identified above contributed to the evolution of the model of the atom

Marks will be awarded for the physics used to solve this problem and for the effective communication of your response.

Sample Response for Written-Response Question

Note: Alternate responses may receive full marks. Student responses that are internally consistent but not identical to this response may receive full marks.

In Rutherford's alpha particle scattering experiment, a beam of alpha particles was directed at a thin gold foil. The vast majority of alpha particles were detected on the other side of the foil, having passed through the foil without deflection. Some of the alpha particles were detected after having undergone deflections of significant angles. In a few extreme cases, alpha particles were found to bounce straight back, deflecting by 180°.

Maxwell's theory of the production of EMR postulated that all accelerating charges emit EMR. An accelerating charge results in a changing electric field and a perpendicular changing magnetic field. As the new electric field is established, it in turn induces a new, changing magnetic field. In effect, the electric and magnetic fields couple together in phase and generate each other. The coupled electric and magnetic field propagate outward in the form of an electromagnetic wave at the speed of light in that medium.

Bright-line (or emission) spectra are produced when the atoms in a low-density gas are excited to a higher energy state. Excited atoms within that gas will drop to lower states and emit specific wavelengths of light that are characteristic of that type of atom.

The model of the atom evolved from a raisin bun/Thomson model (in which negative charges were embedded in a positively charged matrix) to a planetary/nuclear model as a result of Rutherford's experiment. The explanation of the large angle of deflection requires a concentrated, localized positive charge. Maxwell's theory requires that electrons orbiting a Rutherford nucleus should emit EMR continuously. This is not observed; thus, some new electron orbit model is required. The bright-line emission, unique to each element, provides support for a model of the atom that includes stable energy levels.

The **knowledge** expectations of this question are

- The Rutherford alpha particle-scattering experiment consisted of a beam of alpha particles directed at a thin gold foil. Most of the particles passed through the foil with little or no deflection. A few of the particles were deflected through large angles, even coming back at the alpha emitter.
- Accelerating charges emit EMR.
- Bright-line spectra consist of specific wavelengths of EMR distinct to that element.

The student shows **application** by

- Explaining the cause-and-effect relationship present in the development of the model of the atom for **two** of the experiment, theory, or phenomenon identified.

Use the following information to answer this holistic question.

In order to reduce the risk of exposure to radiation, rather than having a beta negative source in the classroom, a teacher models portions of a radioactive decay chain using disk-shaped candies with printing on one side, cylindrical candies, and spherical candies. In the model, the disk candies “decay” whenever they land printed side up, the cylindrical candies “decay” when they land on one of their circular ends, and the spheres do not “decay.”

The teacher provides the students with a shoe box and three bags, each with 100 pieces of candy.

Step 1: The students put all 100 disk candies into the box, place the cover on the box, shake the box, and remove the cover.

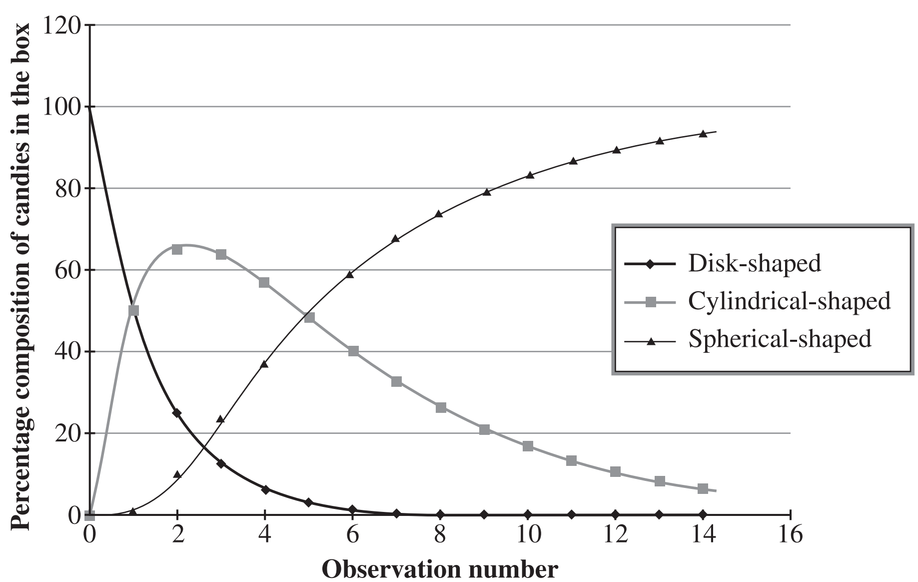
Step 2: They remove all the disk candies that have “decayed,” count the number that have decayed, place that number of cylindrical candies into the box, and record the number of disk candies and the number of cylindrical candies in the box.

Step 3: They place the cover on the box, shake it, and remove the cover.

Step 4: They remove all the candies that have “decayed.” They count the number of disk candies and the number of cylindrical candies that have decayed. They add a cylindrical candy for each disk that decayed and a spherical candy for each cylindrical candy that decayed. They record the number of disk, cylindrical, and spherical candies in the box.

The teacher instructs the students to repeat steps 3 and 4 until only spherical candies are in the box or until 15 observations have been completed.

Relative Composition of Candies in the Box as a Function of Observation Number



Written Response—5 marks

5. Using the concepts of effect of radiation on biological tissues, fundamental forces or binding energy, and half-life, **analyze** this model of nuclear decay. In your response,

- **describe** the effects of alpha, beta, and gamma radiation on biological tissue
- **predict** two characteristics of a nucleus represented in this model by the spherical candy
- **explain** why the curve for the cylindrical candy initially rises and then falls over the 15 observations recorded by the students
- **identify** aspects of the model that accurately parallel the real world and those that do not. You may want to consider health effects, probability, whether environmental changes affect radioactive decay, shapes relating to stability, or half-life. **Evaluate** this model

Marks will be awarded for the physics used to solve this problem and for the effective communication of your response.

Note to Teachers
Although this is written as a holistic question, there is much more that can be done. One could ask students to

1. predict the number of candies in the box each time the lid is closed (because students tell us that the nuclei disappear and that decay can be measured on a scale because the sample gets lighter)
2. explain what makes a nucleus stable or unstable in terms of fundamental forces
3. explain why the rates of decay of the two "radioactive candies" are different
4. predict the shapes of the graphs if the order of decay is reversed (cylinders decay to disk candies)

Sample Response for Written-Response Question

Alpha radiation does significant short range damage if it reaches biological tissue. Beta radiation does less damage but over a longer distance. High-energy beta particles can cause ionization, which results in changes to chemical processes. Gamma radiation also causes ionization damage, only over much longer distances.

The spherical candy is stable so the number of nucleons is such that the strong nuclear force is approximately balanced by the Coulomb force of repulsion of protons. Therefore there are slightly more neutrons than protons. (In terms of binding energy, a stable nucleus has a high binding energy, which means the nucleons are securely held in the nucleus.)

The half-life of the cylindrical candy is longer than that of the disks. The disks decay faster, so initially the cylinders' line rises. However, once the addition of cylinders is less than the number of cylinders that decay, the cylinders' line begins to fall.

This model is good because the number of nuclei in the sample remains constant, because a decay chain ends with a stable isotope, because different isotopes decay at different rates, and because it shows the random nature of decay.

This model is poor because eating the candy may cause harm (weight gain) just as radiation can cause harm.

This model is poor in that different isotopes do not have radically different shapes, and environmental changes do not influence rate of decay but shaking the box does.