Physics | Released Items

2012 Released Assessment Materials for the *Physics 20–30 Program of Studies, 2007*

Alberta Government

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The Alberta Education website is found at education.alberta.ca.

Contents

Introduction

The *Physics 20–30 Program of Studies, 2007* expects students to demonstrate both computational and conceptual understanding. These released materials are designed to help students reach the standard of excellence in their conceptual understanding.

Formative assessment is designed to allow the students to struggle with difficult concepts as they build their understanding working with peers and teachers. Their efforts are aimed at building understanding rather than receiving marks or grades. Nevertheless, for this work to be worthwhile for the students, its links to assessment for grades must be clear.

There are many items in this package: three from Physics 20 and seven from Physics 30. They are not of similar scope or of similar difficulty. For example, the first Physics 20 item, Meteorite Trajectory, explores concepts only from P20-C2, while the second Physics 30 item, Crank Flashlight, explores concepts from P30-B3, C1, and C2. At the start of each item there is a short description of the approximate difficulty/challenge level of the item and the approximate student time required to produce the first completed response. NOTE: This is not expected classroom time. Details in this package provide some suggestions on how to use these materials in the classroom.

For the first Physics 20 item and the first Physics 30 item sample student responses and sample completed peer feedback forms are followed by a complete response and commentary. For the rest of the items, a completed response is provided with commentary. It is hoped that this provides the teachers with an idea of how the materials work. Teachers are encouraged to share the examples with their students as appropriate to model good peer feedback. Research has shown that many students can achieve the standard of excellence once they see a peer achieve it, and once they observe peer-generated responses that reflect the standard.

The final two questions are from the diploma examination banks. They are examples of the old holistically scored questions, and they come with the holistic scoring guide. These questions, or ones similar to them, are designed to be used for producing student marks. The questions should be completable by most students in 20 minutes in a test-taking context.

Every effort has been made to produce error-free items. If any errors are discovered, or students or teachers wish to make comments on these materials, please contact Laura Pankratz at Laura.Pankratz@gov.ab.ca.

Performance Expectations

The performance expectations for Physics 30 are published in the Physics information bulletin. The graphic below is taken from the *2011 Physics 30 Information Bulletin* available at education.alberta.ca, via this pathway: For Administrators > Provincial Testing > Diploma Examinations > Information Bulletins. It shows how different verbs correspond to different cognitive tasks. Here, the verbs are grouped into four categories—knowledge (K), comprehension and application (C/A), higher mental activities (HMA), and attitudes and skills.

<table>
<tr><th colspan="3">Cognitive Expectations</th></tr>
<tr><th>Knowledge</th><th>Comprehension and Application</th><th>Higher Mental Activities</th></tr>
<tr><td>Choose, classify, define, describe, identify, list, label, match, name, outline, predict*, recall, select, state, what, when, who

Use memorized or algorithmic methods to solve problems</td><td>Apply, analyze, calculate, change, compare*, contrast, determine, estimate (interpolate or extrapolate), explain*, generalize, interpret*, infer, relate, translate, solve

Design a procedure for a known experiment</td><td>Assess, compare*, differentiate, compile, compose, conclude, create, defend, evaluate, explain*, interpret*, judge, justify, organize, plan, summarize

Transfer methods from one area to another

Use generalized methods to solve problems

Design a new procedure for an unfamiliar experiment</td></tr>
<tr><td colspan="3">Attitudes and Skills
Appreciate, collect, conduct, develop, gather, measure, observe, plot, work collaboratively</td></tr>
</table>

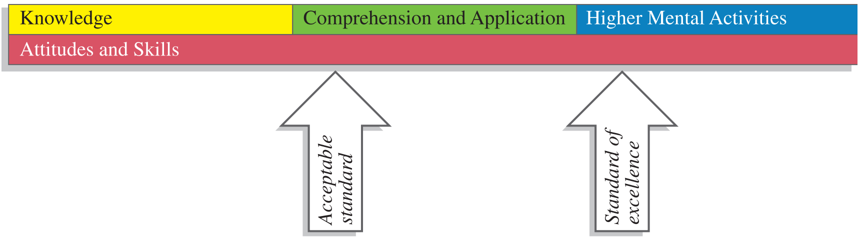
*These verbs are ambiguous because they have multiple connotations. The cognitive expectation is communicated by the context. If it is a very familiar context, the expectation is knowledge or comprehension and application; if it is unfamiliar, the expectation is comprehension and application or higher mental activity.

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**.



Conclusion: Students who are functioning most of the time at only a **knowledge** level will not achieve the acceptable standard (50%) in either Physics 20 or Physics 30. Students who are functioning only at a **comprehension and application** level will not achieve the standard of excellence (80%). One of the purposes of these released items is to help students and teachers understand the level of functioning that a student is demonstrating, and to help students move to a higher level if the student wants to.

For examples of machine-scored items illustrating the different standards, refer to the Archived Physics 30 Bulletin.

Released Machine-Scored Items

The Assessment Sector has released many machine-scored items that assess the Physics 30 portion of the Physics 20–30 Program of Studies, 2007, on the QuestA+ platform at https://questaplus.alberta.ca/ in the practice tests area.

Suggested Use

Day 1 (20 minutes)
Distribute the question and the peer feedback form at the same time.

Have the students read the question and talk about the depth of coverage required by the bolded verbs. Have the students then look at the peer feedback form. In the centre section of the form there are horizontal bars that provide a visual representation of the depth of coverage expected.

Day 2 (non-class time)
Students, individually or in groups, develop a response to the question.

Day 3 (20 minutes)
The responses are shared with others in the class, and peer feedback is provided. This feedback consists of completing the peer feedback form, including comments indicating where the response falls short of the expectation or contains errors. This is the vitally important step: both the peer reviewer and the peer responder get to interact about the content of the course without a mark, score, or judgment about the responder being made.

Day 3 continued (non-class time)
Students receive their feedback forms from their peers and have an opportunity to describe what changes need to be made to the response. This is a critically important step for students, especially the middle- and lower-performing students, because they likely have not developed the process of using constructive criticism for improvement.

After students have had time to respond to the peer feedback, you can have students submit a final response for scoring or you can build a similar question for individualized assessment that covers similar material. It is good practice to score work done by individual students for the purpose of assigning individual grades; group work and peer feedback are excellent activities for practice, improvement, and learning.

Note: These materials vary significantly in scope and difficulty. All of the peer feedback items are much too difficult for tasks being used to generate classroom marks.

Physics 20 Formative Assessment and Peer Feedback Materials

Meteorite Trajectory

Item Introduction

This is a mid-level difficulty formative-assessment item. Students should be able to provide a reasonable response to the full scope of the question in 25 minutes.

What makes this item interesting is that the context is fairly simple and straightforward, but the assumptions that are made in generating the response significantly influence the complexity of the response.

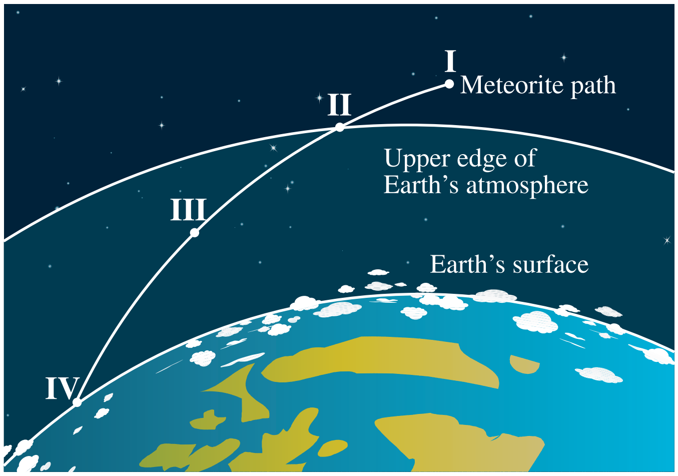
This item explores concepts from Physics 20 in Unit C2.

Use the following information to answer the next question.

Meteorites are rocks that travel from outside Earth's atmosphere to reach Earth's surface. Rock hunters are people who collect fragments of these rocks. These rocks are valuable because they may provide information on how the universe formed.

The path of a meteorite in Earth's atmosphere is often accompanied by a very bright light because of the friction between the high-speed rock and the atmosphere.

The diagram below illustrates the path of a particular meteorite.

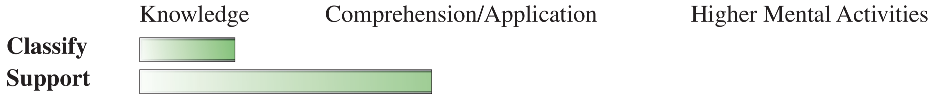
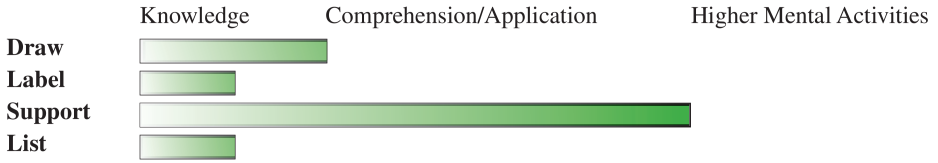


Location II	The meteorite is just entering Earth's atmosphere.
Location IV	The meteorite is just about to hit Earth's surface.

1. Using the concepts of physical systems, free-body diagrams, and conservation of energy, **analyze** the path of the meteorite. In your response

- **classify** the Earth-meteorite system. **Support** your classification
- **draw** and **label** free-body diagrams of the significant forces acting on the meteorite at each of the four locations labelled on its path, above. **Support** your diagrams by explaining why you chose the forces you included and **list** any assumptions that you made
- **describe** the energy transformations in the Earth-meteorite system as the meteorite travels from Location I to Location IV
- **describe** the calculations necessary to determine the work done on the meteorite as it travels from Location I to Location II. **Identify** the assumptions that would have to be made

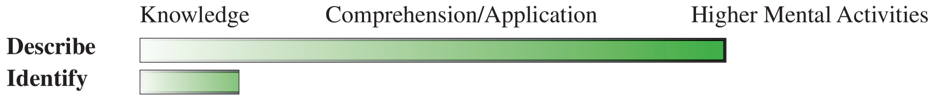
Student Name____________________ *Peer Feedback—Meteorite Path* Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Classify the Earth-meteorite system. **Support** your classification. ((P20-C2.6k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Draw and **label** free-body diagrams of the significant forces acting on the meteorite at each of the four locations labelled on its path, above. **Support** your diagrams by explaining why you chose the forces you included and **list** any assumptions that you made. (P20-C2.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Student Name____________________

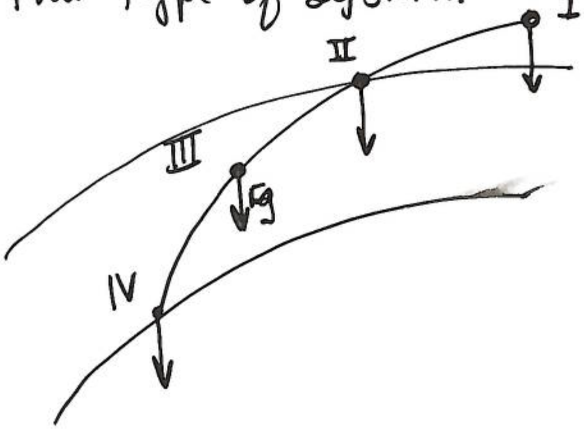
Peer Feedback—Meteorite Path – continued

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Describe the energy transformations in the Earth-meteorite system as the meteorite travels from Location I to Location IV. (P20-C2.1k, 2.2k, 2.6k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Describe the calculations necessary to determine the work on the meteorite as it travels from Location I to Location IV. **Identify** the assumptions that would have to be made. (P20-C2.4k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Sample Response #1

The Earth- meteorite system is closed because all systems are closed. A closed system is useful because things are conserved in this type of system.



The significant force is gravity, $\vec{F_g}$, and it is always down & has the same size.

The meteorite has only E_p at I. This converted to all E_K at IV.

Work done is change in E_K so

$$W = \Delta E_K = E_{kf} - E_{ki}$$

$E_{ki} = 0$ easy!

$E_{kf} = \frac{1}{2} m v_f^2$

So I need the mass of the meteorite and the speed at which it hits Earth's surface.

I am assuming the system is closed so stuff is conserved.

Student Name____________________ Reviewer's Name____________________

Peer Feedback—Meteorite Path

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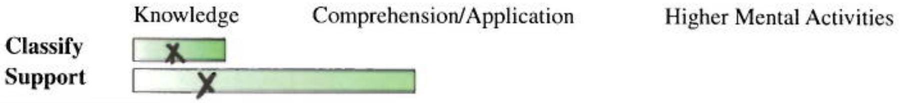
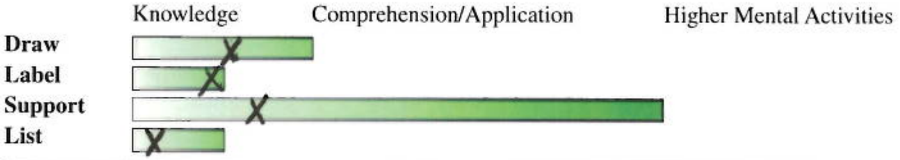
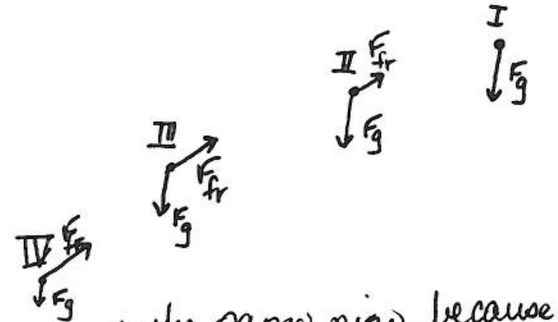
Classify the Earth-meteorite system. **Support** your classification. ((P20-C2.6k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… You classified the system but not correctly. You should think about mass & energy & types of systems)	**Changes that I am going to make** to my response…
Draw and **label** free-body diagrams of the significant forces acting on the meteorite at each of the four locations labelled on its path, above. **Support** your diagrams by explaining why you chose the forces you included and **list** any assumptions that you made. (P20-C2.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… Your F_g forces are all arrows & you've labelled them. What about the other forces? Is gravity really constant? $F_g = \frac{Gm_1m_2}{r^2}$ ….	**Changes that I am going to make** to my response…

Student Name____________________ ***Peer Feedback—Meteorite Path – continued*** Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Describe the energy transformations in the Earth-meteorite system as the meteorite travels from Location I to Location IV. (P20-C2.1k, 2.2k, 2.6k)	Knowledge Comprehension/Application Higher Mental Activities **Describe**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… You got the big picture but you didn't answer the question. What happens between I + II ?, II+III, etc?	**Changes that I am going to make** to my response…
Describe the calculations necessary to determine the work on the meteorite as it travels from Location I to Location IV. **Identify** the assumptions that would have to be made. (P20-C2.4k)	Knowledge Comprehension/Application Higher Mental Activities **Describe** **Identify**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… You stated a formula & the consistent variables but it isn't sufficient for this question. Your assumptions were just restating the first ones	**Changes that I am going to make** to my response…

Sample Response #2

The Earth Meteorite system is closed to mass but open to energy. The total mass remains constant as long as you include the mass of the meteorite dust as it crumbles in the atmosphere. The system is open to energy because light is produced as the mass is burned off and because the sound means energy is lost.



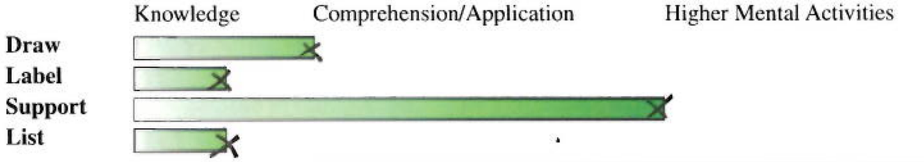
F_g at I + II is about the same size because the distance to the center didn't change very much and the mass of the meteorite hasn't changed much yet either. $F_g = G\frac{m_1 m_2}{r^2}$ hasn't changed. at 3 the m is less so the force is less. at 4 the m is smallest so the F_g is smallest. As the speed + thickness of the atmosphere increase the F_{fr} increases. So F_{fr} is larger at each later location.

Energy transformation: Energy cannot be created or destroyed - just transformed from one form to another.

at I the E is E_{pg}. At II the energy is $E_{pg} + E_k$ because the meteorite is falling now. at III the E is just $E_{pg} + E_k$ still. At IV all the E_p has become E_K. Some E_k is converted into sound & light too. Some might have gone into breaking the meteorite up.

Work needs a force: $W = F \cdot d_{\parallel}$ The force has to be F_g so we need the meteorite's change in altitude which would be the displacement parallel to F_g. We could use $W = F_g d = G \frac{m_1 \cdot m_2}{r^2} \cdot d$ so then we need the mass of earth for m_2, the mass of meteorite, m_1, and the starting height for r.

Student Name______________________ *Peer Feedback—Meteorite Path* Reviewer's Name______________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Classify the Earth-meteorite system. **Support** your classification. ((P20-C2.6k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… yours def'n of closed system is ok. your def'n of open system is ok. I don't think you answered the question	**Changes that I am going to make** to my response…
Draw and **label** free-body diagrams of the significant forces acting on the meteorite at each of the four locations labelled on its path, above. **Support** your diagrams by explaining why you chose the forces you included and **list** any assumptions that you made. (P20-C2.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… I think you did great! I didn't think of how the mass would change. The formula is the right one too ☺	**Changes that I am going to make** to my response…

Student Name____________________

Peer Feedback—Meteorite Path – continued

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Describe the energy transformations in the Earth-meteorite system as the meteorite travels from Location I to Location IV. (P20-C2.1k, 2.2k, 2.6k)	Knowledge Comprehension/Application Higher Mental Activities **Describe**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… You've stated trueth at start but then have the energy moving in 'blockiness' instead of gradually. Remember what we talked about in class yesterday!	**Changes that I am going to make** to my response…
Describe the calculations necessary to determine the work on the meteorite as it travels from Location I to Location IV. **Identify** the assumptions that would have to be made. (P20-C2.4k)	Knowledge Comprehension/Application Higher Mental Activities **Describe** **Identify**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… you gave inconsist formulas because you said the meteor's mass will change and then you kept it constant in the calculation. I think the value you want for r isn't correct.	**Changes that I am going to make** to my response…

Sample Response #3

System: Isolated: no outside forces can act on objects

closed: no energy can get in or out.

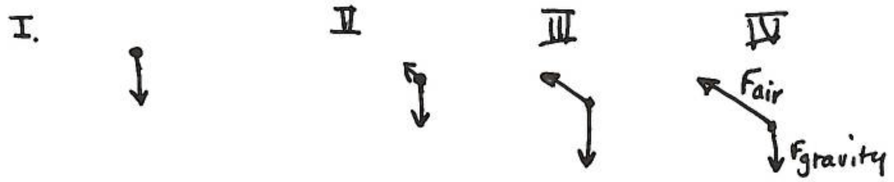
open: energy gets out.

I think the system is $\boxed{\text{isolated}}$ because it is so big, there aren't any outside forces.

I think it is $\boxed{\text{open}}$ because as the meteorite falls it makes a bright light which could be seen on the moon so the energy escapes the system.

FBD: above the atmosphere: no resistance so only the force of gravity <u>But</u> it won't be very strong because the meteorite is far away.

Once in the atmosphere, air resistance begins to act AGAINST the motion. This force will do work that produces energy: thermal heat, breaking up meteorite, bright light, rushing sound. lots of things affect the magnitude of this force but as the air gets thicker, this force gets bigger. The F_g will get bigger as the meteorite gets closer because $\propto \frac{1}{r^2}$. <u>But</u>, What happens if it breaks apart? Assume it stays together (ignore stuff above).



Energy: As the mass moves in the field, its energy will gradually convert from E_{pg} + E_k. Initially the meteorite has E_k, too, because it doesn't fall straight down - it must have been launched with some speed. When other types of energy are observed: light, sound, heat, it means not all the E_{pg} is converted into just E_k.

Calculation

~~Method I: $W = F.d$ in same direction~~

~~the force that acts along the path is the fricional force and it does work to decrease E_K. We would need the length of the trajectory and the size of the force.~~

Cannot because F not constant.

Try: $W = F.d = \frac{Gm_1m_2}{r^2}.d$ This force acts toward the center. It changes too because r changes But: that's ok because the change in r matches the change in altitude (not the actual path) of the meteorite!

So, we need mass of earth ✓
mass of meteorite - measure when we find it (it cannot break apart)
starting height - we get this from photograph.
Earth's radius ✓

Assumptions: Meteorite remains whole.
we have photograph to measure height.

Student Name____________________

Peer Feedback—Meteorite Path

Reviewer's Name____________________

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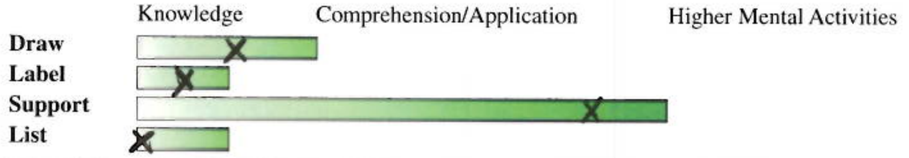
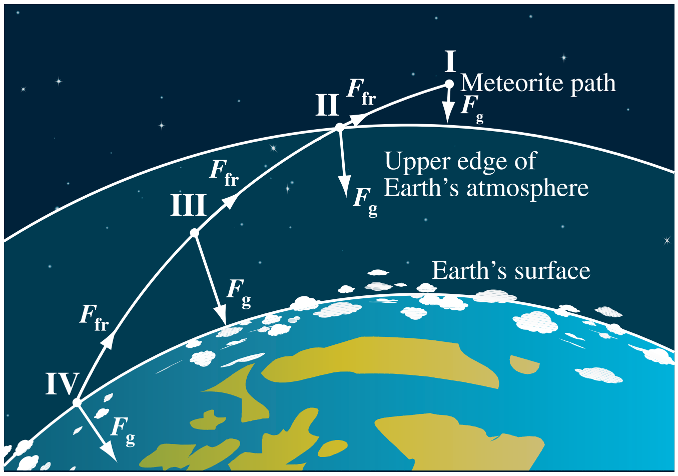
Classify the Earth-meteorite system. **Support** your classification. ((P20-C2.6k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… Great def'ns + support	**Changes that I am going to make** to my response…
Draw and **label** free-body diagrams of the significant forces acting on the meteorite at each of the four locations labelled on its path, above. **Support** your diagrams by explaining why you chose the forces you included and **list** any assumptions that you made. (P20-C2.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… why is Fair pointing backwards from path? You need to label ALL your diagrams. Your assumptions aren't listed (but I liked the support discussion.) Don't disagree with yourself.	**Changes that I am going to make** to my response…

Student Name____________________ **_Peer Feedback—Meteorite Path – continued_** Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Describe the energy transformations in the Earth-meteorite system as the meteorite travels from Location I to Location IV. (P20-C2.1k, 2.2k, 2.6k)	Knowledge Comprehension/Application Higher Mental Activities **Describe**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… Great - gradual + lots of types.	**Changes that I am going to make** to my response…
Describe the calculations necessary to determine the work on the meteorite as it travels from Location I to Location IV. **Identify** the assumptions that would have to be made. (P20-C2.4k)	Knowledge Comprehension/Application Higher Mental Activities **Describe** **Identify**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… I couldn't give you HMA because you changed your mind. (I like it but shouldn't you know?) you have identified what is needed.	**Changes that I am going to make** to my response…

Sample Response and Commentary for Teachers

The Earth-meteorite system is an open, non-isolated system. There will be a loss of mass as the meteorite falls and it experiences a significant frictional force as it travels through the atmosphere. This means that some of the energy is lost to doing work against non-conserved forces.



At Location I only one force, F_g, acts on the meteorite. All the other free-body diagrams contain two significant forces at each of the locations: F_g and F_{fr}. F_g always acts towards the centre of Earth, getting larger as the meteorite gets closer to Earth, but decreasing as the mass of the meteorite decreases.

Notes: *The arrows that indicate the magnitude of the forces can be either getting longer to indicate F_g forces getting larger, because the effect of distance is $1/r^2$, or getting smaller because mass falls off the surface of the meteorite. Support must be provided by the student for what is claimed. "F_g is constant because g is constant" is clearly a knowledge-level answer that does not meet the expectation of this bullet.*

F_{fr} always acts against the direction of motion, tangential to the path. F_{fr} increases as the meteorite gets closer to Earth because the thickness of the atmosphere increases. Eventually, $F_g = F_{fr}$ and the meteorite will have reached terminal velocity.

Notes: *There are various possible answers here, too. As the mass decreases, the surface area decreases so the force of friction decreases. Or, as the speed increases to terminal velocity, the frictional force increases but then remains constant. Look for the support provided by the students in the response.*

At Location I the meteorite has its maximum gravitational potential energy relative to Earth's surface. It will also have some kinetic energy. As it falls through Location II its gravitational potential energy will be decreasing, and this energy will be transformed into kinetic energy, heat, and light. Once the meteorite reaches terminal velocity, its kinetic energy will remain constant and the decrease in E_{pg} will be converted into heat and light.

Notes: *The energy is not converted into friction, because friction is a force. It is okay to say that the energy is "lost" doing work against friction.*

Gradual loss of gravitational potential energy continues as the meteorite falls through Location III with an increase in kinetic energy, heat, light, and sound. As the mass of the meteorite decreases, more E_{pg} is lost. Finally, at Location IV all of the E_{pg} is gone, the meteorite has lots of E_k and there will still be energy in the forms of light, heat, and possibly sound energy.

Notes: *"E_k increases as E_p decreases" is a K-level response. Stating that mechanical energy decreases due to energy lost to friction is a knowledge answer. Stating that mechanical energy decreases due to non-conservative forces such as friction may move a response up to a C/A level. Recognizing that there are many forces acting and many variables changing (e.g., mass, speed, force of gravity, friction), students who provide a more expanded answer are showing HMA thinking.*

The formula for work done is $W = Fd$, where F and d are in the same direction. One of the challenges in this method is to recognize that the force of gravity is acting at an angle to the path so that d is the change in altitude, not the path length. The second challenge is that the magnitude of F_g changes with location. So to actually do the calculation, we would need a way to estimate the gravitational force at various places along the path and then apply a geometric mean, or do the calculations between each of the places and take the sum of the calculations. In calculus terms, we need to integrate Fd over the path.

OR

Work done by a force causes a change in kinetic energy. One of the challenges in this method is to recognize that the speed will be changing non-uniformly, so a way of estimating the speed at various locations is important. A second challenge is that the mass changes, too.

Finally, the system is complex: do we want to include the heat in the atmosphere? Is the sound also just kinetic energy? What about the light? Photon energy is also E_k ($E = pc$, from Physics 30, so it is not really part of this answer, but certainly a place to build connections for the students moving forward).

Notes: *To demonstrate the K level, students must state the formula and that d is the altitude, or, in the work-energy analysis, state the formula and address either the mass or the speed issue.*

To achieve the C/A level, students need to indicate that F_g (or mass or speed) is changing and that the usual methods of calculation will be insufficient.

To achieve the HMA level, students need to devise a non-standard way of making the calculations – they do not need to go to a formal calculus, integral method, but something that indicates values at various locations is required, multiple calculations must be made, and the results of the calculations must be combined in some valid way. Although calculus is beyond the scope of the Physics 20–30 Program of Studies, 2007, the idea that non-uniform forces may require non-standard methods of analysis is not. Students should be exposed to the limitations of the models they are learning and come to an appreciation of creativity in finding solutions to tough problems.

Water Slide

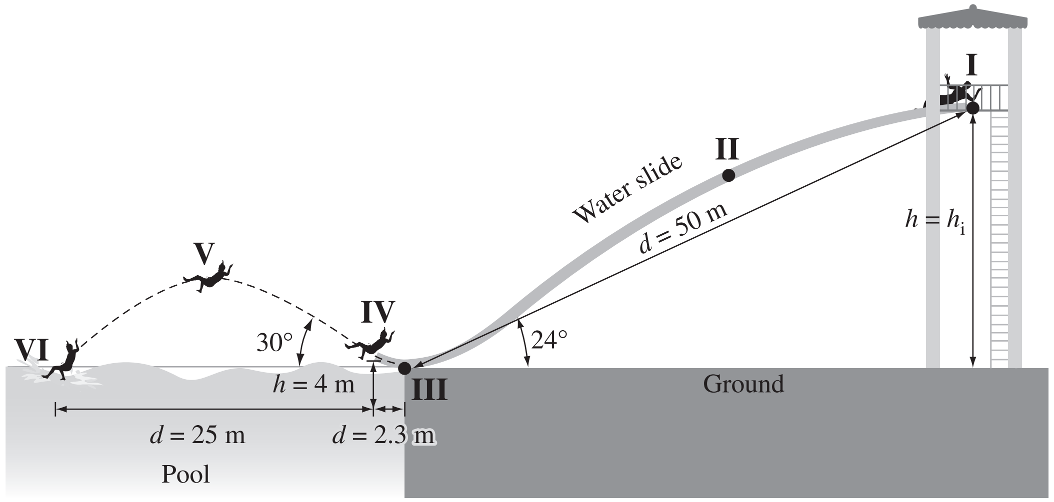
Item Introduction

This is a very difficult item. Students should be able to provide a reasonable response to the full scope of this question in 45 minutes.

Both the context and the analysis are complex. Although there are simple calculations that the just-passing student may want to do, the attention to detail required to do the complete analysis will allow the honours-level students to demonstrate their true ability.

This item explores concepts from Physics 20 in units A1, B1, and C2.

Use the following information to answer the next question.



Location I	At the horizontal top of the water slide. The person pushes himself until he begins to slide. His mass is 70 kg.
Location II	Somewhere along the slide
Location III	Just past the bottom of the water slide, as it curves upward
Location IV	At the lip of the slide, just as the person is no longer in contact with the slide
Location V	At the top of the trajectory
Location VI	At the height just before the person enters the water

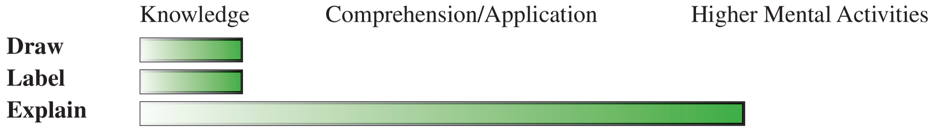
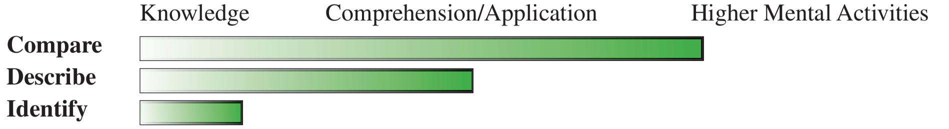
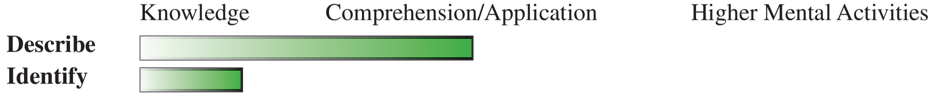
1. Using the concepts of free-body diagrams, conservation of energy, and Newton's laws, **analyze** the path of the person as represented in the diagram above. In your response,

- **draw** and **label** free-body diagrams of the significant forces acting on the person at each of the locations described. **Explain** why you selected the forces you did, and why you made them the lengths you did
- **compare** the magnitude of the net acceleration experienced by the person at each of the locations
- **describe** the changes in the system's mechanical energy as the person moves from Location I to Location III. **Identify** any assumptions that you had to make
- **describe** a calculation that you could do that would produce the value of the average force of kinetic friction experienced by the person as he moves from Location I to Location III. **Identify** any additional measurements that you would need to make
- **determine** the person's minimum speed at Location IV for him to reach Location VI
- **evaluate** this statement: "At Location V the speed of the person is 0 m/s."

Student Name____________________

Peer Feedback—Water Slide

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Draw and **label** free-body diagrams of the significant forces acting on the person at each of the locations described. **Explain** why you selected the forces you did, and why you made them the lengths you did. (P20–A1.5k, A1.3s, B1.1k, B1.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Compare the magnitude of the net acceleration experienced by the person at each of the locations. **Describe** the changes in the system's mechanical energy as the person moves from Location I to Location III. **Identify** any assumptions that you had to make. (P20– A1.1k, A1.3s, B1.2k, C2.1k, C2.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Describe a calculation that you could do that would produce the value of the average force of kinetic friction experienced by the person as he moves from Location I to Location III. **Identify** any additional measurements that you would need to make. (P20–B1.5k)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

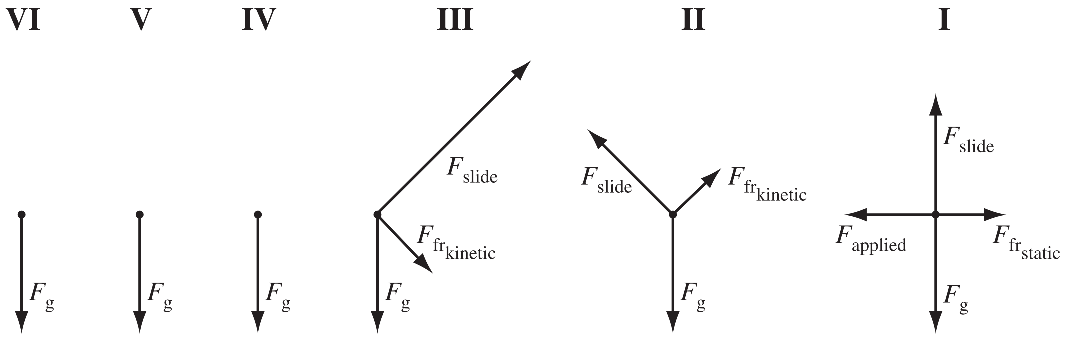
Student Name____________________

Peer Feedback—Water Slide – continued

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Describe a calculation that you could do that would produce the value of the average force of friction experienced by the person as he moves from Location I to Location II. **Identify** any additional measurements that you would need to make. (P20–B1.5k, B1.3s)	Knowledge — Comprehension/Application — Higher Mental Activities **Describe** **Identify**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Determine the person's minimum speed at Location IV for him to reach Location VI. (P20–A1.3s)	Knowledge — Comprehension/Application — Higher Mental Activities **Determine**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Evaluate this statement: "At Location V the speed of the person is 0 m/s." (P20–A1.3s)	Knowledge — Comprehension/Application — Higher Mental Activities **Evaluate**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Sample Response and Commentary for Teachers



F_g is the same everywhere because the change in height is insignificant and the mass of the slider remains the same. The slide exerts a force normal to its surface as long as the slider is in contact with the slide. While the slider is moving along the slide there is a friction force that acts opposite to the direction of motion. This force disappears when the slider is no longer touching the slide.

At Location I, F_{slide} and F_g are the same because the slide is horizontal. There is an F_{app} which is greater than $F_{fr\ static}$ because the slider has just begun to move.

At Location II, F_{slide} is perpendicular to the slide, and its component parallel to F_g is less than F_g because the slider is accelerating down. Friction is present but is less than the parallel component of F_{slide}.

At Location III, F_{slide} is much greater than F_g because the slider is accelerating upward. F_{fr} is still present.

At locations IV, V, and VI the slider is not in contact with the slide, so there is only F_g.

The acceleration is in the direction of the net force acting on the slider. At Location I the acceleration is minimal. Along the slide the acceleration is less than 9.81 m/s^2. At Location III the acceleration is large. At locations IV, V, and VI the acceleration is 9.81 m/s^2.

At Location I, the slider has E_{pg} and E_k; as he travels along the slide, the E_{pg} gradually decreases and E_k increases. The increase in E_k is less than the decrease in E_{pg} because there is energy lost to the work done by friction. If water is directed onto the top of the water slide with significant E_k, then the initial E_k of the system will be greater.

Note: *K: Answer would just state that* $E_{pg\ top} = E_{k\ bottom}$.

C/A: Answer would state that E_{pg} *gradually decreases while* E_k *gradually increases.*

HMA: Answer would include effects of frictional forces and outside sources of energy.

To determine the friction we can use

$$E_{\mathrm{M}_{\mathrm{top}}} = E_{\mathrm{M}_{\mathrm{bottom}}} + W_{\mathrm{friction}}$$

$$E_{\mathrm{pg}_{\mathrm{top}}} + E_{\mathrm{k}_{\mathrm{top}}} = E_{\mathrm{M}_{\mathrm{bottom}}} + F_{\mathrm{fr}} \bullet d_{\text{slide length}}$$

$$mgh_{\mathrm{top}} + \frac{1}{2}mv_{\mathrm{top}}{}^2 = \frac{1}{2}mv_{\mathrm{bottom}}{}^2 + F_{\mathrm{fr}} \bullet d_{\text{slide length}}$$

$$\therefore F_{\mathrm{fr}} = \frac{mgh_{\mathrm{top}} + \frac{1}{2}mv_{\mathrm{top}}{}^2 - \frac{1}{2}mv_{\mathrm{bottom}}{}^2}{d_{\text{slide length}}}$$

We can get h_{top} from $\sin 24^{\circ} = \frac{\text{height}}{\text{slide length}}$.

We still need v_{bottom}.

Note: *K-level answer uses the idea that energy lost is equal to the work done on friction. C/A-level answer has formulas and identifies that height and* v_{bottom} *are needed. HMA-level answer starts with a physics big picture and realizes that height is findable but* v_{bottom} *is still lacking.*

Calculation of speed at IV (where the slider just leaves the lip)

Horizontal motion:
Uniform motion

$$d = v_{\mathrm{x}} \bullet t$$

$$v_{\mathrm{x}} = v \cos 30^{\circ}$$

Vertical motion:
Accelerated motion

$$a = \frac{v_{\mathrm{f}} - v_{\mathrm{i}}}{t}$$

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

Want to use symmetry to make calculations easy.

$$v_{y_{\mathrm{i}}} = \sin 30^{\circ}$$

at top $v_{y_{\mathrm{f}}} = 0$

$$\therefore t = \frac{0 - v \sin 30}{-9.81\ \mathrm{m/s^2}}$$

This is the same as the time to travel $\frac{1}{2}$(25.0 m – 4.0 m) (to get to the same height) assuming no air resistance.

$$\therefore d = 10.5 \text{ m}$$

$$t = \frac{10.5 \text{ m}}{v \cos 30^\circ}$$

$$t = t$$

$$\frac{10.5 \text{ m}}{v \cos 30^\circ} = \frac{v \sin 30^\circ}{-9.81 \text{ m/s}^2}$$

$$t = 15 \text{ s}$$

Note: *K: Answer has horizontal and vertical motion classification.*
C/A: Answer incorporates the fact that the time travelled vertically is the same as that travelled horizontally but uses the wrong values.
HMA: Answer will be clearly communicated following logical physics processes to arrive at the correct solution.

The statement that the speed of the person at Location V is 0 m/s is not correct but has some value. Although vertically the speed is instantaneously zero, the horizontal motion is uniform and not equal to zero.

Note: *K: Answer states that the statement is false.*
C/A: Answer states that the statement is false and gives reasons.
HMA: Answer states that the statement is false for horizontal motion but true for vertical motion.

Springs

Item Introduction

This is a skills-based formative assessment item that reviews the lab experiences that the students should have had and extends them a bit with an inclined frictionless surface. If students are familiar with the analysis of a linear graph, it should be possible for them to complete this question in 20 minutes. If they are not, it may take twice that long, as the process of applying the model of a line, $y = mx + b$, from math class to its physics significance is a high-level task.

This item explores concepts from Physics 20 in Unit D1.

Use the following information to answer the next question.

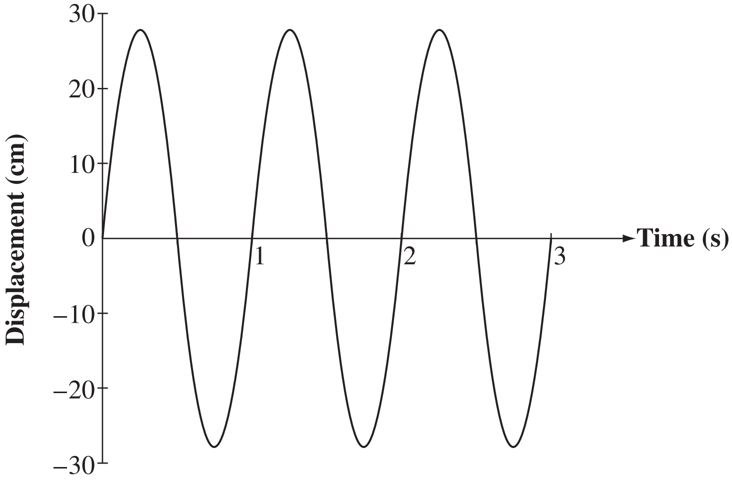
Investigation I—Spring Hanging Vertically

A group of students has a spring and selection of masses of different sizes. They suspend one end of the spring and hang the different masses on the other end of the spring. They record the distance that the spring stretched as a function of the mass hung. The data are provided below.

Mass (g)	Distance from Equilibrium Position (cm)
0	0
50	3.8
100	7.2
150	10.5
200	14.2
250	17.4
300	21.0
350	22.8

Investigation II—Spring on Horizontal, Frictionless Surface

The students use the same spring as in Investigation I, a horizontal frictionless surface, and an object that has a mass of 400 g. The students fix one end of the spring so that it doesn't move and set the object in motion. They used a motion sensing device to collect data that was analyzed by computer software to produce the following graph of the object's displacement as a function of time.



Investigation III— Spring on Diagonal, Frictionless Surface

The students gradually raise one end of the horizontal surface, described in Investigation II, and observe the motion of the mass.

1. Using the physics models of Hooke's Law, Newton's laws, and the physics principle of conservation of energy, **analyze** the mass-spring systems described above.
In your response,

- use graphical analysis to **determine** the spring constant of the spring
- **determine** the period, amplitude, and maximum speed of the mass in the horizontal mass-spring system
- **draw** and **label** free-body diagrams of the significant forces acting on the mass for each of the following situations:
  - —the mass suspended from the bottom of the vertical spring in Investigation I
  - —the mass at the equilibrium position in the horizontal mass-spring system in Investigation II
  - —the mass at its maximum displacement in the horizontal mass-spring system in Investigation II
  - —the mass at its half-way displacement in the horizontal mass-spring system in Investigation II
- **explain** the changes in restoring force caused by the spring and the acceleration of the mass during one complete oscillation in Investigation II
- **define** the physics terms *open system* and *closed system*. **Compare** the oscillation of a spring in an open system with that in a closed system
- **explain** the effect of changing the horizontal surface to an inclined surface on the stretching of the spring and the motion of the mass as described in Investigation III. **Support** your answer with a free-body diagram.

____
(Title)

____
(Label)

____
(Label)

Student Name______________________

Peer Feedback—Springs

Reviewer's Name______________________

<table>
<tr><th>Program Links to Tasks in this Question</th><th>The horizontal bar indicates the scope required in the response.
Place an "x" on the bar to indicate the level demonstrated in the response.</th><th>Looking Back</th></tr>
<tr><td>Use graphical analysis to determine the spring constant of the spring.
(P20–D1.3k, D1.3s)</td><td><table>
<tr><th></th><th>Absent</th><th>Present with error(s)</th><th>Present and correct</th></tr>
<tr><td>Title</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Axes labels</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Axes scales</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Plotted points</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Line of best fit</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Formula(s)</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Substitutions</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Answer</td><td>○</td><td>○</td><td>○</td></tr>
</table>
Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
<tr><td>Determine the period, amplitude, and maximum speed of the mass in the horizontal mass-spring system.
(P20–D1.1k, D1.3k, D1.3s)</td><td><table>
<tr><th></th><th>Knowledge</th><th>Comprehension/Application</th><th>Higher Mental Activities</th></tr>
<tr><td>Determine</td><td>🟩</td><td>🟩</td><td></td></tr>
</table>
Peer Feedback: I've placed an "x" on the bar to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
<tr><td>Draw and label free-body diagrams of the significant forces acting on the mass for each of the following situations.
(P20–D1.2k, D1.3s)</td><td><table>
<tr><th></th><th>Knowledge</th><th>Comprehension/Application</th><th>Higher Mental Activities</th></tr>
<tr><td>Draw and label</td><td>🟩</td><td></td><td></td></tr>
</table>
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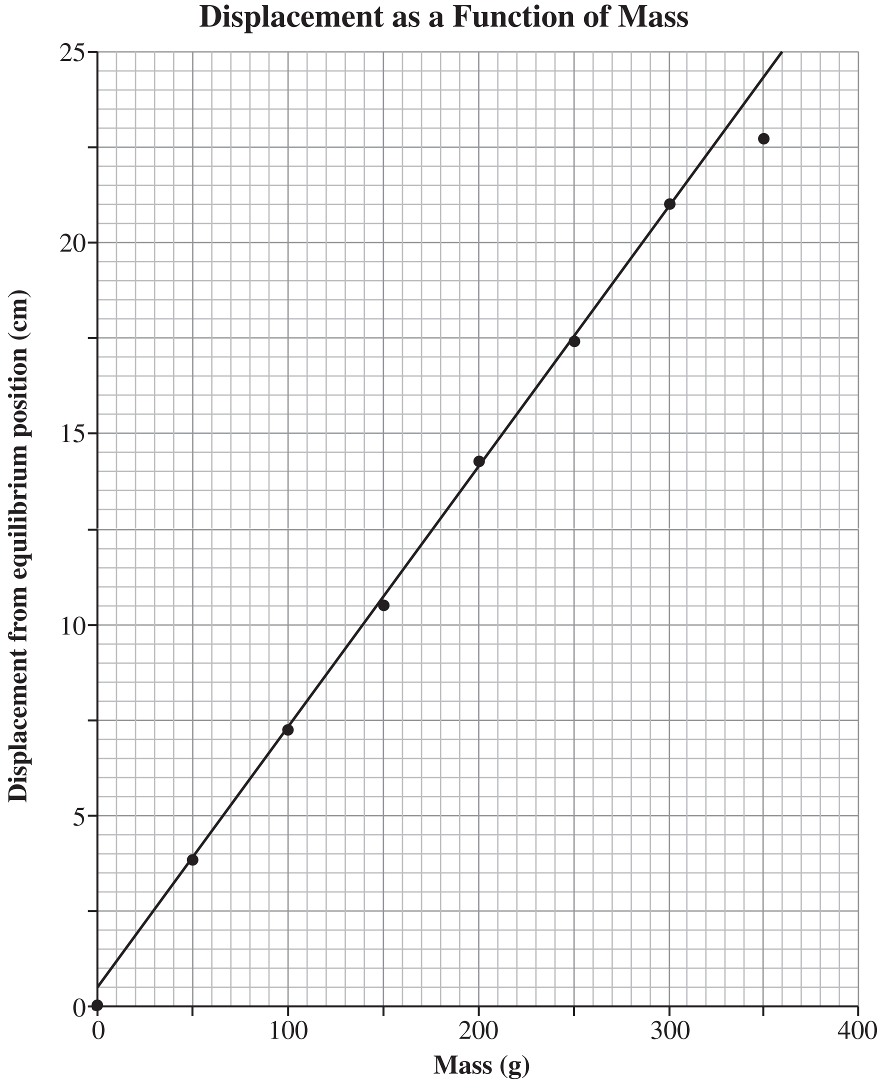
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
</table>

Student Name____________________ ***Peer Feedback—Springs – continued*** Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Explain the changes in restoring force caused by the spring and the acceleration of the mass during one complete oscillation in Investigation II. (P20–D1.2k, D1.3k)	Knowledge Comprehension/Application Higher Mental Activities **Explain**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Define the physics terms *open system* and *closed system*. **Compare** the oscillation of a spring in an open system with that in a closed system. (P20–C2.3k, D1)	Knowledge Comprehension/Application Higher Mental Activities **Define** **Compare**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Explain the effect of changing the horizontal surface to an inclined surface on the stretching of the spring and the motion of the mass as described in Investigation III. **Support** your answer with a free-body diagram. (P20–D1.4k)	Knowledge Comprehension/Application Higher Mental Activities **Explain** **Support**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Sample Response and Commentary for Teachers



The equation of a line is $y = mx + b$.

In this context, Hooke's Law, $\vec{F} = k\vec{x}$, and $\vec{F} = m\vec{g}$ apply:

$$|F_{\text{Hooke's Law}}| = |F_{\text{g}}|$$

$$kx = mg$$

$$x = \frac{mg}{k}$$

Matching to $y = \text{slope}\ x + b$ gives $slope = \dfrac{g}{k}$

Rearranging for k gives $k = \dfrac{g}{\text{slope}}$

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

$$= \frac{23.5\ \text{cm} - 4.5\ \text{cm}}{340\ \text{g} - 60\ \text{g}}$$

$$= 0.06785\ \text{cm/g} \quad \text{or} \quad 0.67856\ \text{m/kg}$$

$$k = \frac{g}{\text{slope}} = \frac{9.81\ \text{m/s}^2}{0.6785\ \text{m/kg}} = 14.456\ \text{N/m}$$

A possible spring constant value is 14.5 N/m.

The period is the time required for one cycle. The graph shows 3 cycles in 3.0 s, so the period, T, is 1.0 s. The amplitude is the maximum displacement from equilibrium.

The positive amplitude is approximately 28.0 cm, and the negative amplitude is approximately –28.0 cm. The amplitude of the graph would then be 28.0 cm.

The maximum speed can be found by using the conservation of energy, which is a valid model if there is no friction.

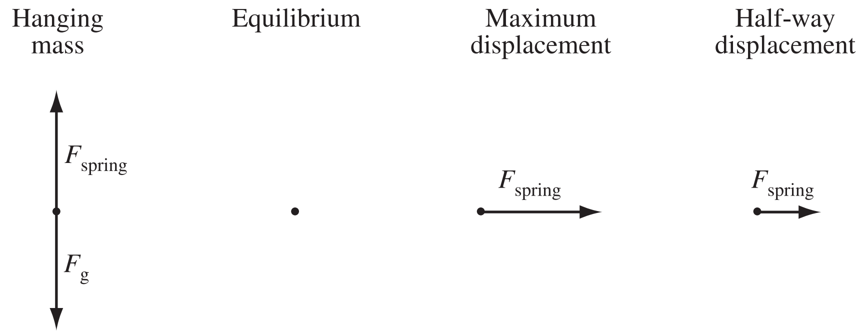
$$E_{\text{k}_{\text{max}}} = E_{\text{p}_{\text{max}}}$$

$$\frac{1}{2}mv_{\text{max}}{}^2 = \frac{1}{2}kx^2$$

$$v_{\text{max}} = \sqrt{\frac{(14.5\ \text{N/m})(0.28\ \text{m})^2}{(0.400\ \text{kg})}}$$

$$v_{\text{max}} = 1.7\ \text{m/s}$$

Free-body diagrams


Hanging mass

Equilibrium

Maximum displacement

Half-way displacement

During one complete cycle, starting at maximum displacement on one side, the restoring force is maximum as described by $\vec{F} = k\vec{x}$ and $\vec{F} = m\vec{g}$. This means the mass has its maximum acceleration at this location as modelled by $\vec{F} = k\vec{x}$ and $\vec{F} = m\vec{g}$. As the mass accelerates toward the equilibrium position, the restoring force acting on the mass decreases, and the acceleration decreases. As the mass moves through the equilibrium position, the force and acceleration are instantaneously zero. Then they both increase, but in the opposite directions of the motion, causing the mass to slow down until the maximum displacement on the other side is reached. At this point the force and acceleration are again maximums and directed toward the equilibrium position. This whole description repeats for the second half of the cycle.

An open system can experience changes in mass or energy. A closed system has changes in neither mass nor energy. A vertical spring in an open system will lose energy from the system so that the amount of stretch will gradually decrease. A spring in a closed system will not lose energy so it will continue to oscillate by the same amount.

Tilting the horizontal surface can have two effects, depending on which way the surface is tilted.

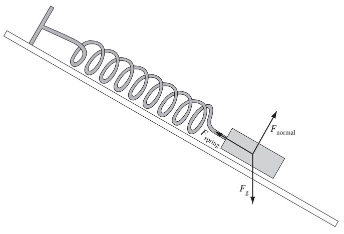
Case I

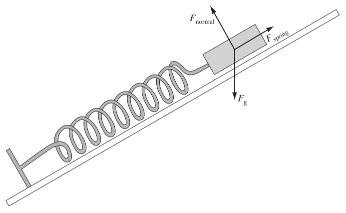
The spring will stretch more because gravity will do work, making the equilibrium distance closer to the bottom of the ramp.

OR

Case II

The spring will be more compressed because gravity will do work making the equilibrium distance closer to the bottom of the ramp.





Note: *Some springs when unweighted have no space between the coils and do not show simple harmonic motion. Other springs, such as those in automotive suspensions or retractable pens, have space and therefore show simple harmonic motion, again closer to the bottom of the ramp.*

Physics 30 Formative Assessment and Peer Feedback Materials

Coulomb's Law

Item Introduction

This item is designed to explore graphical analysis and 2-D analysis, when the physics model works and when the physics model doesn't work. Students who are competent with 2-D vector analysis, graphing skills, and vector analysis should be able to respond to the full scope of the question in 40 minutes.

What makes this item interesting is that the graph of the observations is perfectly linear, but the graph that applies a physics model is not. It is intended that the honors-level students understand that physics models have strengths and weaknesses. Because of this, there are times in the real world where the physics models make accurate predictions, and situations in which they do not. One of the goals of science is to figure out when the models are good, and if they are not good, how they can be made better.

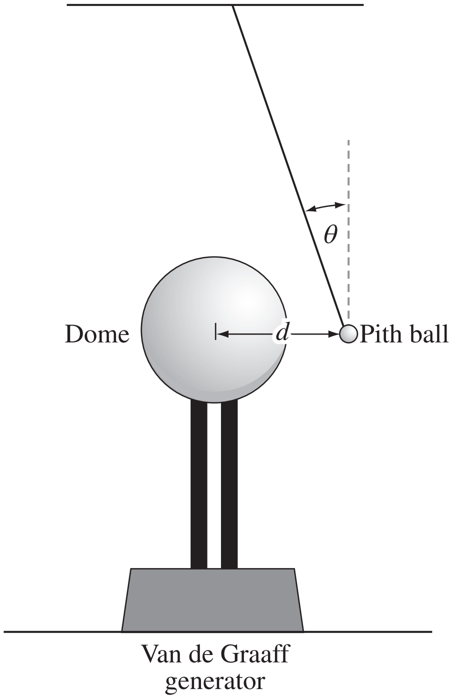
This item explores concepts from Physics 30 units B1 and B2.

Use the following information to answer the next question.

An investigation is performed to determine the value of the product of the charges on the dome of a Van de Graff generator and a charged pith ball. An initially neutral pith ball is suspended using an insulated string near the dome of an initially neutral Van de Graaff generator. The generator is turned on and becomes negatively charged; the pith ball swings toward the dome, touches the dome, and is repelled away from the dome. The generator is turned off, and the pith ball remains at its location.

As the Van de Graaff generator is moved to the left, the angle, θ, that the string makes to the vertical is measured as shown below.

Experimental Set-Up



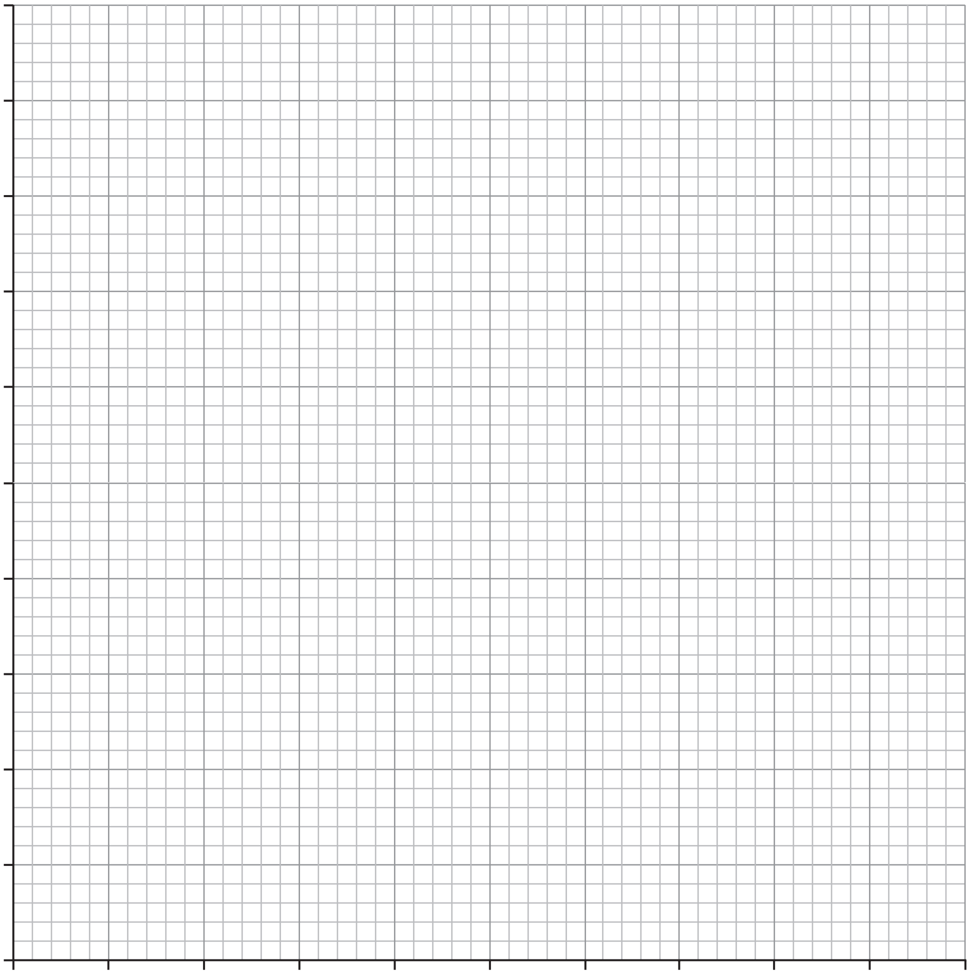
Experimental Results

Separation Distance (m)	Angle (°)	Electrostatic Force (10^{-3} N)
0.25	17.3	5.5
0.30	15.8	5.0
0.35	14.0	4.4
0.40	10.8	3.3
0.50	7.0	2.2
0.60	4.9	1.5
0.70	3.6	1.1

1. Using the physics concepts of electric charge, electric forces and fields, and graphical analysis, **analyze** the interaction of the charge on the pith ball and that on the dome of the Van de Graaff generator. In your response,

   - **draw** and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field
   - **sketch** the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball
   - **explain** what happens at the instant that the pith ball touches the dome of the generator
   - **explain** the differences in the charges on the pith ball and on the dome after the generator is turned off
   - **explain** the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design
   - **determine** the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis
   - **provide** a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, **determine** the product of the two charges.
   - **evaluate** the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.

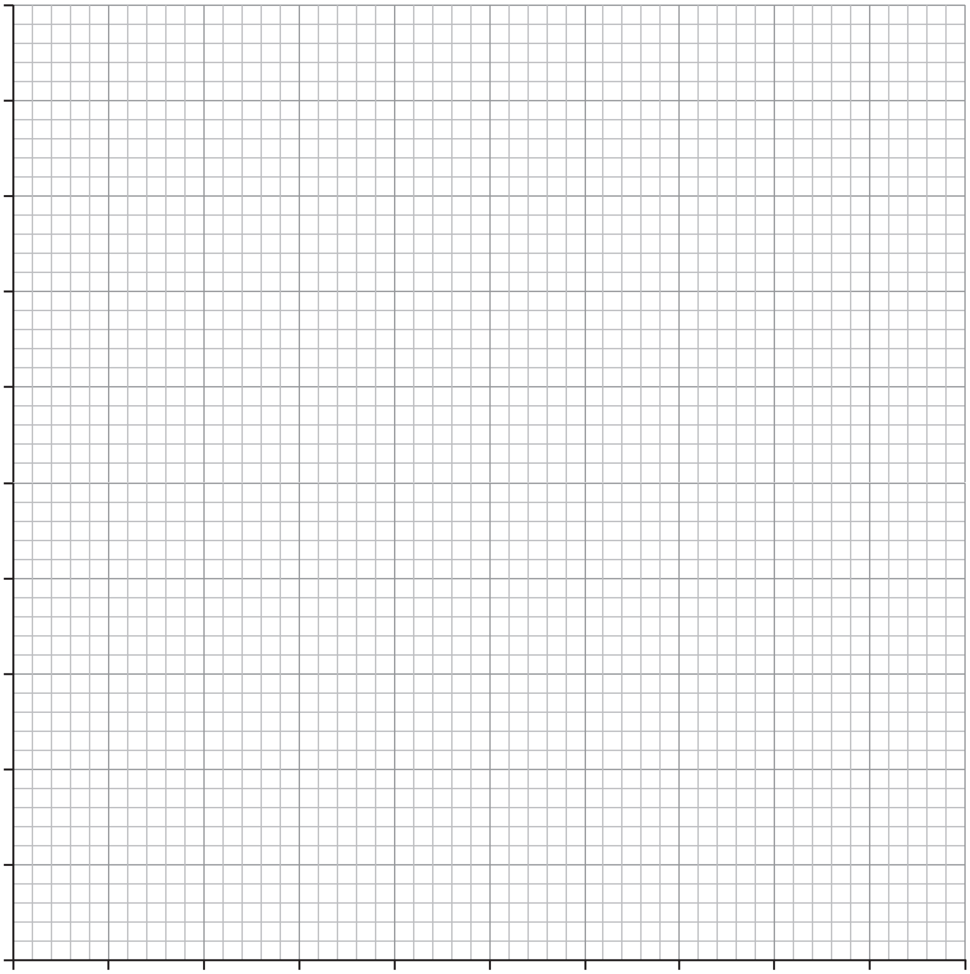
(Title)



(Label)

(Label)

(Title)



(Label)

(Label)

Student Name____________________

Peer Feedback—Coulomb's Law

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Draw and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field. (P30–B2.6k, B2.2s)	Knowledge Comprehension/Application Higher Mental Activities **Draw** **Label** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Sketch the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball (P30–B1.1k, B1.2k, B1.3s)	Knowledge Comprehension/Application Higher Mental Activities **Sketch** **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Explain what happens at the instant that the pith ball touches the dome of the generator. (P30–B1.3k)	Knowledge Comprehension/Application Higher Mental Activities **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Explain the differences in the charges on the pith ball and on the dome after the generator is turned off. (P30–B1.4k, B2.4k)	Knowledge Comprehension/Application Higher Mental Activities **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Student Name____________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name____________________

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Place an "x" on the bar to indicate the level demonstrated in the response.</th><th>Looking Back</th></tr>
<tr><td>Explain the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design
(P30–B1.1s)</td><td><table><tr><th></th><th>Knowledge</th><th>Comprehension/Application</th><th>Higher Mental Activities</th></tr><tr><td>Explain</td><td></td><td></td><td></td></tr></table>Peer Feedback: I've placed an "x" on the bar to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
<tr><td>Determine the mass of the pith ball. Support your answer with appropriate vector diagrams and graphical analysis.
(P30–B1.6k, B1.3s)</td><td><table><tr><th></th><th>Absent</th><th>Present with error(s)</th><th>Present and correct</th></tr><tr><td>Reference Direction</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Vector Conventions</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Physics Principles</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Formula(s)</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Substitutions</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Consistent Answer</td><td>○</td><td>○</td><td>○</td></tr></table><table><tr><th></th><th>Absent</th><th>Present with error(s)</th><th>Present and correct</th></tr><tr><td>Title</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Axes labels</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Axes scales</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Plotted points</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Line of best fit</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Formula(s)</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Substitutions</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Answer</td><td>○</td><td>○</td><td>○</td></tr></table>Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
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Student Name____________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name____________________

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Place an "x" on the bar to indicate the level demonstrated in the response.</th><th>Looking Back</th></tr>
<tr><td>Provide a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, determine the product of the two charges.
(P30–B1.6k, B1.3s)</td><td>
<table>
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<tr><td>Title</td><td>○</td><td>○</td><td>○</td></tr>
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<tr><td>Line of best fit</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Formula(s)</td><td>○</td><td>○</td><td>○</td></tr>
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Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
<tr><td>Evaluate the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.
(P30–B1.6k, B1.8k, B1.3s)</td><td>
<table>
<tr><th></th><th>Knowledge</th><th>Comprehension/Application</th><th>Higher Mental Activities</th></tr>
<tr><td>Evaluate</td><td colspan="3">▭</td></tr>
</table>
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I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
</table>

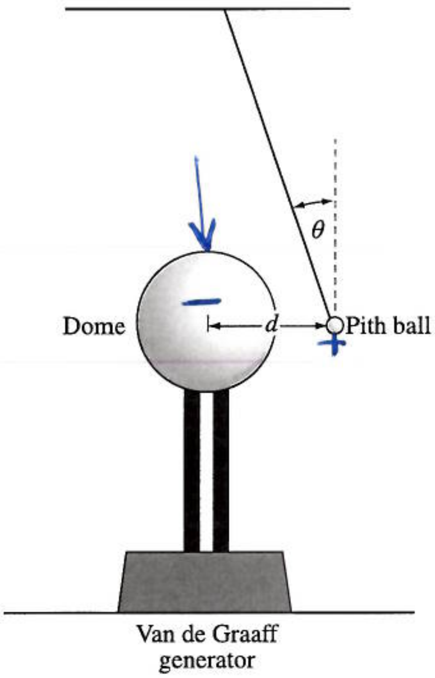
Student Response # 1

Use the following information to answer the next question.

An investigation is performed to determine the value of the product of the charges on the dome of a Van de Graff generator and a charged pith ball. An initially neutral pith ball is suspended using an insulated string near the dome of an initially neutral Van de Graaff generator. The generator is turned on, the pith ball swings toward the dome, touches the dome, and is repelled away from the dome. The generator is turned off and the pith ball remains at its location.

As the Van de Graaff generator is moved to the left, the angle, θ, that the string makes to the vertical is measured as shown below.

Experimental Set-Up



Experimental Results

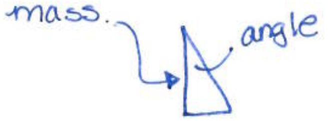
Separation Distance (m)	Angle (°)	Electrostatic Force (10^{-3} N)
0.25	17.3	5.5
0.30	15.8	5.0
0.35	14.0	4.4
0.40	10.8	3.3
0.50	7.0	2.2
0.60	4.9	1.5
0.70	3.6	1.1

The pith ball is positively charged so it is attracted to the dome. Opposites attract. Ball touches dome, becomes the same charge as dome, because charge is conserved so evenly distributed. The charges are the same.

The ball staying in the same place means nothing is changing. The variables are controlled.

1. Using the physics concepts of electric charge, electric forces and fields, and graphical analysis, **analyze** the interaction of the charge on the pith ball and that on the dome of the Van de Graaff generator. In your response,

- **draw** and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field
- **sketch** the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball
- **explain** what happens at the instant that the pith ball touches the dome of the generator
- **explain** the differences in the charges on the pith ball and on the dome after the generator is turned off
- **explain** the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design
- **determine** the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis
- **provide** a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, **determine** the product of the two charges.
- **evaluate** the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.



$$\tan\theta = \frac{F_e}{F_g}$$

$$F_{g①} = \frac{5.5\times10^{-3}\,N}{\tan 17.3} = 0.017658467$$

$F_{g②} =$ 0.0176696254

$F_{g_3} =$ 0.0176474361

$F_{g_4} =$ 0.0172992058

$F_{g_5} =$ 0.0179175621

$F_{g_6} =$ 0.0174967429

$F_{g_7} =$ + 0.0174839993

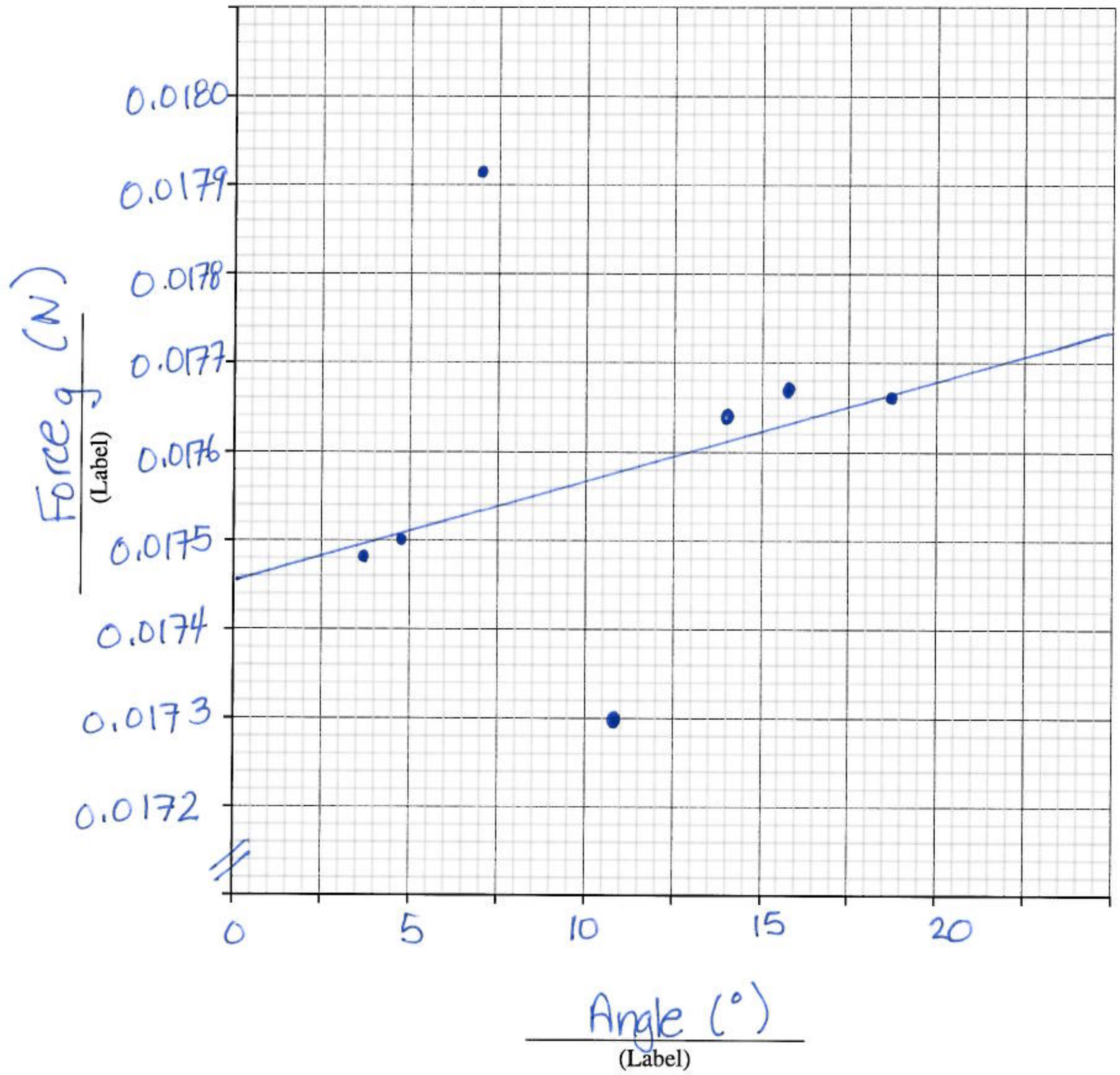
0.1231721993

$$\text{mean: } \frac{0.12317}{7} = 0.0025137\,N$$

$$\text{mass} = \frac{F_g}{g} = 2.56\times10^{-4}\ kg$$

Force Vs. Angle

(Title)

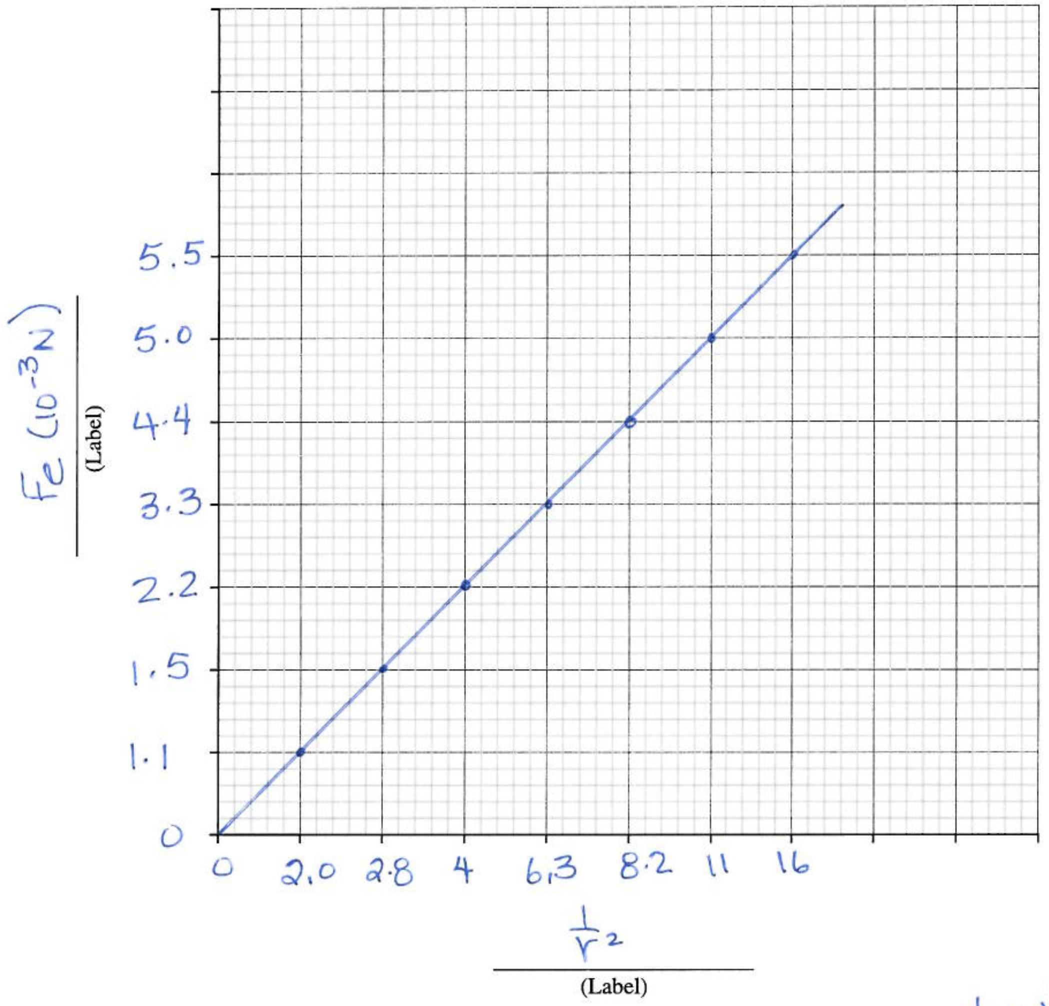


use y-intercept: $F_g = 0.01746 \text{ N}$

$$m = \frac{0.01746\text{N}}{9.81\text{m/s}^2}$$

$$= 1.7798 \times 10^{-3} \text{ kg}$$

(Title)



Second graph:
based on Coulomb's law: $Fe = \frac{Kq_1 q_2}{r^2}$

plot Fe as a function of $\frac{1}{r^2}$

$\frac{1}{r^2}(m^{-2})$	Fe $(10^{-3}N)$
16	5.5
11	5.0
8.2	4.4
6.3	3.3
4	2.2
2.8	1.5
2.0	1.1

$$q_1 q_2 = \frac{r^2 \cdot Fe}{K}$$

$$= \frac{(0.25m)^2(5.5\times10^{-3}N)}{8.99\times10^{9}\,N\cdot m^2/C^2}$$

$$= 1.53\times10^{-13}C$$

Coulomb's law is excellent b/c straight linegraph!

Student Name____________________ *Peer Feedback—Coulomb's Law* Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Draw and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field. (P30–)	Knowledge Comprehension/Application Higher Mental Activities **Draw** X **Label** X **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… your arrow is in the correct direction but it doesn't answer the question. where's the label?	**Changes that I am going to make** to my response… more arrows
Sketch the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball (P30–)	Knowledge Comprehension/Application Higher Mental Activities **Sketch** X **Explain** X **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… The dome's charges are on S.A. the ball isn't charged + ever! You got opposites attract correct	**Changes that I am going to make** to my response… use likes repel/ opposites attract more.
Explain what happens at the instant that the pith ball touches the dome of the generator. (P30–)	Knowledge Comprehension/Application Higher Mental Activities **Explain** X **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… You got that charges transfere but the conclusion based on conservation of charge is not valid.	**Changes that I am going to make** to my response…
Explain the differences in the charges on the pith ball and on the dome after the generator is turned off. (P30–)	Knowledge Comprehension/Application Higher Mental Activities **Explain** X **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… Charges have same nature, yes, but different magnitudes… Explain better!	**Changes that I am going to make** to my response… charges ARE the same.

Student Name________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Explain the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design (P30–)	**Explain** — Knowledge X — Comprehension/Application — Higher Mental Activities **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… you identified charge + stated variables are controlled but didn't relate to experimental context	**Changes that I am going to make** to my response… stat charge is controlled
Determine the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis. (P30–)	See rubric below	**Changes that I am going to make** to my response…

	Absent	Present with error(s)	Present and correct
Reference Direction	⊗	○	○
Vector Conventions	⊗	○	○
Physics Principles	⊗	○	○
Formula(s)	○	○	X ●
Substitutions	○	○	X ○
Consistent Answer	○	⊗	○

	Absent	Present with error(s)	Present and correct
Title	○	○	⊗
Axes labels	○	○	⊗
Axes scales	○	⊗ y-axis bad	○
Plotted points	○	⊗ Last pt off	○
Line of best fit	○	○	⊗
Formula(s)	⊗	○	○
Substitutions	○	⊗	○
Answer	○	⊗ s.D	○

Peer Feedback: I've placed an "x" in the circles to indicate the level of your response. I set the level there because I noticed that…

vector analysis too simplistic - redo!
math analysis wrong - missed a measurement in mean.
answers from both methods s/b same.

Student Name____________________ ## *Peer Feedback—Coulomb's Law – continued* Reviewer's Name____________________

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Place an "x" on the bar to indicate the level demonstrated in the response.</th><th>Looking Back</th></tr>
<tr><td>Provide a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, determine the product of the two charges.
(P30–)</td><td>
<table>
<tr><th></th><th>Absent</th><th>Present with error(s)</th><th>Present and correct</th></tr>
<tr><td>Title</td><td>●</td><td>○</td><td>○</td></tr>
<tr><td>Axes labels</td><td>○</td><td>☒</td><td>○</td></tr>
<tr><td>Axes scales</td><td>○</td><td>☒ WRONG!</td><td>○</td></tr>
<tr><td>Plotted points</td><td>○</td><td>☒</td><td>○</td></tr>
<tr><td>Line of best fit</td><td>○</td><td>☒</td><td>○</td></tr>
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<tr><td>Substitutions</td><td>○</td><td>☒</td><td>○</td></tr>
<tr><td>Answer</td><td>○</td><td>☒</td><td>○</td></tr>
</table>
Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…
Although you built a graph, the scale is wrong so all the analysis is wrong.
You missed squaring the distance in the Coulomb law calculation</td><td>Changes that I am going to make to my response…
remember to square r!</td></tr>
<tr><td>Evaluate the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.
(P30–)</td><td>Evaluate Knowledge ~~X~~ — Comprehension/Application X — Higher Mental Activities
Peer Feedback: I've placed an "x" on the bar to indicate the level of your response.
I set the level there because I noticed that…
your conclusion follows from your graph, but your graph is WRONG!</td><td>Changes that I am going to make to my response…
use Coulomb's law correctly</td></tr>
</table>

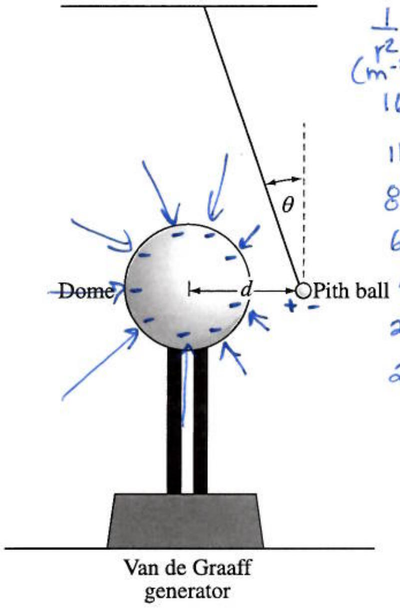
Student Response #2

Use the following information to answer the next question.

An investigation is performed to determine the value of the product of the charges on the dome of a Van de Graff generator and a charged pith ball. An initially neutral pith ball is suspended using an insulated string near the dome of an initially neutral Van de Graaff generator. The generator is turned on, the pith ball swings toward the dome, touches the dome, and is repelled away from the dome. The generator is turned off and the pith ball remains at its location.

As the Van de Graaff generator is moved to the left, the angle, θ, that the string makes to the vertical is measured as shown below.

Experimental Set-Up



Van de Graaff generator

Experimental Results

$\frac{1}{r^2}$ (m^{-2})	Separation Distance (m)	Angle (°)	Electrostatic Force (10^{-3} N)
16	0.25	17.3	5.5
11	0.30	15.8	5.0
8.2	0.35	14.0	4.4
6.3	0.40	10.8	3.3
4.0	0.50	7.0	2.2
2.8	0.60	4.9	1.5
2.0	0.70	3.6	1.1

The pith ball swings toward, touches, and swings away. This is because oposite charges attract and like charges repel. The Ball touches the dome and becomes charged because some of the negative charge transferes. The total charge in the system stays constant so the ball gets some but the dome keeps most.

The ball remaining in its place after the generator is turned off means the force is constant. Since the experiment is trying to measure force, keeping it controlled is important. It also means that the charge isnt changing either. Another variable controlled.

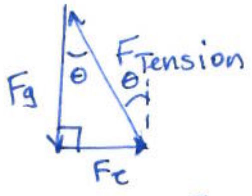
1. Using the physics concepts of electric charge, electric forces and fields, and graphical analysis, **analyze** the interaction of the charge on the pith ball and that on the dome of the Van de Graaff generator. In your response,

    - **draw** and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field
    - **sketch** the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball
    - **explain** what happens at the instant that the pith ball touches the dome of the generator
    - **explain** the differences in the charges on the pith ball and on the dome after the generator is turned off
    - **explain** the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design
    - **determine** the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis
    - **provide** a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, **determine** the product of the two charges.
    - **evaluate** the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.

mass:

$m = \frac{Fg}{g}$

how to get Fg?



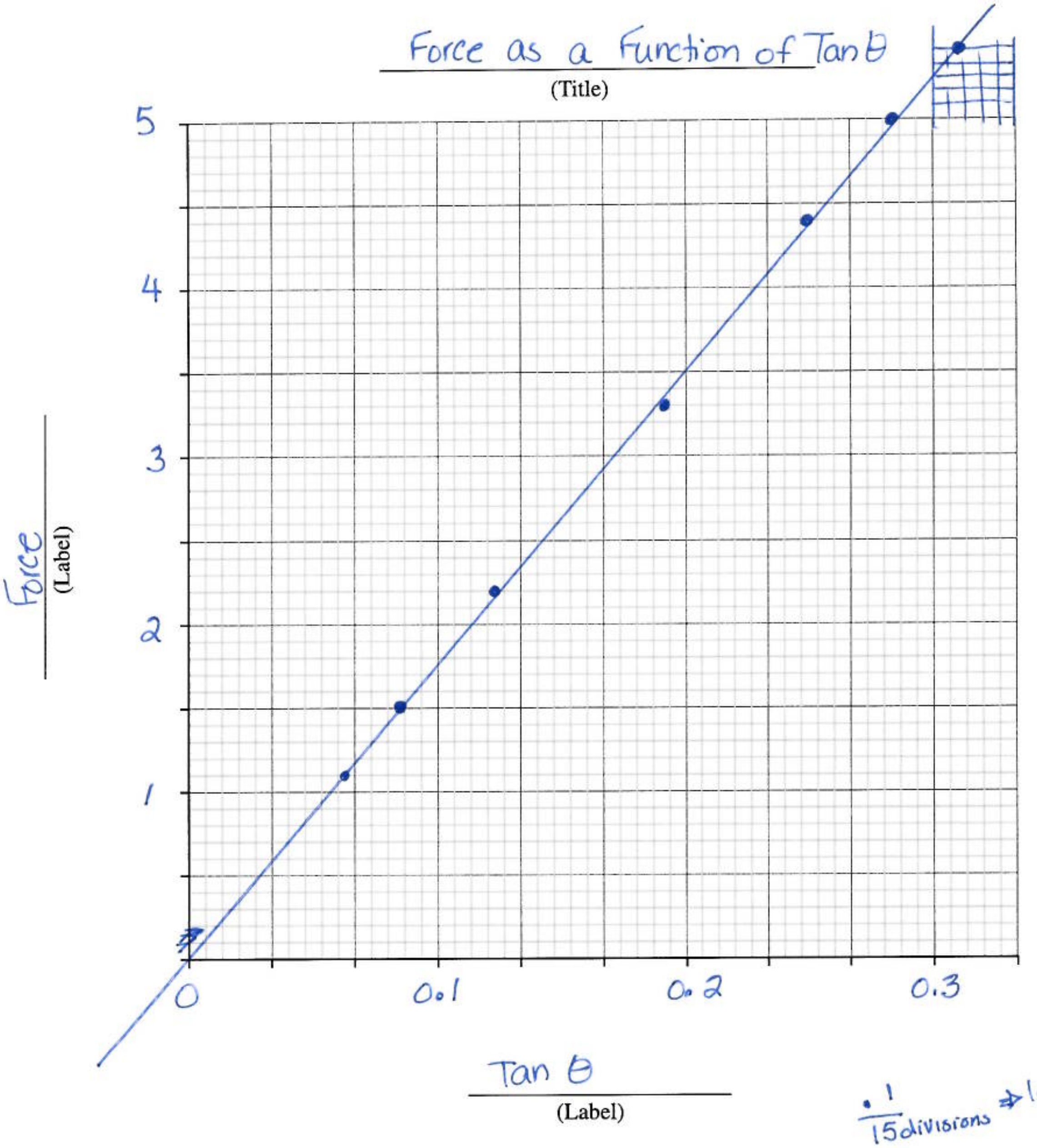
$\text{tangent}\,\theta = \frac{Fe}{Fg}$

$Fg = \frac{Fe}{\tan\theta}$

graph Fc vs tanθ

then slope = Fg.

θ	tan θ	Fe
17.3	0.311	5.5
15.8	0.283	5.0
14.0	0.249	4.4
10.8	0.191	3.3
7.0	0.123	2.2
4.9	0.086	1.5
3.6	0.063	1.1



Force as a Function of Tan θ

$\frac{.1}{15 \text{ divisions}} \Rightarrow 1 \text{ divion} = 0.00\overline{6}$

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

$$= \frac{3.3}{0.191}$$

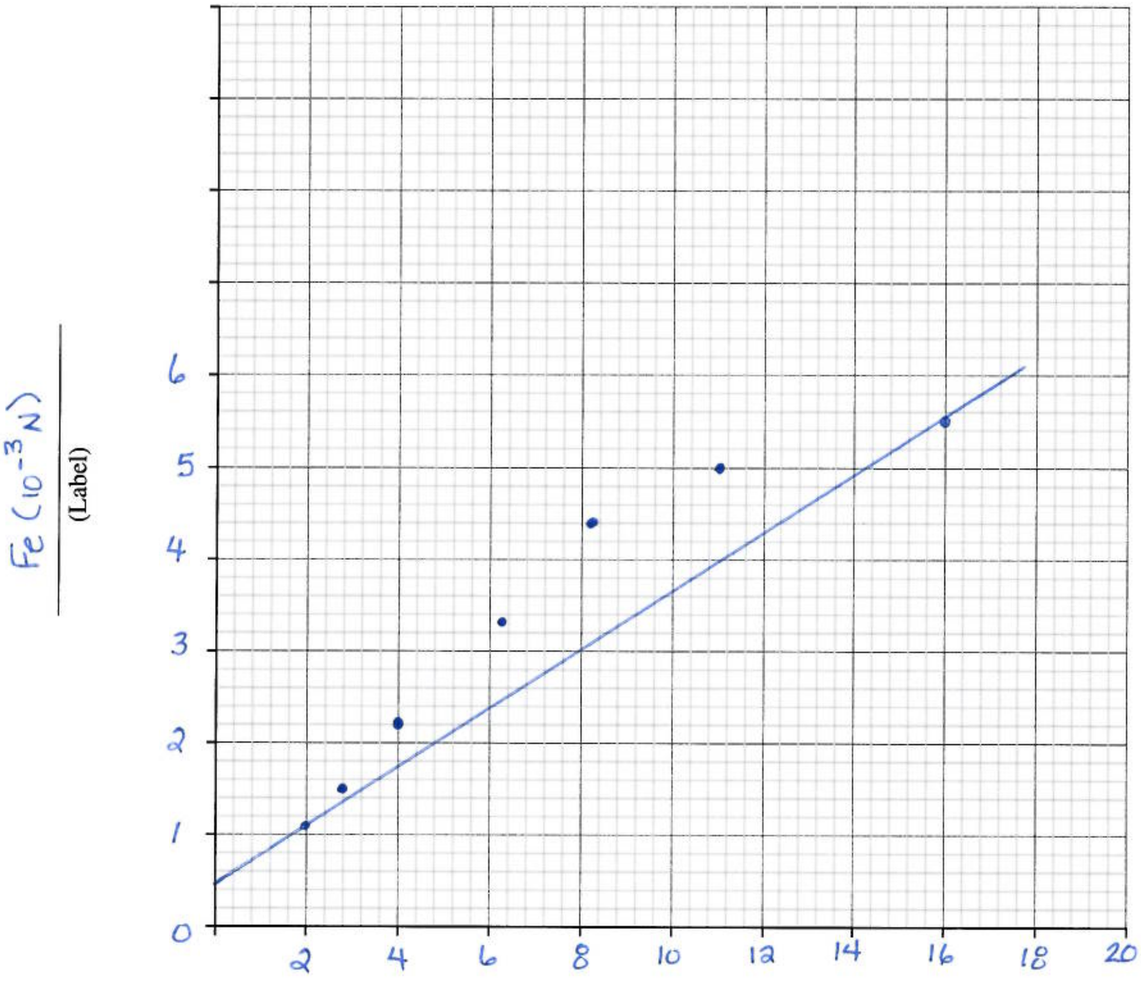
$$= 17.277$$

$$m = \frac{17.277}{9.81}$$

$$= 1.7612\text{kg}.$$

Coulomb's Law Graph

(Title)



$\frac{1}{r^2}(m^{-2})$

(Label)

Coulomb's Law

$F_e = k\frac{q\,q}{r^2}$

Fe varies as $\frac{1}{r^2}$

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

$= \frac{5.5\times10^{-3}N}{16\ m^{-2}}$

$= 3.4375\times10^{-4}\ N\cdot m^2$

$q_1 q_2 = 3.44\times10^{-4}\ C^2$

Coulombs law seems to be a poor model for this data because the points aren't on the line.

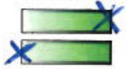
There must be error in the procedure, because physics equations describe the real world.

The problem is with the lab not the law ☺

Student Name____________________

Peer Feedback—Coulomb's Law

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Draw and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field. (P30–)	Knowledge · Comprehension/Application · Higher Mental Activities **Draw** **Label**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… your arrows point in, are of many different lengths but you have the shape idea ok. Label MISSING!	**Changes that I am going to make** to my response… make arrows the same length & READ the QUESTION.
Sketch the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball (P30–)	Knowledge · Comprehension/Application · Higher Mental Activities **Sketch** **Explain**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… you kept the pith ball neutral but didn't say why/how	**Changes that I am going to make** to my response…
Explain what happens at the instant that the pith ball touches the dome of the generator. (P30–)	Knowledge · Comprehension/Application · Higher Mental Activities **Explain**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… you got negative charge motion ✓ need to explain how/why - consider "conduction"	**Changes that I am going to make** to my response… more specific e^- flow • use words like conduction and enduction
Explain the differences in the charges on the pith ball and on the dome after the generator is turned off. (P30–)	Knowledge · Comprehension/Application · Higher Mental Activities **Explain**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… your conservation of charge is right & some charge goes. Still missing "why" only some.	**Changes that I am going to make** to my response… enclude E.P.D & conservation of energy.

Student Name__________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name__________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Explain the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design (P30–)	**Explain** Knowledge — Comprehension/Application X — Higher Mental Activities **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… You got controlled charge but Force isn't constant because we are moving VDG + the P.B. will move.	**Changes that I am going to make** to my response… Remove reference to forces.
Determine the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis. (P30–)	See checklists below. **Peer Feedback:** I've placed an "x" in the circles to indicate the level of your response. I set the level there because I noticed that… See above ☺	**Changes that I am going to make** to my response… include power of 10 from data chart. include units in substitutions.

	Absent	Present with error(s)	Present and correct
Reference Direction	○	○	☒
Vector Conventions	○	○	☒
Physics Principles	☒	○	○
Formula(s)	○	○	☒
Substitutions	○	☒ missed units	○
Consistent Answer	○	☒ missed power of 10 on Force	○

	Absent	Present with error(s)	Present and correct
Title	○	○	☒
Axes labels	○	☒ missing units	○ and powers of 10
Axes scales	○	☒ both poor	○
Plotted points	○	○	☒
Line of best fit	○	○	☒
Formula(s)	○	○	☒
Substitutions	○	☒ not online	○
Answer	○	☒ S.D.	○

Student Name____________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name____________________

Program Links to Tasks in this Question

The horizontal bar indicates the scope required in the response.
Place an "x" on the bar to indicate the level demonstrated in the response.

Looking Back

Provide a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, **determine** the product of the two charges.
(P30–)

	Absent	Present with error(s)	Present and correct
Title	○	● not good enough	○
Axes labels	○	○	●
Axes scales	○	○	●
Plotted points	○	○	●
Line of best fit	○	● not good L-B-F	○
Formula(s)	○	○	●
Substitutions	○	● single pt wrong	○
Answer	○	●	○

Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…

doesn't follow - what happened to k ?

Changes that I am going to make to my response…

draw a better line.

use two pts for slope & divide by k

Evaluate the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.
(P30–)

Evaluate

Knowledge	Comprehension/Application	Higher Mental Activities
	X	

Peer Feedback: I've placed an "x" on the bar to indicate the level of your response.
I set the level there because I noticed that…

judgment supported by graph, but graph is wrong.

Re think the apparent shape of field near pith ball

Changes that I am going to make to my response…

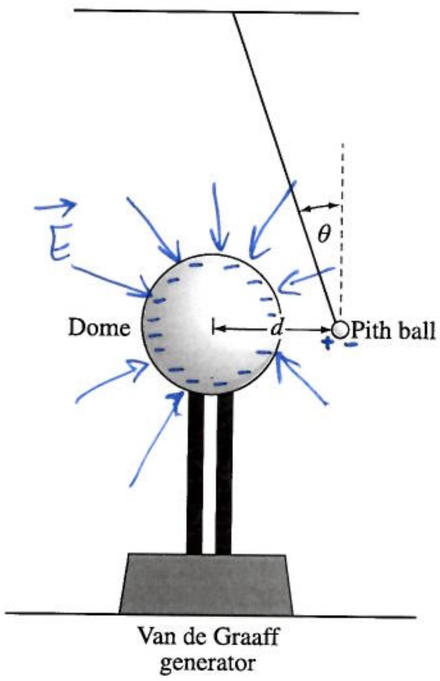
Student Response #3

Use the following information to answer the next question.

An investigation is performed to determine the value of the product of the charges on the dome of a Van de Graff generator and a charged pith ball. An initially neutral pith ball is suspended using an insulated string near the dome of an initially neutral Van de Graaff generator. The generator is turned on, the pith ball swings toward the dome, touches the dome, and is repelled away from the dome. The generator is turned off and the pith ball remains at its location.

As the Van de Graaff generator is moved to the left, the angle, θ, that the string makes to the vertical is measured as shown below.

Experimental Set-Up



Experimental Results

Separation Distance (m)	Angle (°)	Electrostatic Force (10^{-3} N)
0.25	17.3	5.5
0.30	15.8	5.0
0.35	14.0	4.4
0.40	10.8	3.3
0.50	7.0	2.2
0.60	4.9	1.5
0.70	3.6	1.1

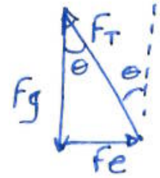
The electric field near the dome causes the ~~charge~~ initially neutral pith ball to experience charge "polarization": positives are attracted, negatives repelled, so the side of the ball closest to dome appears positively charged. Opposites attract (more than likes repel, because distance to negative charges is much greater, so force is much less). Once the ball touches the dome. Charges transfer until the electric potential between near by charges is minimum. The Ball will have the same type of charge, negative, as the dome, but a smaller value because it is much smaller than the dome.

1. Using the physics concepts of electric charge, electric forces and fields, and graphical analysis, **analyze** the interaction of the charge on the pith ball and that on the dome of the Van de Graaff generator. In your response,

   - **draw** and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field
   - **sketch** the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball
   - **explain** what happens at the instant that the pith ball touches the dome of the generator
   - **explain** the differences in the charges on the pith ball and on the dome after the generator is turned off
   - **explain** the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design
   - **determine** the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis
   - **provide** a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, **determine** the product of the two charges.
   - **evaluate** the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases.

The ball remaining in its location means its charge + the charge on the dome are not changing. The product of the charges, the goal of the experiment, should remain constant. If the ball slowly fell/swung toward the dome, then the charges would be bleeding away.

Finding mass.



Because the ball remains stationary its acceleration is zero so the forces sum to zero.

use θ as measured from the vertical

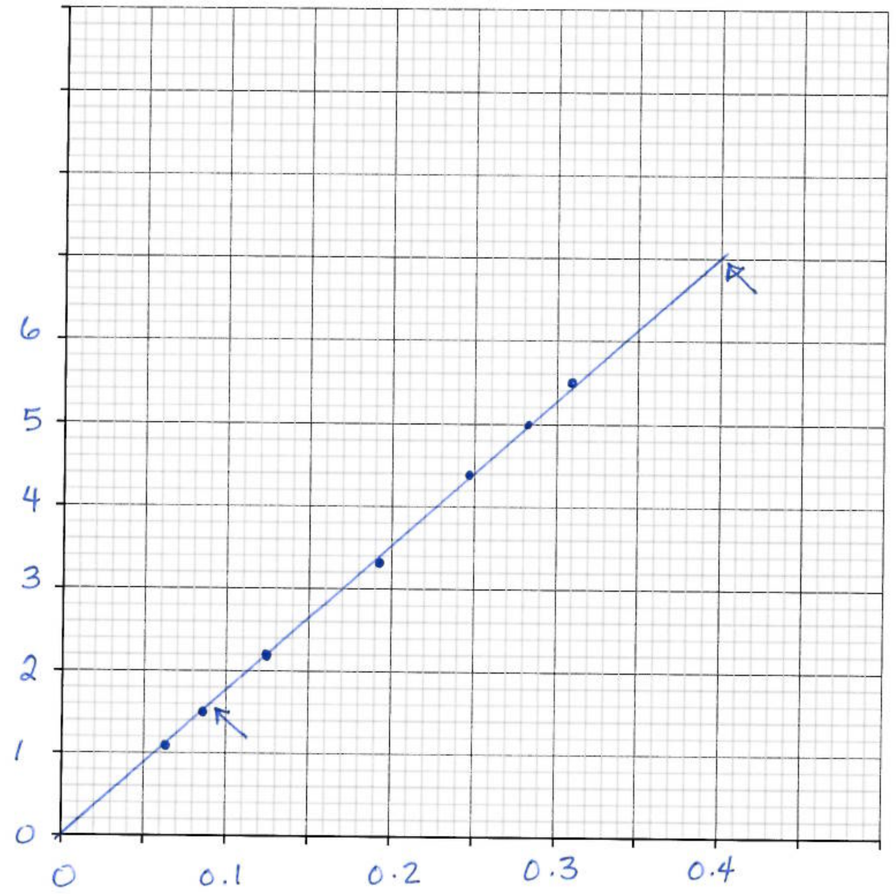
$m = \frac{F_g}{g}$ $\quad$ $F_g = \frac{F_c}{\tan\theta}$

∴

$m = \frac{\text{slope}}{g}$

Force as a Function of Tangent of Angle

(Title)



Force (10^{-3} N)

(Label)

tan θ (no units)

(Label)

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

$$= \frac{7.0 \times 10^{-3}\,\text{N} - 1.6 \times 10^{-3}\,\text{N}}{0.4 - 0.09}$$

$$= 0.01741935\,\text{N}$$

$$m = \frac{\text{slope}}{g}$$

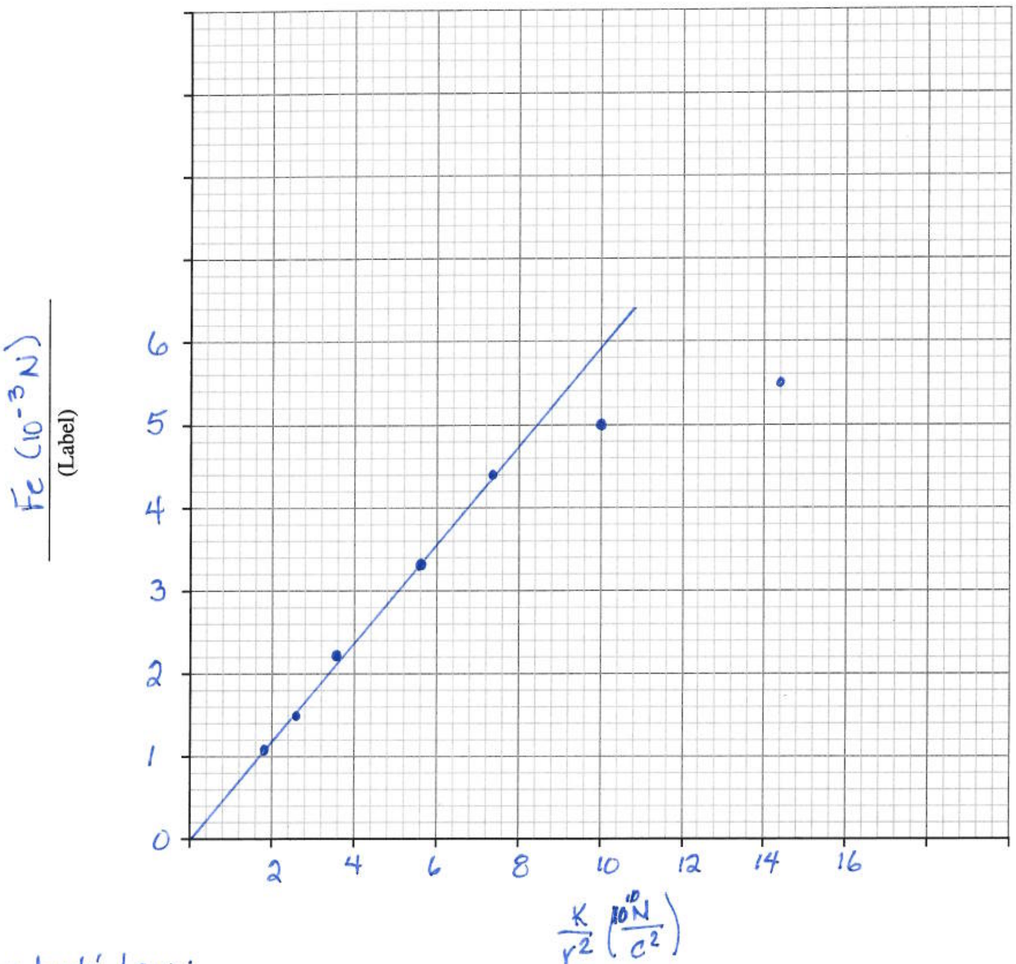
$$= \frac{0.01741935\,\text{N}}{9.81\,\text{m/s}^2}$$

$$= 1.77567 \times 10^{-3}\,\text{kg}$$

$$= 1.8 \times 10^{-3}\,\text{kg}$$ (2 s.d. from subtraction in slope calculation).

Electrostatic Force as a Function of $\frac{K}{r^2}$

(Title)



Coulomb's Law:

$$Fe = \frac{K q_1 q_2}{r^2}$$

want $q_1 \cdot q_2$

$$Fe = \left(\frac{K}{r^2}\right) q_1 \cdot q_2$$

If we plot Fe as a function of $\frac{K}{r^2}$ then the slope should be $q_1 q_2$ because

$y = mx + b$ can be matched

$Fe = (q_1 q_2)\frac{K}{r^2} + 0$ graph should go through (0.0).

$\frac{K}{r^2}\left(\frac{N\cdot m^2/c^2}{10^{10}}\right)$	Fe $(10^{-3} N)$
14.4	5.5
9,99	5.0
7.34	4.4
5.62	3.3
3.60	2.2
2.50	1.5
1.83	1.1

The first few points seem to work, then the data stray from Coulomb's Law. These pts are from observations of SMALL distances. The curved dome will appear to be a flat surface, so not a point charge. That is why the data stray. Coulomb's law is valid for pt. charges!

Student Name________________

Peer Feedback—Coulomb's Law

Reviewer's Name________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Draw and **label** several electric field lines in the region near the dome of the Van de Graaff generator to show the shape and direction of the electric field. (P30–)	Knowledge — Comprehension/Application — Higher Mental Activities **Draw** **Label** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… The arrows point to the dome, are almost the same length and are labelled	**Changes that I am going to make** to my response… make arrows same length
Sketch the charge distribution on both the dome and the pith ball just after the generator has been turned on but before the pith ball touches the dome. **Explain** the motion of the pith ball (P30–)	Knowledge — Comprehension/Application — Higher Mental Activities **Sketch** **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… The negatives on the dome are at the surface. your explaination hints at positive charges moving but your epd discussion is good.	**Changes that I am going to make** to my response… explicitly state e⁻ moving. explicity use Coulomb's law to support forces
Explain what happens at the instant that the pith ball touches the dome of the generator. (P30–)	Knowledge — Comprehension/Application — Higher Mental Activities **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… need to be more specific epd discussion good	**Changes that I am going to make** to my response… again, need to state that e⁻ are the charge carriers
Explain the differences in the charges on the pith ball and on the dome after the generator is turned off. (P30–)	Knowledge — Comprehension/Application — Higher Mental Activities **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that… Good. ☺	**Changes that I am going to make** to my response…

Student Name____________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name____________________

Program Links to Tasks in this Question

The horizontal bar indicates the scope required in the response.
Place an "x" on the bar to indicate the level demonstrated in the response.

Looking Back

Explain the significance of the ball remaining in its location when the generator is turned off in terms of the controlled variables in this experimental design
(P30–)

	Knowledge	Comprehension/Application	Higher Mental Activities
Explain			x

Peer Feedback: I've placed an "x" on the bar to indicate the level of your response.
I set the level there because I noticed that…

Good ☺

Changes that I am going to make to my response…

re-order sentences
to make clearer.

Determine the mass of the pith ball. **Support** your answer with appropriate vector diagrams and graphical analysis.
(P30–)

	Absent	Present with error(s)	Present and correct
Reference Direction	○	○	●
Vector Conventions	○	○	●
Physics Principles	○	○	●
Formula(s)	○	○	●
Substitutions	○	○	●
Consistent Answer	○	○	●

	Absent	Present with error(s)	Present and correct
Title	○	○	●
Axes labels	○	○	●
Axes scales	○	○	●
Plotted points	○	○	●
Line of best fit	○	○	●
Formula(s)	○	○	●
Substitutions	○	○	●
Answer	○	○	●

Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…

Wow!

Changes that I am going to make to my response…

Student Name________________

Peer Feedback—Coulomb's Law – continued

Reviewer's Name________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Provide a second linear graph of the data that can be used to find the product of the two charges. Using the slope of the line of best fit, **determine** the product of the two charges. (P30–)	see checklist below	**Changes that I am going to make** to my response…
Evaluate the validity of Coulomb's law as a model for describing the interactions of the charge on the pith ball and the charge on the dome of the Van de Graaff generator as the distance between the objects decreases. (P30–)	see evaluation bar below	**Changes that I am going to make** to my response…

	Absent	Present with error(s)	Present and correct
Title	○	○	●
Axes labels	○	○	●
Axes scales	○	○	●
Plotted points	○	○	●
Line of best fit	○	○	●
Formula(s)	○	○	●
Substitutions	○	○	●
Answer	○	○	●

Peer Feedback: I've placed an "x" in the circles to indicate the level of your response.
I set the level there because I noticed that…

$\frac{K}{r^2}$ neat idea.

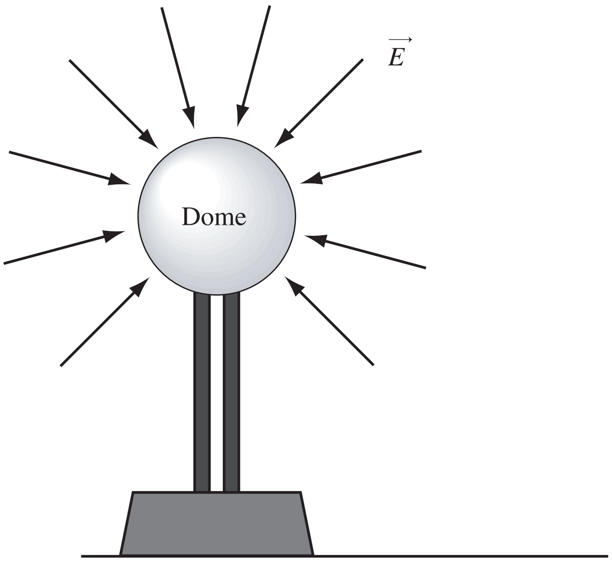
Evaluate Knowledge — Comprehension/Application — Higher Mental Activities X

Peer Feedback: I've placed an "x" on the bar to indicate the level of your response.
I set the level there because I noticed that…

Great.

Sample Response and Commentary for Teachers

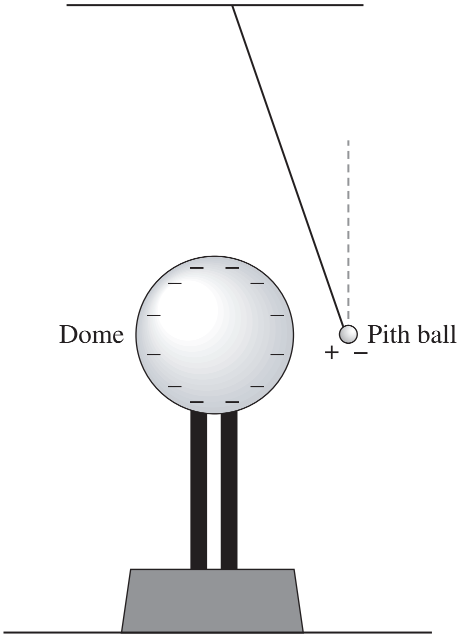
The electric field in the region near the dome of the Van de Graaff generator is shown below.



Van de Graaff generator

Note: *The electric field must be represented as arrows, pointing toward the surface, perpendicular to the surface. Students might curve the arrows to imply that the base of the generator is relatively positively charged.*

The charge distribution is shown below.



Van de Graaff generator

Note: *The net charge on the ball must remain zero – it experiences an induced charge separation but is not charged.*
The charge on the dome is uniformly distributed on its surface. The induced charge separation on the ball is too small to cause a change in the distribution of the charge on the dome of the generator.

The pith ball will experience an induced charge separation as the electrons free to move will be repelled by the negative charge on the dome. This leaves the side of the ball near the dome relatively positively charged. Since opposite charges attract, the ball is accelerated toward the dome. The like charge on the far side of the ball is repelled, but Coulomb's Law is a one-over-*r*-squared relationship, which means the increased distance results in decreased force. The net effect is that the ball will accelerate toward the dome.

Note: *The K-level response is "opposites attract" or "likes repel".*
The C/A-level response describes the charge redistribution on the ball and mentions that the ball accelerates toward the dome because opposites attract.
The HMA-level response explicitly identifies that electrons are free to move, that like charges repel so that the far side of the ball becomes relatively negatively charged, leaving the side near the dome relatively positively charged. It is necessary for an HMA answer to leave the ball neutral. The response contains one-over-r-squared analysis that supports an acceleration toward the dome.

When the pith ball touches the dome, extra electrons on the dome move onto the pith ball. This continues until the potential difference between the charges on the surface of the dome and the surface of the ball are the same. The ball reaches a charge similar to that of the dome and accelerates away because like charges repel. The net charge on the ball is much less than that on the dome because its surface area is much less.

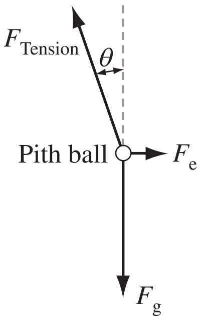
Note: *K: Charges transfer until equal.*
C/A: Electrons transfer until charge is equal.
HMA: Electrons transfer until the potential energy is uniform.

When the generator is turned off, no more charge is being added to the dome. The pith ball remaining at its location means the charges are not changing. This allows us to analyze the data with the values of the charges being controlled.

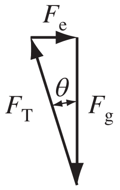
Note: *K: Charges remain constant.*
HMA: The variables are controlled, so the experimental analysis is valid.

Mass of pith ball.

Free-body diagram



Vector-addition diagram

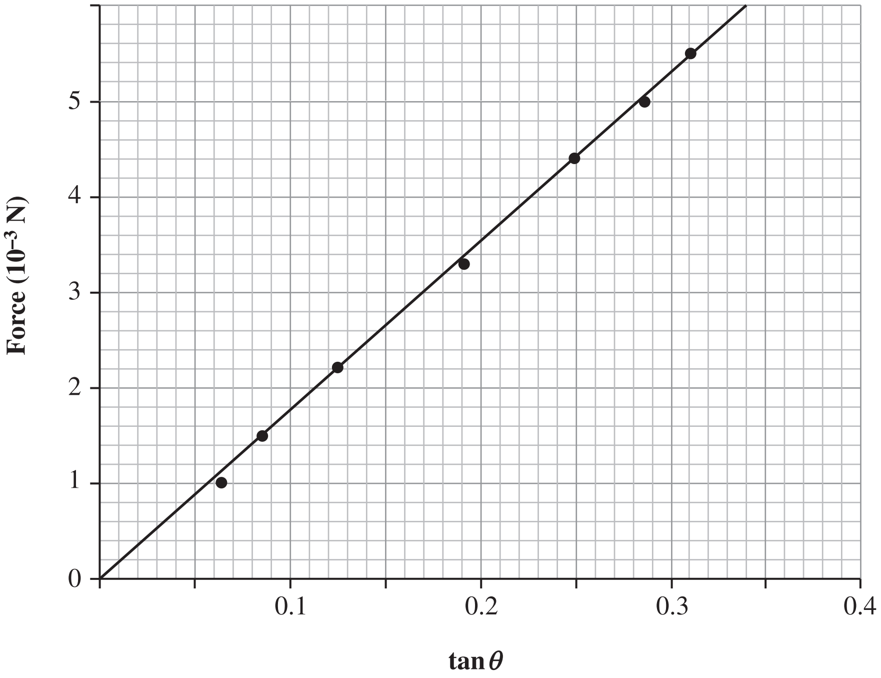


$$F_e = F_g \cdot \tan\theta$$

$$F_e = m \cdot g \cdot \tan\theta$$

To get the mass from graphical analyses, plot F_e as a function of $\tan\theta$. The equation suggests this should be a line through the origin that has a slope of mg.

Force as a Function of Tangent of Angle



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

$$= \frac{6.0 \times 10^{-3}\ \text{N} - 1.6 \times 10^{-3}\ \text{N}}{0.34 - 0.09}$$

$$= 0.0176\ \text{N}$$

$$\therefore F_{\text{e}} = m \underset{\uparrow}{\bullet} g \bullet \underset{\uparrow}{\tan\theta}$$

$$y = \text{slope} \bullet x + b$$

$$\text{slope} = m \bullet g$$

$$m = \frac{\text{slope}}{g}$$

$$= \frac{0.976\ \text{N}}{9.81\ \text{m/s}^2}$$

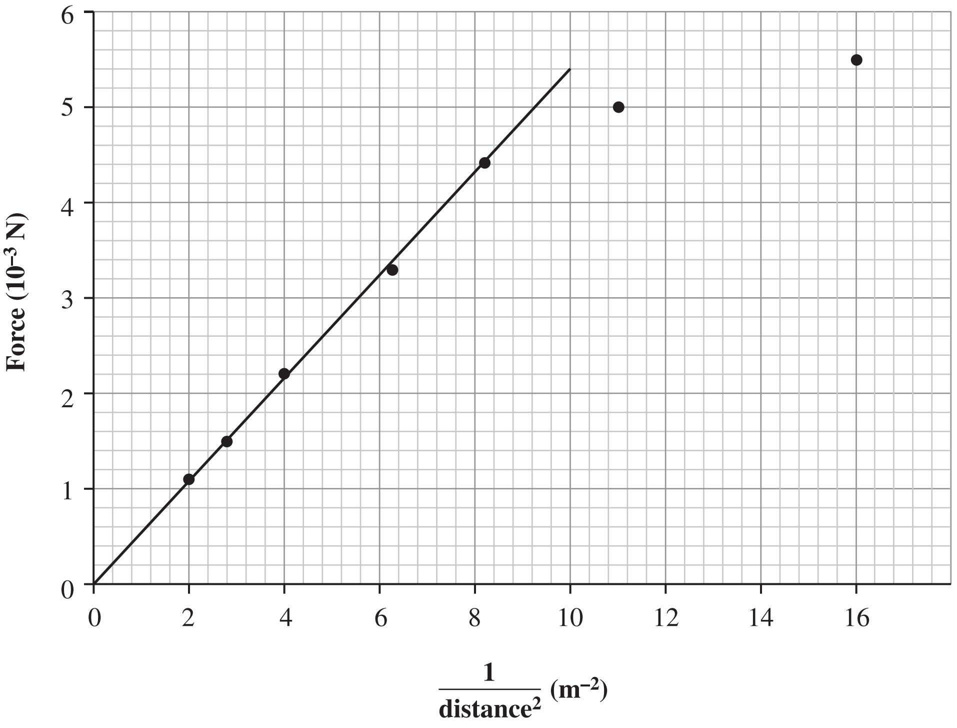
$$= 0.00179\ \text{N}{\cdot}\text{s}^2/\text{m}$$

$$= 1.80 \times 10^{-3}\ \text{kg}$$

Note: *K: Single data point calculation.*
C/A: Calculates slope.
HMA: Explicitly relates equation of line y = mx + b to the physics significance of the situation.

Graph of observations:

Force as a Function of Reciprocal of Square of Distance



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

$$= \frac{5.4 \times 10^{-3}\ \text{N} - 0 \times 10^{-3}\ \text{N}}{10\ \text{m}^{-2} - 0\ \text{m}^{-2}}$$

$$= 5.4 \times 10^{-4}\ \text{N·m}^2$$

$$\underset{\uparrow}{F_e} = \frac{kq_1q_2}{r^2 \nwarrow}$$

$$y = \text{slope} \bullet x + b$$

$$q_1q_2 = \frac{\text{slope}}{k}$$

$$= \frac{5.4 \times 10^{-4}\ \text{N·m}^2}{8.99 \times 10^9\ \text{N·m}^2/\text{C}^2}$$

$$= 6.0 \times 10^{-14}\ \text{C}^2$$

Evaluation of Coulomb’s Law in this Situation

Coulomb’s Law provides a really good model for some of the data, as seen by how close to a straight line the data lie, and then provides a really poor model for other data, as seen by how far from the straight line the data lie. These points come from distances that are very close to the dome. It makes sense that the model is less good, because from the perspective of the pith ball, the dome begins to look more like a surface rather than a point source. Coulomb’s law is a model for point sources only.

Notes: *K: Response contains a statement of “good” or “poor” (must be a value statement).*
C/A: Response contains a value statement supported by either physics (point sources, looks like a surface) or graph (close alignment of points, or data does not follow linear trend predicted by Coulomb’s law).
HMA: Response contains both options and provides support for why both are possible.

Electron Storage Ring

Item Introduction

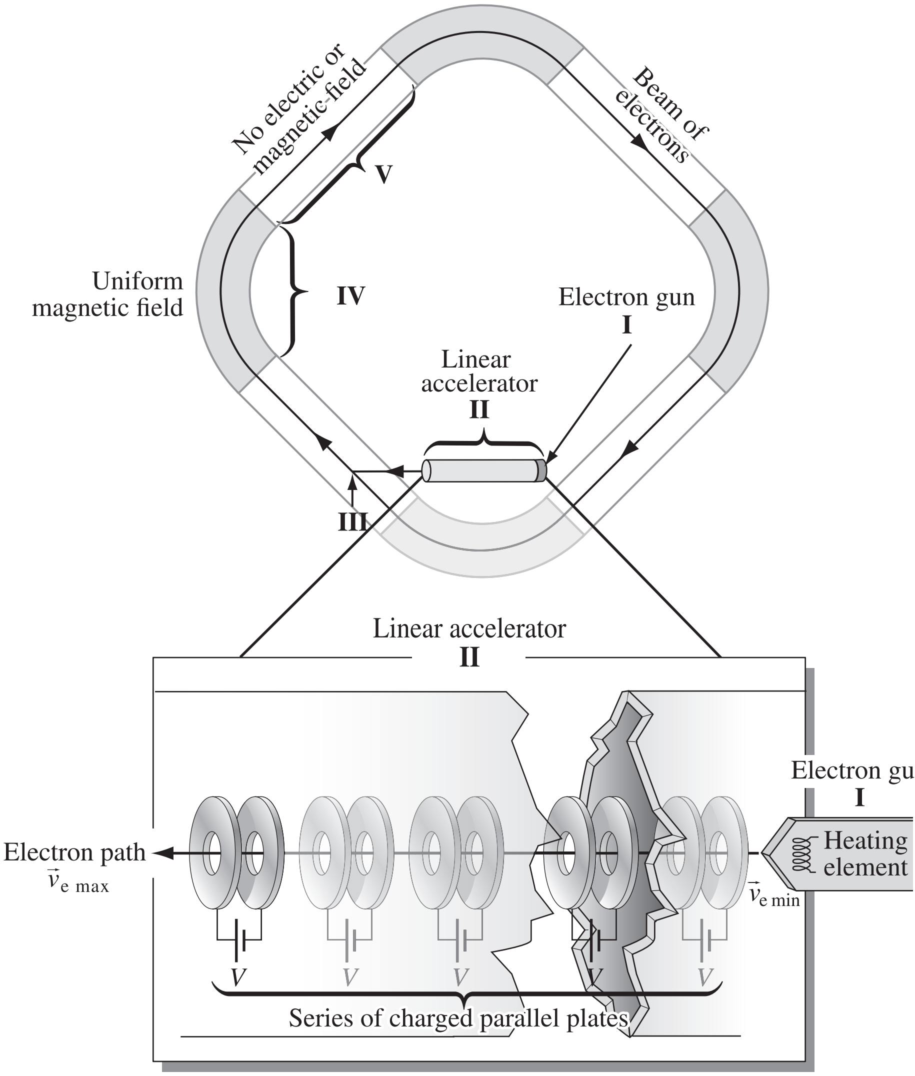
This is a mid-level difficulty formative-assessment item. Students should be able to respond to the full scope of the question in 25 minutes.

This item explores the application of physics 30 to a real-world technology. One of the significant ideas in this item is the level of explanation that the students provide when they explain the application of a hand rule.

This item explores concepts from Physics 30 units B2, B3, and C1.

Use the following information to answer the next question.

A particle accelerator uses a storage ring for a beam of electrons, as shown in the diagram below. This entire apparatus is in a vacuum.



A large number of electrons are boiled off the heating element in the electron gun at I. They have their lowest speed at this location in the storage ring apparatus. When the linear accelerator is activated, the large number of electrons are collected together and form a packet. The packet enters the linear accelerator, II, where it passes through small holes in a series of parallel plates and is accelerated by successive electric potential differences. It leaves the accelerator at its highest speed. The packet is transferred to the storage ring at III by a non-uniform electric field. Once in the ring, the packet of electrons encounters a uniform magnetic field labelled IV, followed by a region with no significant fields, labelled V. This sequence of magnetic field followed by no fields is repeated as the packet travels around the storage ring.

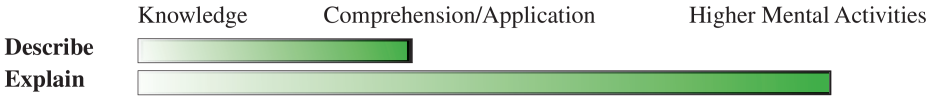
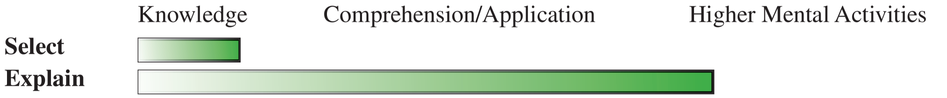
1. Using the concepts of electric and magnetic fields, energy, and electromagnetic radiation, **analyze** the design and function of the storage ring apparatus. In your response,

   - **draw** and **label** an arrow showing the direction of the electric field between one set of parallel plates in the linear accelerator. **Support** your diagram
   - **describe** the changes that occur to the kinetic energy of an electron in the packet as it travels from I to just before it leaves V. **Explain** why these changes occur
   - **select** two labelled locations or regions in the storage ring diagram above where electromagnetic radiation would be emitted by the electron packet. **Explain** why electromagnetic radiation would be emitted at these locations or regions
   - **identify** the direction of the external magnetic field in IV. **Explain** how you determined this direction
   - **describe** two methods to generate an external magnetic field. **Justify** the use of one method rather than the other for generating the field at IV.

Student Name____________________

Peer Feedback—Electron Storage Ring

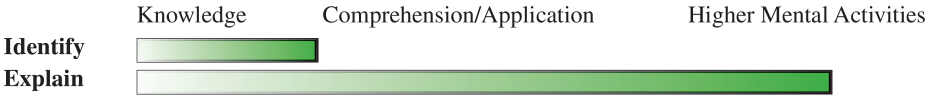
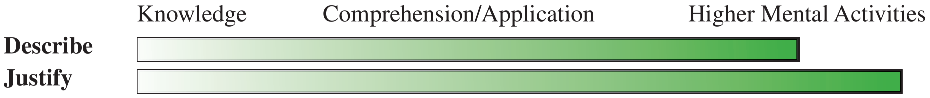
Reviewer's Name____________________

Draw and **label** an arrow showing the direction of the electric field between one set of parallel plates in the linear accelerator. **Support** your diagram. (P30–B2.6k, B2.2s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Describe the changes that occur to the kinetic energy of an electron in the packet as it travels from I to just before it leaves V. **Explain** why these changes occur (P30–B2.9k, B2.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Select two labelled locations or regions in the storage ring diagram above where electromagnetic radiation would be emitted by the electron packet. **Explain** why electromagnetic radiation would be emitted at these locations or regions. (P30–B2.8k, B3.5k, C1.1k, B2.3s, B3.3s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Student Name____________________

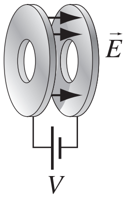
Peer Feedback—Electron Storage Ring – continued

Reviewer's Name____________________

Identify the direction of the external magnetic field in IV. **Explain** how you determined this direction. (P30–B3.5k, B3.2s)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Describe two methods to generate an external magnetic field. **Justify** the use of one method rather than the other for generating the field at IV. (P30–B3.3k, B3.3sts)	 **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	

Sample Response and Commentary for Teachers

The electric field between sets of parallel plates looks like this:



The plate on the left is positively charged because it is connected to the long leg of the electric potential source.

Or

The electric field direction is defined as the direction of the force on a positive test charge. Since electrons are negatively charged, they experience a force in the opposite direction. Since electrons are accelerating to the left, they experience a force to the left, so the electric field is to the right.

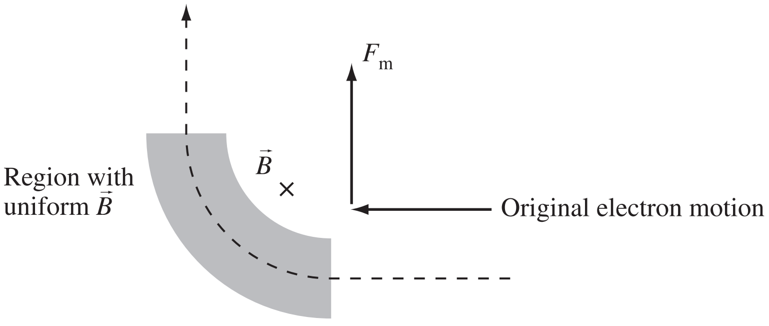
An electron at I has its minimum kinetic energy. As the electron accelerates in the linear accelerator, its speed increases, so its kinetic energy increases. This increase can be described using the work-energy theorem $\Delta E = \frac{V}{q}$, where $\Delta E = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$ and $v_i = 0$, or using the principle that an unbalanced force causes acceleration, where $F = ma$, $a = \frac{v_f - v_i}{t}$, $|\vec{E}|q = \frac{Vq}{d}$, and $E_k = \frac{1}{2}mv_f^2$. At III, the electron's kinetic energy could increase, if a portion of the non-uniform electric field is parallel (or opposite to) the electron's velocity; if the non-uniform electric field is radial, then the electron's speed won't change, and it won't have a change in its kinetic energy. At IV, the circular motion of the electron means that its velocity changes, but not its speed, so its kinetic energy does not change. Finally, in V there are no forces acting, so there is no change in the kinetic energy of the electron.

Note: *K: A response demonstrates this level by stating that the kinetic energy increases in the linear accelerator. It is likely that a response at this level will also describe a decrease in kinetic energy at III or IV.*
C/A: A response demonstrates this level by describing how the electric potential difference causes an increase in the electrons' kinetic energy.
HMA: A response demonstrates this level by supporting the analysis with equations or verbal descriptions of the applicable physics. The response will also contain explicit analysis of how circular motion does not change speed, because the force and displacement are perpendicular, so the force does no work.

Electromagnetic radiation is produced at any location where the electrons are accelerated. Acceleration is a change in velocity, which is a magnitude and a direction. The magnitude of the velocity changes in the linear accelerator, and the direction changes at III and IV. The heater that boils the electrons off also emits EMR, in the form of infrared radiation.

Note: *K: Identifies valid locations.*
C/A: Identifies valid locations and supports by stating the electrons are accelerating at those locations.
HMA: Identifies locations, supports with electrons accelerating and describes the type of acceleration (change in speed or change in direction).

The external magnetic field direction at IV is determined using a hand rule. Use the left hand because electrons are negatively charged, where the thumb points in the direction of the electron motion, the palm faces in the direction of the force, and the index finger points in the direction of the magnetic field. The thumb points to the left of the page and the palm faces the top of the page, indicating the path curves upward, and resulting in the fingers pointing into the page. Thus, the direction of the magnetic field is into the page.



× indicates $\vec{B}$ into the page

Note: *K: States into the page.*
C/A: States into the page and identifies the use of a hand rule.
HMA: States into the page, explicitly describes the application of the different parts of the hand to this particular situation such that the reader could reproduce the observation.

Generating magnetic fields.

One way to make an external field is to use large, permanent magnets. A second way is to use current-carrying conductors.

An advantage of permanent magnets is that they have a constant magnetic field strength, and the magnetic field is stable. An advantage of electromagnets is that they are adjustable and can be turned on and off so that the magnetic field is easier to work with, and the magnetic fields that can be produced are very, very strong.

Permanent magnets have the following disadvantages: they are not very strong; they require special materials to be made; they are very bulky for their strength. Electromagnets have the following disadvantages: they require high levels of electrical power, so they are expensive to operate, and they require special conditions to function (supercooled coils, for example).

The current-carrying conductors (electromagnets) are preferable because they make stronger magnetic fields, which are adjustable and can be turned off.

Note: *K: A response demonstrates the knowledge level by identifying two ways of producing a magnetic field.*
C/A: A response demonstrates a C/A level by providing true statements about the different ways of making magnetic fields, but does not address which method is better.
HMA: A response achieves the HMA level by identifying the methods, providing statements that compare the methods, and providing explicit support regarding which method is better.

Crank Flashlight

Item Introduction

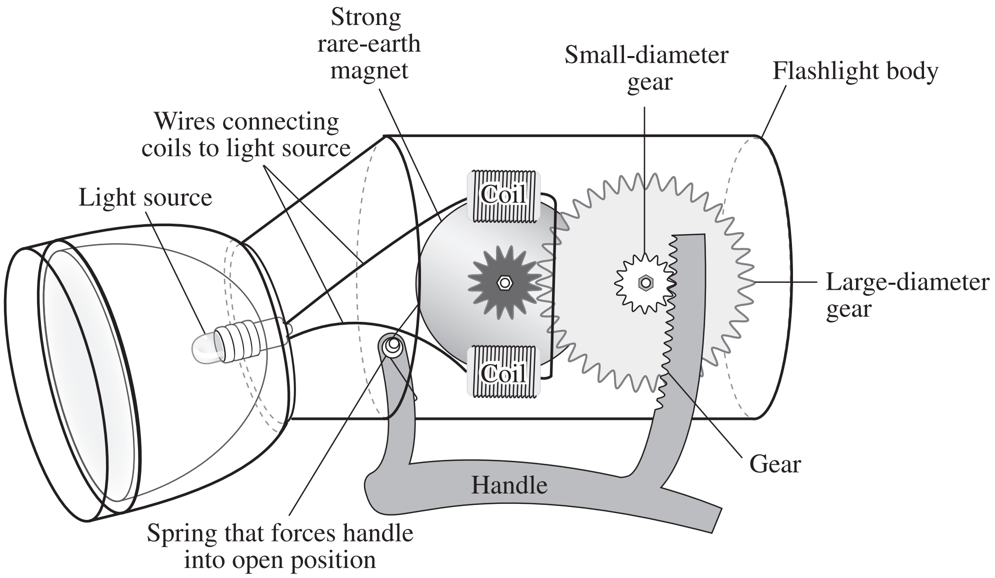
This is a mid-level formative assessment item, slightly less demanding than the storage ring. Students should be able to respond to the full scope of the question in 20 minutes.

What makes this item interesting is that the graph of the observations is perfectly linear, but the graph that applies a physics model is not. It is intended that the honors-level students understand that physics models have strengths and weaknesses. Because of this, there are times in the real world where the physics models make accurate predictions, and situations in which they do not. One of the goals of science is to figure out when the models are good, and if they are not good, how they can be made better.

This item explores concepts from Physics 30 units B3, C1, and C2.

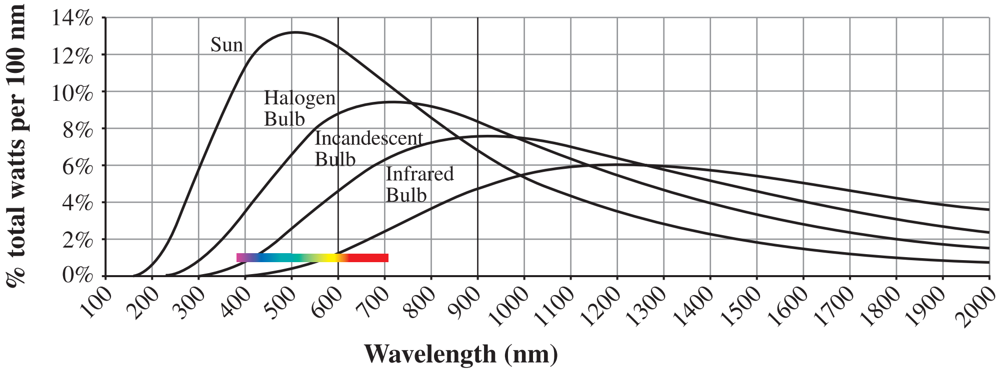
Use the following information to answer the next question.

The following diagram illustrates a flashlight that does not require batteries for power.

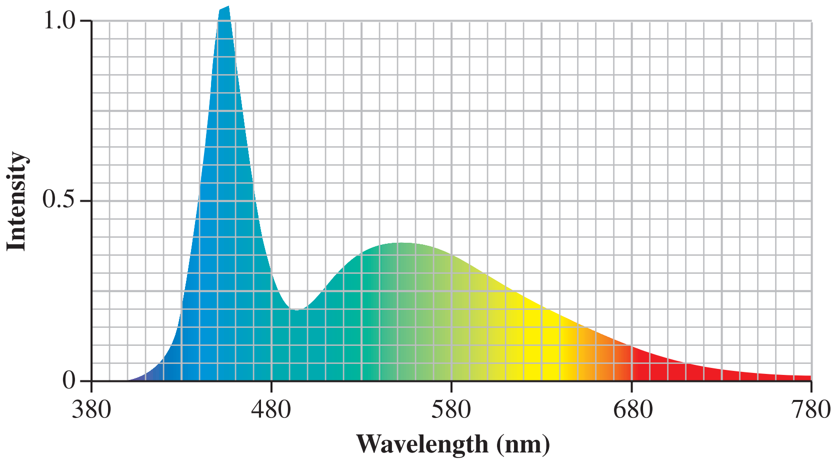


The flashlight’s light source can be either an incandescent bulb or an LED (light emitting diode). The incandescent bulb has a tungsten filament that glows when it is heated to 3 300 K. The LED emits light when electrons that have the same or more energy than the energy gap in the diode cross the gap.

The following graphs show the emission spectra of various incandescent bulbs and LEDs.



Incandescent



LED

1. Using the physics concepts of electromagnetic induction, experimental design, electromagnetic radiation, and STS applications, **analyze** the design and function of this flashlight. In your response,

- **explain** how spinning the magnet generates an electric current in the coils
- **identify** the nature of the charge that moves in the coils. **Support** your answer
- **design** a procedure that could be followed to observe the spectra described by the graphs above
- **compare** the spectrum from the incandescent bulb to that from the LED
- **evaluate** the efficiency of each of the the two light sources
- **predict** one change to the design above that would improve the flashlight's usefulness or efficiency. **Explain** how this change would have that effect. Include advantages and disadvantages associated with this change

Student Name____________________ **_Peer Feedback—Crank Flashlight_** Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Explain how spinning the magnet generates an electric current in the coils. (P30–B3.9k, B3.3sts)	Knowledge Comprehension/Application Higher Mental Activities **Explain** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Identify the nature of the charge that moves in the coils. **Support** your answer. (P30–B3.7k, B3.8k, B3.2s)	Knowledge Comprehension/Application Higher Mental Activities **Identify** **Support** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Design a procedure that could be followed to observe the spectra described by the graphs above. (P30–C1.6k, C1.8k, C1.1s)	Knowledge Comprehension/Application Higher Mental Activities **Design** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Student Name____________________

Peer Feedback—Crank Flashlight – continued

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Compare the spectrum from the incandescent bulb to that from the LED. (P30–C1.2k, C2.2k, C1.3s)	Knowledge Comprehension/Application Higher Mental Activities **Compare**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Evaluate the efficiency of each of the the two light sources. (P30–C2.2k)	Knowledge Comprehension/Application Higher Mental Activities **Evaluate**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Predict one change to the design above that would improve the flashlight's usefulness or efficiency. **Explain** how this change would have that effect. Include advantages and disadvantages associated with this change (P30–C2.3sts)	Knowledge Comprehension/Application Higher Mental Activities **Predict**  **Explain**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Sample Response and Commentary for Teachers

The spinning magnet causes magnetic field lines to “cut” across the conductors in the coils. The changing magnetic field causes a force to act on charges in the wire. Electrons are free to move and are forced to one end of the coil. This charge motion is an electric current.
or
The spinning magnet causes magnetic field lines to “cut” across the conductors in the coils. The conductors induce a magnetic field that resists the changing external field. To do this, charges that are free to move in the conductors, namely electrons, move in the coils. The moving charges create a magnetic field.

Note: *K: States that a changing magnetic field induces a current to flow in a conductor.*
C/A: Relates the changing magnetic field to an induced magnetic field (either F or E or V).
HMA: Explicitly communicates the relationship between the changing magnetic field and the cause of electron motion.

The reason that electrons are free to move is that the positive charge carriers, the protons, are bound in the nucleus.
or
Electrons move one way in the circuit. As they move, they leave behind positively charged “holes”. The holes migrate in the opposite direction to that of the electrons. Protons remain fixed within the nucleus.

Note: *K: States electrons move.*
C/A: States electrons are free to move and protons are fixed in the nucleus.

These spectra can be observed using either a diffraction grating or a prism. In either case, electronic detectors will be required because both light sources emit light outside the visible region. In addition to being able to detect a wide range of wavelengths, the detectors also need to be able to measure intensity at various wavelengths.

To produce the spectrum, direct the light onto the diffraction grating, or prism, and observe the spectrum on a screen. For a diffraction grating, the longer wavelengths will diffract more. For a prism, the longer wavelengths will refract less.

Note: *K: Identifies either diffraction grating or prism, and describes sending the light through the apparatus.*
C/A: Identifies either a diffraction grating or a prism, describes sending the light through the apparatus, and describes the characteristics of the detectors.

The spectra are very similar in that there are peak outputs, long tails at either end, and a range of emitted wavelengths. They also both contain the visible portion of the EMR spectrum. They are different in that the LED spectrum is much narrower, and the LED spectrum has two peaks.

Note: *K: States two or more similarities.*
C/A: Provides both similarities and differences.

Efficiency is the ratio of useful energy out to energy in. The LED is much more efficient because much more of its energy out is in the form of useful energy.

Note: *K: Defines efficiency and states the LED is efficient (not more efficient – statement of truth but not of value).*
C/A: Defines efficiency and states the LED is more efficient (or that the incandescent bulb is less efficient).
HMA: Defines efficient, states the LED is more efficient, and provides support in terms of useful energy produced based on information in graphs.

Possible changes, advantages, and disadvantages

Change	Effect	Advantage	Disadvantage
Stronger magnets	Brighter light	Greater current with less spinning, might need less wire in coils, so lighter and cheaper	Harder to crank because of greater back EMF, might be heavier, stronger magnets might be more expensive
Larger coils	Brighter light	Greater current with same spinning	Harder to crank because of greater back EMF, might be heavier, might be more expensive because of the price of copper
Larger storage device	Light shines after cranking has stopped	Less cranking to keep light shining	Potential safety risk of significant shock if storage device is shorted
More light bulbs	Bright light	More light, flashlight lasts longer because it still emits light after one or several bulbs stop working	Increased cranking required, more costly to produce more bulbs

Note: *K: Identifies a change.*
C/A: Identifies a change, provides a reason or effect, and an advantage or disadvantage.
HMA: Identifies a change, provides a reason or effect and advantages and disadvantages.

Green Laser Pointer

Item Introduction

This is the least challenging formative assessment item in the Physics 30 set. Students should be able to provide a reasonable response to the full scope of the item in 20 minutes.

This item was included to illustrate how classroom technology such as a cellphone camera or a web camera could be used to allow students to “see” invisible infrared radiation. CAUTION: If you do this investigation with your students, be sure that the detectors are directed toward reflected light. If you do not have a green laser pointer, students can still use the technology to observe infrared radiation by using a remote control as the light source.

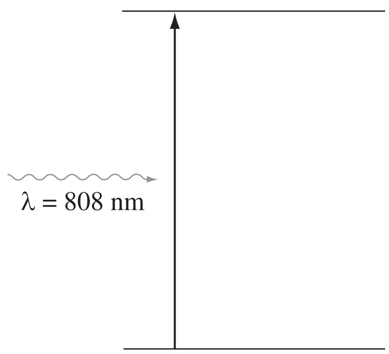
This item explores concepts from Physics 30 units C1, C2, and D2.

Use the following information to answer the next question.

Inexpensive green laser pointers can emit dangerous, high-intensity electromagnetic radiation (EMR) other than the expected green light they are designed to produce. Safety standards are in place so that only pointers that pass the tests can be sold in Canada.

Green laser pointers use a pumping diode to produce EMR that has a wavelength of 808 nm. This light is absorbed by the lasing material that re-emits it as light that has a wavelength of 1 064 nm.

Incomplete Energy Level Diagram of the Lasing Material

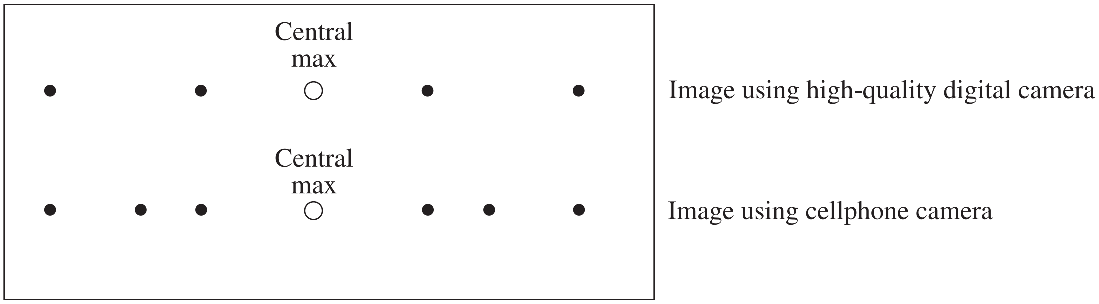


This light is then absorbed by a KTP crystal. KTP crystals have the special property of absorbing high-intensity EMR of a certain frequency and re-emitting the energy at half the intensity and twice the frequency.

Experimental Set-Up

The following procedure was followed to observe the EMR being emitted by an inexpensive green laser pointer. NOTE: if you attempt this procedure, follow all laser-related safety protocols, do not look directly at the laser source, and protect your eyes from dangerous EMR. Use digital equipment to make the observations.

The laser pointer was set up so that light from the pointer travelled through a small hole in a piece of paper and onto a CD. The light reflected off the CD and produced an interference pattern observed on the piece of paper. The following image represents the pattern as photographed by a cellphone camera and by a high-quality digital camera. In both spectra, the laser source is in the location of the central maximum.



1. Using the concepts of electromagnetic radiation, conservation of energy, and design, **analyze** the green laser technology described on the previous page. In your response,

   - **classify** the three types of EMR described on the previous page: that produced by the pumping diode, that emitted by the lasing material, and that emitted by the KTP crystal. **Identify** the potentially dangerous EMR, and **explain** why it is dangerous
   - **complete** the energy level diagram by indicating the relative location of the third energy level. **Determine** the efficiency of the lasing material
   - **compare** the energy and the speed of a photon absorbed by the KTP crystal to those of a photon emitted by the KTP crystal
   - **compare** the interference patterns, and **label** the order number for the antinodes shown in the diagram on the previous page
   - **predict** a design feature that could be added to an inexpensive green laser pointer so that it could be sold in Canada. Hint: What is different between the cellphone camera and the high-quality digital camera? **Describe** how your design feature would work.

Student Name____________________

Peer Feedback—Green Laser Pointer

Reviewer's Name____________________

Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	**Looking Back**
Classify the three types of EMR described on the previous page: that produced by the pumping diode, that emitted by the lasing material, and that emitted by the KTP crystal. **Identify** the potentially dangerous EMR, and **explain** why it is dangerous. (P30–C1.2k, C2.2k, C2.3sts)	Knowledge Comprehension/Application Higher Mental Activities **Classify** **Identify** **Explain**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Complete the energy level diagram by indicating the relative location of the third energy level. **Determine** the efficiency of the lasing material. (P30–D2.5k, C2.1k, D2.2sts)	Knowledge Comprehension/Application Higher Mental Activities **Complete** **Determine**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Compare the energy and the speed of a photon absorbed by the KTP crystal to those of a photon emitted by the KTP crystal. (P30–C1.2k, C2.2k, C1.2sts)	Knowledge Comprehension/Application Higher Mental Activities **Compare**  **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Student Name____________________

Peer Feedback—Green Laser Pointer – continued

Reviewer's Name____________________

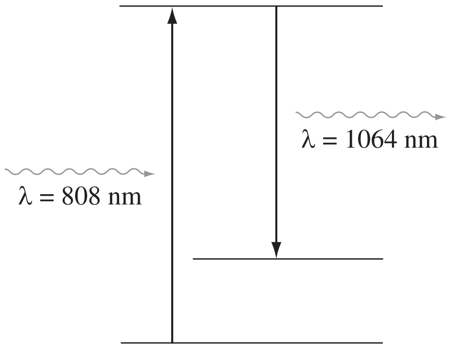
Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Compare the interference patterns, and **label** the order number for the antinodes shown in the diagram on the previous page. (P30–C1.10k, C1.2s)	 Knowledge Comprehension/Application Higher Mental Activities **Compare** **Label** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…
Predict a design feature that could be added to an inexpensive green laser pointer so that it could be sold in Canada. Hint: What is different between the cellphone camera and the high-quality digital camera? **Describe** how your design feature would work. (P30–C1.2sts)	 Knowledge Comprehension/Application Higher Mental Activities **Predict** **Describe** **Peer Feedback:** I've placed an "x" on the bar to indicate the level of your response. I set the level there because I noticed that…	**Changes that I am going to make** to my response…

Sample Response and Commentary for Teachers

The initial EMR, with a wavelength of 808 nm, is infrared. The lasing material emits EMR with a wavelength of 1 064 nm, which is also infrared. The KTP crystal emits EMR with a wavelength of 532 nm, which is green visible light. The potentially dangerous EMR is the infrared because it can heat up and burn living tissue.

Note: *K: Classifies 808 nm and 1 064 nm as infrared.*
C/A: Classifies 808 nm and 1 064 nm as infrared, provides calculations to support the KTP crystal's emission of 532 nm EMR and classifies it as visible, or omits the calculations, identifies that IR is the harmful EMR and links IR to burns.
HMA: Classifies 808 nm and 1064 nm as infrared, provides calculations to support the KTP crystal's emission of 532 nm, and explains how IR can do harm.

The emitted wavelength is 1 064 nm, which is longer than 808 nm. That means it has less energy because $E = \frac{hc}{\lambda}$. The diagram looks like this:



The efficiency of the lasing material is

$$\text{Efficiency} = \frac{E_{\text{out}}}{E_{\text{in}}} \times 100\%$$

$$= \frac{\frac{hc}{\lambda_{\text{out}}}}{\frac{hc}{\lambda_{\text{in}}}} \times 100\%$$

$$= \frac{808\text{ nm}}{1\,064\text{ nm}} \times 100\%$$

$$\text{Efficiency} = 75.9\%$$

The speed of the photons absorbed by the KTP crystal and those emitted by the crystal is the same: 3.00×10^8 m/s. The energy of the emitted photons is twice that of the absorbed photons because $E = hf$, and twice the frequency means twice the energy. Half the intensity makes sense, then, because intensity is roughly the count of the number of photons. If each photon carries twice the energy, then there need to be half as many to carry the same total energy.

The interference patterns are similar in that they are symmetrical and have the laser pointer at the central maximum.

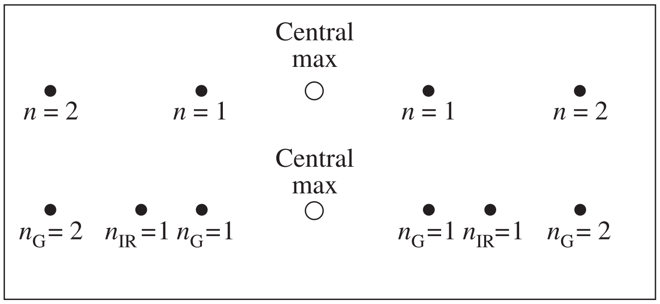


Image using high-quality digital camera

Image using cellphone camera

The green-visible pattern is narrower than the IR pattern because the diagram shows the second order maxima for green, but only the first order for the IR in the second pattern. This makes sense because longer wavelengths will diffract more so that the longer IR wavelengths will have a first order maximum further from the central maximum than the green light does.

The easiest design feature is a green filter that allows only green light through. (**Note:** Need to specify whether filter blocks or transmits the particular light. For example, an IR filter might block IR, while a green filter transmits green.) This addition would make the laser pointer safe because only the non-harmful green light would emerge from the apparatus.

Note: *K: Identifies a filter.*
C/A: Identifies a filter, describes the filter in terms of what it blocks or transmits and, based on this function, describes how the harmful IR EMR cannot escape from the pointer.

Compton Scattering

Item Introduction

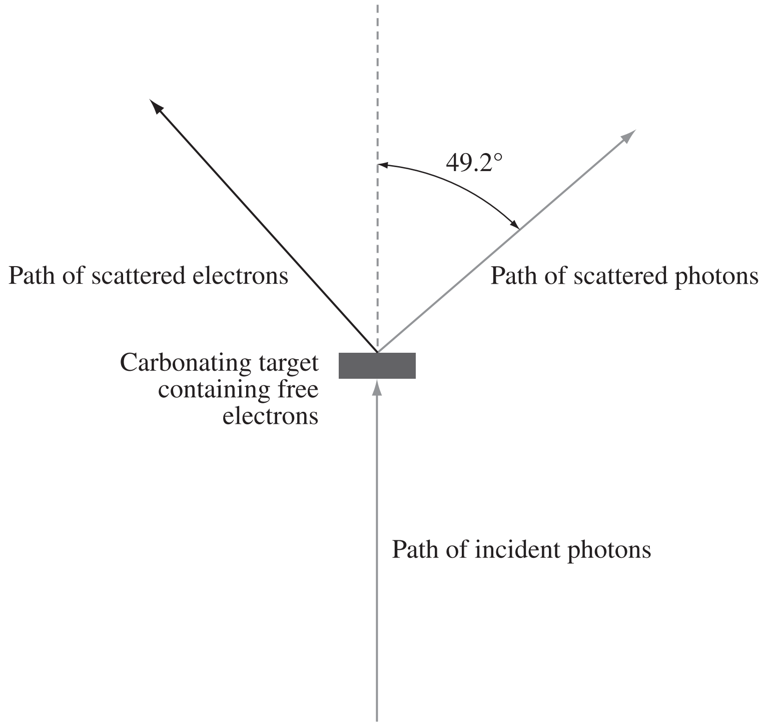
This item is designed to explore 2-D analysis. Students should be able to provide a complete response in 15 minutes.

This item is included so that students are able to review the process of verification.

This item explores concepts from Physics 30 units A1 and C2.

Use the following information to answer the next question.

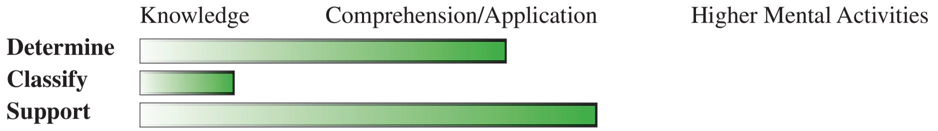
An incident X-ray photon has a momentum of 9.35×10^{-24} J·s/m. It interacts with an initially stationary free electron. The scattered X-ray photon has a momentum of 9.27×10^{-24} J·s/m, 49.2° from the incident photon's direction.



1. Using the physics principles of conservation of momentum, conservation of energy, and wave-particle duality, **analyze** the interaction described above. In your response,

   - using 2-D vector analysis, **determine** the momentum of the scattered electron
   - **determine** the energy of the scattered electron. **Classify** the interaction described above. **Support** your classification.

Student Name____________________ ## *Peer Feedback—Compton Scattering* Reviewer's Name____________________

<table>
<tr><th>Program Links to Tasks in this Question</th><th>The horizontal bar indicates the scope required in the response.
Place an “x” on the bar to indicate the level demonstrated in the response.</th><th>Looking Back</th></tr>
<tr><td>Using 2-D vector analysis, determine the momentum of the scattered electron.
(P30–A1.4k, A1.3s, C2.6k)</td><td>
<table>
<tr><th></th><th>Absent</th><th>Present with error(s)</th><th>Present and correct</th></tr>
<tr><td>Reference Direction</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Vector Conventions</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Physics Principles</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Formula(s)</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Substitutions</td><td>○</td><td>○</td><td>○</td></tr>
<tr><td>Consistent Answer</td><td>○</td><td>○</td><td>○</td></tr>
</table>
Peer Feedback: I've placed an “x” on the circles to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
<tr><td>Determine the energy of the scattered electron. Classify the interaction described above. Support your classification.
(P30–A1.5k, C2.6k)</td><td>


Peer Feedback: I've placed an “x” on the bar to indicate the level of your response.
I set the level there because I noticed that…</td><td>Changes that I am going to make to my response…</td></tr>
</table>

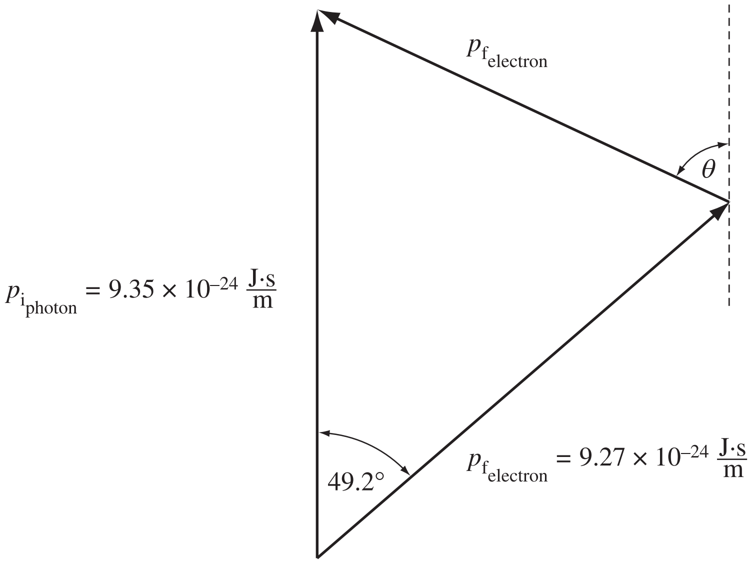
Sample Response and Commentary for Teachers

Find momentum of scattered electron.

Momentum is conserved in an isolated system.

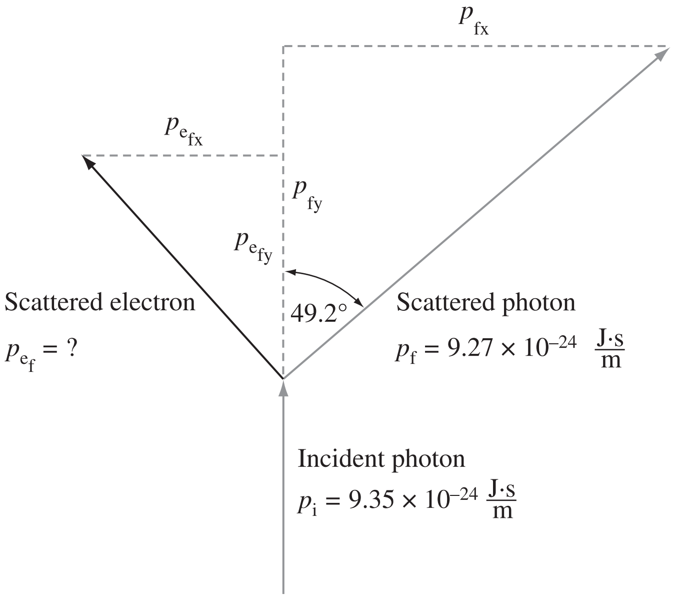
Method 1 – Scaled Vector Addition

Using scale of 1 cm = 1.0×10^{-24} J·s/m, one gets



Measuring the scattered electron vector shows that $p_{\text{e}_\text{f}} = 7.75 \times 10^{-24}$ J·s/m, 65° from the incident X-ray's direction.

Method 2 – Components



$$\vec{p}_i = \vec{p}_f$$

$$p_{i\,x} = p_{f\,x}$$
$$p_{i\,x} = 0$$
$$p_{f\,x} = p_{f\,x\text{ photon}} + p_{f\,x\text{ electron}}$$

$$\begin{aligned} p_{f\,x\text{ photon}} &= p_p \bullet \sin\theta \\ &= (9.27 \times 10^{-24}\ \text{J·s/m}) \times \sin 49.2° \\ &= 7.0173 \times 10^{-24}\ \text{J·s/m} \end{aligned}$$

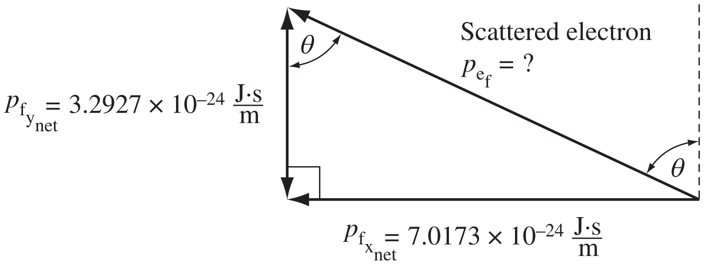
$$\begin{aligned} p_{f\,x\text{ electron}} &= p_{i\,x} - p_{f\,x\text{ photon}} \\ &= 0 - 7.0173 \times 10^{-24}\ \text{J·s/m} \\ &= -7.0173 \times 10^{-24}\ \text{J·s/m} \end{aligned}$$

$$p_{\text{i y}} = p_{\text{f y}}$$
$$p_{\text{i y}} = 9.35 \times 10^{-24} \text{ J·s/m}$$

$$p_{\text{f y}} = p_{\text{f y photon f}} + p_{\text{f y electron}}$$

$$\begin{aligned} p_{\text{f y photon}} &= p_{\text{f}} \bullet \cos\theta \\ &= (9.27 \times 10^{-24} \text{ J·s/m}) \times \sin 49.2° \\ &= 6.057 \times 10^{-24} \text{ J·s/m} \end{aligned}$$

$$\begin{aligned} p_{\text{f y electron}} &= (9.35 \times 10^{-24} \text{ J·s/m}) - (6.057 \times 10^{-24} \text{ J·s/m}) \\ &= 3.2927 \times 10^{-24} \text{ J·s/m} \end{aligned}$$



$$\begin{aligned} p_{\text{f e}} &= \sqrt{{p_{\text{f x e}}}^2 + {p_{\text{f y x}}}^2} \\ &= \sqrt{(7.0173 \times 10^{-24} \text{ J·s/m})^2 + (3.2927 \times 10^{-24} \text{ J·s/m})^2} \\ &= 7.75 \times 10^{-24} \text{ J·s/m} \end{aligned}$$

$$\tan\theta = \frac{p_{\text{f x e}}}{p_{\text{f y e}}}$$

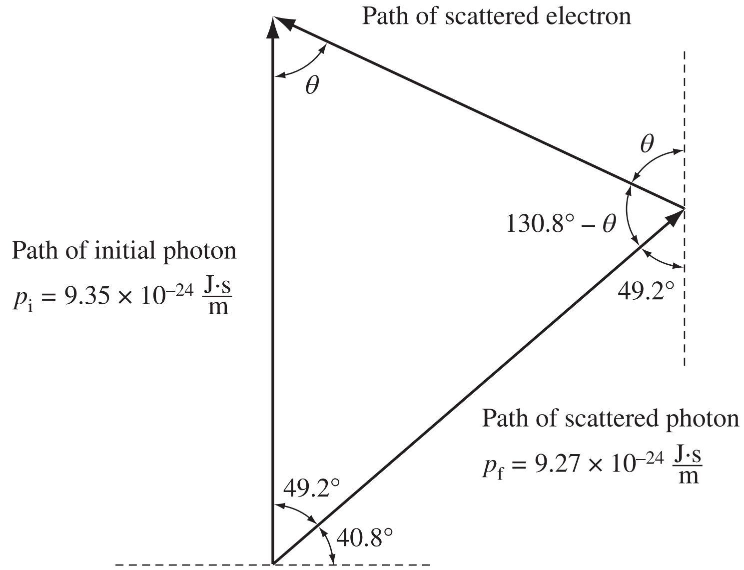
$$\theta = \tan^{-1}\left(\frac{7.0173 \times 10^{-24} \text{ J·s/m}}{3.2927 \times 10^{-24} \text{ J·s/m}}\right)$$

$$= 65°$$

$$\therefore\ p_{\text{e}_\text{f}} = 7.75 \times 10^{-24} \text{ J·s/m, } 65° \text{ from the incident photon's direction}$$

Method 3 – Cosine Law and Sine Law

Note: This solution uses mathematics **not** mandated by the program of studies.



$$a^2 = b^2 + c^2 - 2bc\cos A$$

$$p_{e_f}{}^2 = p_{\text{photon i}}{}^2 + p_{\text{photon f}}{}^2 - 2p_{\text{photon i}} \times p_{\text{photon f}} \times \cos 49.2°$$

$$p_{e_f}{}^2 = (9.35 \times 10^{-24}\ \text{J·s/m})^2 + (9.27 \times 10^{-24}\ \text{J·s/m})^2$$
$$- 2(9.35 \times 10^{-24}\ \text{J·s/m})^2 \times (9.27 \times 10^{-24}\ \text{J·s/m})^2 \times \cos 49.2°$$

$$p_{e_f} = 7.751489 \times 10^{-24}\ \text{J·s/m}$$

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

$$\frac{\sin\theta}{p_{\text{photon f}}} = \frac{\sin 49.2°}{p_{e_f}}$$

$$\sin\theta = \frac{(\sin 49.2°)(9.27 \times 10^{-24}\ \text{J·s/m})}{7.751489 \times 10^{-24}\ \text{J·s/m}}$$

$$\sin\theta = 0.9052898$$
$$\theta = 64.8623°$$
$$\theta = 65°$$

The momentum of the scattered electron is 7.75×10^{-24} J·s/m at an angle of 65° to the incident photon's direction.

Finding energy of scattered electron

$$p = mv$$

$$v = \frac{p}{m}$$

$$= \frac{7.751489 \times 10^{-24} \text{ J·s/m}}{9.11 \times 10^{-31} \text{ kg}}$$

$$= 8.508769 \times 10^{6} \text{ m/s}$$

$$E_\text{k} = \frac{1}{2}mv^2$$

$$= \frac{1}{2}(9.11 \times 10^{-31} \text{ kg})(8.508769 \times 10^{6} \text{ m/s})^2$$

$$= 3.29778165 \times 10^{-17} \text{ J}$$
$$= 3.230 \times 10^{-17} \text{ J}$$

Classify interaction:

Elastic $E_\text{k i} = E_\text{k f}$ Inelastic $E_\text{k f} < E_\text{k i}$

$$E_\text{k i} = E_\text{photon i}$$
$$= pc$$
$$= (9.35 \times 10^{-24} \text{ J·s/m})(3.00 \times 10^{8} \text{ m/s})$$
$$= 2.805 \times 10^{-15} \text{ J}$$

$$E_\text{k f} = E_\text{photon f} + E_\text{k electron}$$
$$= pc + (3.30 \times 10^{-17} \text{ J})$$
$$= (9.27 \times 10^{-24} \text{ J·s/m})(3.00 \times 10^{8} \text{ m/s}) + (3.30 \times 10^{-17} \text{ J})$$
$$= 2.814 \times 10^{-15} \text{ J}$$
$$= 2.81 \times 10^{-15} \text{ J}$$

Since $E_\text{k i} = E_\text{k f}$ the interaction is elastic.

Note: The following response contains a fundamental flaw in logic.

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

$$E_{\text{photon i}} = E_{\text{photon f}} + E_{\text{k electron}}$$

$$p_{\text{i}}c = p_{\text{f}}c + E_{\text{k electron}}$$

$$(9.35 \times 10^{-24}\ \text{J}\cdot\text{s/m})(3.00 \times 10^{8}\ \text{m/s}) = (9.27 \times 10^{-24}\ \text{J}\cdot\text{s/m})(3.00 \times 10^{8}\ \text{m/s}) + (3.30 \times 10^{-17}\ \text{J})$$

$$2.805 \times 10^{-15}\ \text{J} = 2.81 \times 10^{-15}\ \text{J}$$

Therefore the interaction is elastic.

The flaw is in the **assumption** that energy is conserved. This is not known until it is determined.

Physics 30 Summative Assessment

Two holistic style questions designed for summative assessment

Evolution of the Atomic Model

Question

Use the following information to answer this holistic question.

> Scientific theories are continually being revised. Sometimes a new theory is inconsistent with an existing theory; in other cases, new observations are made that cannot be explained by an existing theory. In either situation, the existing theory has to be revised or replaced.
>
> Rutherford's planetary model of the atom was revised for two reasons: it was inconsistent with Maxwell's theory of electromagnetism, and it could not explain the observation of line spectra.

Written Response—5 marks

1. **Describe** what led to the revision of Rutherford's planetary model of the atom. In your response, **identify** the main features of Rutherford's planetary model of the atom, and **explain** why revisions were required as a result of Maxwell's theory of electromagnetic radiation and as a result of analysis of line spectra. **Identify** the main features of a revised atomic model that has replaced Rutherford's planetary model of the atom.

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

Scoring Guide for Holistic Questions

Major Concepts: Rutherford Model; Maxwell’s Theory of EMR; Line Spectra; Modern Atomic Model	
Score	**Criteria**
5 **Excellent**	The student provides a complete solution that covers the full scope of the question. • The reader has no difficulty following the strategy or solution presented by the student. • Statements made in the response are supported explicitly but may contain minor errors or have minor omissions. *In the response, the student uses major physics generalizations such as balanced or unbalanced forces and conservation laws. The student applies knowledge from one area of physics to another.*
4 **Good**	The student provides a solution to the significant parts of the question. • The reader may have some difficulty following the strategy or solution presented by the student. • Statements made in the response are supported implicitly and may contain errors. *In the response, the student uses major physics generalizations. The response is mostly complete, mostly correct, and contains some application of physics knowledge.*
3 **Satisfactory**	The student provides a solution in which he/she has made significant progress toward answering the question. • The reader has difficulty following the strategy or solution presented by the student. • Statements made in the response may be open to interpretation and may lack support. *In the response, the student uses item-specific methods that reflect a memorized approach, but the student does not apply them to the question. (For example, the student provides relevant memorized facts but fails to apply them to the situation, technology, experiment, etc., described in the question.)*
2 **Limited**	The student provides a solution in which he/she has made some progress toward answering the question. • Statements made in the response lack support. *In the response, the student uses an item-specific method.*
1 **Poor**	The student provides a solution that contains a relevant statement that begins to answer the question.
0 **Insufficient**	The student provides a solution that is invalid for the question.
NR	No response is given.

**The statements in italics relate the scoring guide to the standard statements developed by the Assessment Sector of Alberta Education.*

Sample Response

Rutherford's planetary model of the atom describes the atom as containing a very small, massive, positively charged nucleus surrounded by electrons orbiting the nucleus in a manner similar to planets orbiting a star.

Maxwell's theory of electromagnetic radiation predicts the failure of the planetary model because electrons orbiting a nucleus in a manner similar to planets orbiting a sun are held in orbit by an unbalanced electrostatic force. An unbalanced force causes acceleration. Therefore, the electrons in Rutherford's planetary model are continuously accelerating and should be continuously emitting electromagnetic radiation. Because they are emitting energy, their orbits should decay, and the atom should collapse.

Line spectra are evidence that atoms emit or absorb energy only in specific energy bands. (This reinforces the idea that the electrons are not continually being accelerated but make only certain transitions.) The specific energies correspond to the change in energy between the unique energy levels of the particular atom involved. This is a very different model from planets moving in stable orbits at any distance around their sun while being continuously accelerated by a perpendicular force.

Features of models that have replaced Rutherford's planetary model:

Rutherford-Bohr planetary model: Electrons exist in quantized, stable, circular orbits called energy levels that do not require an energy release for motion to continue. Energy is absorbed or emitted only when electrons make transitions between these energy levels. The nucleus remains small, massive, and positively charged.

Rutherford-Bohr model with de Broglie: Electrons are wave-particles. There are only certain orbit sizes where the electron wavelength forms a standing wave. To move from one wave configuration to another requires the addition or emission of a bit of energy. The nucleus remains small, massive, and positively charged.

Quantum-mechanical model: Electrons have mass, charge, and wave-particle properties simultaneously. Their actual location is unknown, but their likely location can be estimated using Schroedinger's wave equations. The nucleus contains protons and neutrons. The nucleus is held together by the strong nuclear force, which overcomes the Coulomb electrostatic repulsion between the protons.

Anything beyond this is no longer Physics 30 but could be correct. Markers should verify the correctness of such responses.

Descriptions of student responses at different scores

Criteria for Marks of 5, 4, 3, 2, and 1

A complete answer will answer the full scope of the question. It will contain clear and explicit support for the conclusions drawn. It does not need to be perfect—an error does not necessarily force the response below a score of 5.

- Student explicitly describes Rutherford's model and its main weaknesses. Student describes main ideas of Maxwell's theory, line spectra, and a revised atomic model and explicitly applies Physics 30 concepts to why this revised model is an improvement over Rutherford's model.

A mostly complete, mostly correct response, which is given a mark of 4, contains implied relationships between statements and conclusions. This type of response will also show some application of physics to the information given.

- Student makes true statements about Rutherford's model, Maxwell's theory, line spectra, and a revised model and begins to link ideas together to show a "development" or "evolution" of a more accurate model of the atom. Some connections in the response are implied.

A recall-based response, which is given a mark of 3, is awarded to a response that has correct and appropriate physics but which does not attempt to apply the physics to the situation described in the item.

- Student will likely make true statements about all of the main concepts in the question but may fail to relate them to the question.

Some progress, which is given a mark of 2, requires that the student shows more knowledge. Usually, the ideas will be disjointed. Often they will be surrounded by erroneous information.

- Student addresses two main concepts in the question.

A student response that contains a relevant statement receives a mark of 1. Such a response "begins to answer the question".

- Student addresses one main concept in the question.

Binding Energy

Question

Use the following information to answer the next question.

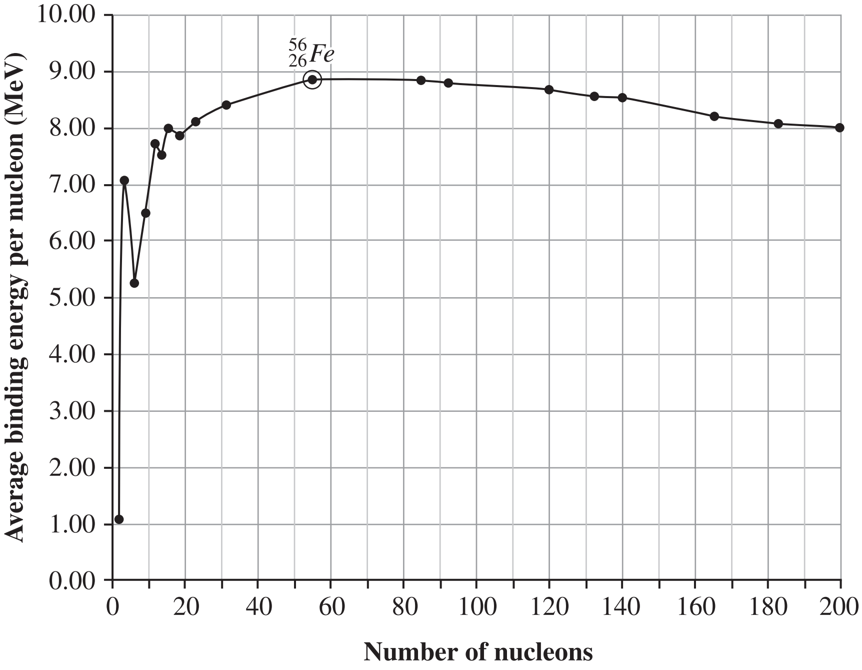
As a star ages it can go through a stage called the alpha process in which elements of increasing nucleon number are formed. The alpha process begins with hydrogen-1 and ends with iron-56. Elements that have a nucleon number greater than that of iron-56 are formed by neutron capture during a supernova event.

Three Steps in the Alpha Process

	Reaction Equation	**Energy Associated with Reaction**
Reaction I	${}^{4}_{2}\text{He} + {}^{4}_{2}\text{He} \rightarrow {}^{8}_{4}\text{Be}$	–92 keV
Reaction II	${}^{8}_{4}\text{Be} + {}^{4}_{2}\text{He} \rightarrow {}^{12}_{6}\text{C}$	7.367 MeV
Reaction III	${}^{12}_{6}\text{C} + {}^{4}_{2}\text{He} \rightarrow {}^{16}_{8}\text{O}$	7.151 MeV

A graph of average binding energy per nucleon as a function of the number of nucleons in a nucleus is given below. The most stable nucleus is iron-56.

Average Binding Energy per Nucleon as a Function of Number of Nucleons



Written Response—5 marks

2. Using the concepts of graphical analysis, mass-energy equivalence, and fundamental forces (strong nuclear force and electrostatic force), **analyze** the graph shown on the previous page. In your response,

- using isotope notation, **label** the dots on the graph that correspond to the nuclei involved in reactions I, II, and III given on the previous page
- **predict** qualitatively how the mass of products compares to the mass of reactants for reactions I and II. **Explain** what the negative sign, -, and the positive sign, +, signify for these two reactions
- **identify** the particles that each of the fundamental forces identified above acts on
- **explain** the characteristics of the nucleus that make it stable.

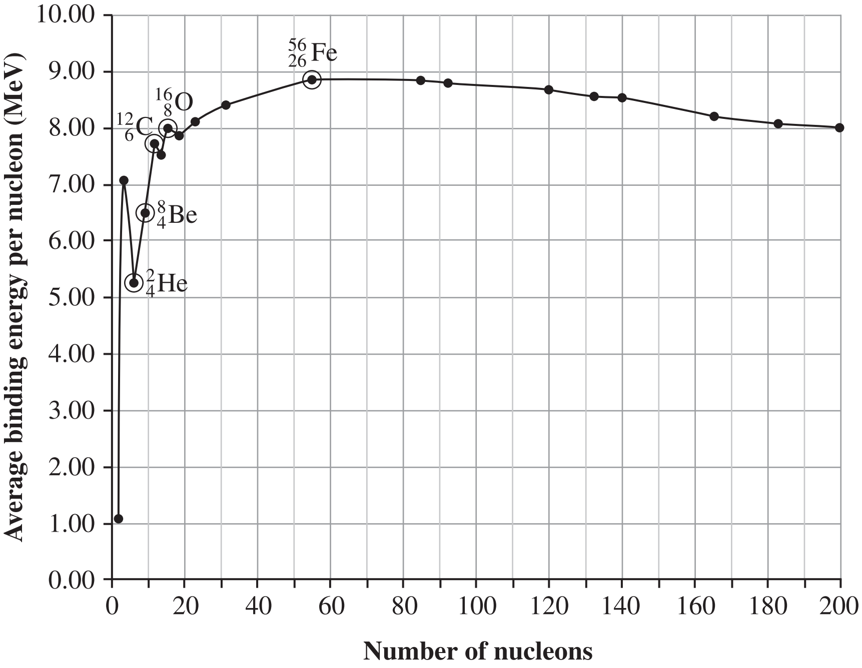
Scoring Guide for Holistic Questions

Major Concepts: Graphical Analysis; Isotope Notation; Mass-Energy Equivalence; Fundamental Forces	
Score	**Criteria**
5 Excellent	The student provides a complete solution that covers the full scope of the question. • The reader has no difficulty following the strategy or solution presented by the student. • Statements made in the response are supported explicitly but may contain minor errors or have minor omissions. *In the response, the student uses major physics generalizations such as balanced or unbalanced forces and conservation laws. The student applies knowledge from one area of physics to another.*
4 Good	The student provides a solution to the significant parts of the question. • The reader may have some difficulty following the strategy or solution presented by the student. • Statements made in the response are supported implicitly and may contain errors. *In the response, the student uses major physics generalizations. The response is mostly complete, mostly correct, and contains some application of physics knowledge.*
3 Satisfactory	The student provides a solution in which he/she has made significant progress toward answering the question. • The reader has difficulty following the strategy or solution presented by the student. • Statements made in the response may be open to interpretation and may lack support. *In the response, the student uses item-specific methods that reflect a memorized approach, but the student does not apply them to the question. (For example, the student provides relevant memorized facts but fails to apply them to the situation, technology, experiment, etc., described in the question.)*
2 Limited	The student provides a solution in which he/she has made some progress toward answering the question. • Statements made in the response lack support. *In the response, the student uses an item-specific method.*
1 Poor	The student provides a solution that contains a relevant statement that begins to answer the question.
0 Insufficient	The student provides a solution that is invalid for the question.
NR	No response is given.

**The statements in italics relate the scoring guide to the standard statements developed by the Assessment Sector of Alberta Education.*

Sample Response

Answer with points labelled



When the sign on the energy is negative, energy is released and the measured mass of the products is less than the measured mass of the reactants. When the sign on the energy is positive, energy is required to cause the reaction to occur. This means matter has to have been put into the system, or the mass of the reactants is less than the mass of the products. The equivalence of mass-energy is modelled by $E = \Delta mc^2$. The delta here means: $m_f - m_i$. This reinforces the idea that a negative means the initial mass is greater.

The strong nuclear force, a fundamental force, acts on nucleons: proton to proton, proton to neutron, and neutron to neutron. The electrostatic force acts on charged objects: proton to proton, or going outside the nucleus, proton to electron and electron to electron.

For a nucleus to be stable, the strong nuclear force holding all the nucleons in the nucleus must be equal to or greater than the electrostatic force of repulsion created by the protons in the nucleus. In general, then, the number of neutrons must increase faster than the number of protons as the nucleus gets larger.

Descriptions of student responses at different scores

Criteria for Marks of 5, 4, 3, 2, and 1 on Binding Energy Question

A complete answer will answer the full scope of the question. It will contain clear and explicit support for the conclusions drawn. It does not need to be perfect – an error does not necessarily force the response below a score of 5.

- Students label all the nuclei on the graph; they support the positive and negative signs mathematically or with reference to the chemistry concepts of exothermic and endothermic; they clearly identify the particles that the two forces act on; they indicate that the strong nuclear force must be greater than the electrostatic force; and they provide a mechanism that would produce that result.

A mostly complete, mostly correct response, which is given a mark of 4, contains implied relationships between statements and conclusions. This type of response will also show some application of physics to the information given.

- The students provide true statements and address either the significance of the sign on the energy or the characteristics of a stable nucleus. Some connections in the response are implied.

A recall-based response, which is given a mark of 3, is awarded to a response that has correct and appropriate physics but which does not attempt to apply the physics to the situation described in the item.

- Students will likely make true statements about all of the main concepts in the question but may fail to relate them to the question.

Some progress, which is given a mark of 2, requires that the student shows more knowledge. Usually, the ideas will be disjointed. Often they will be surrounded by erroneous information.

- Students address two main concepts in the question.

A student response that contains a relevant statement receives a mark of 1. Such a response "begins to answer the question".

- Students address one main concept in the question.