Physics 30

2010 Released Formative Assessment Materials

Government of Alberta

Alberta

Freedom To Create. Spirit To Achieve.

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Contents

Introduction

The goal of these materials is to promote the learning of the mandated *Physics 20-30 Program of Studies, 2007*. Each question in this set of materials is accompanied by a peer feedback form (more on this below) and a sample response. Scoring guides are **not** provided. The learning from peers and formative assessment is centred around meaningful and timely feedback. Limiting feedback to a numerical value has been shown to reduce student engagement.

Descriptions of Items

This package contains several items that started as holistic items but that now have an emphasis on the *explain* bullet points from the program of studies. It also contains a graphing-skills question and a two-dimensional vector-skills question. Each part of each item has a direct tie to the *Physics 20-30 Program of Studies, 2007*, as indicated on the peer feedback form.

Suggested Use

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

For theoretical (i.e., non-skills) questions, have 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 graphical representation of the depth of coverage expected. Later in this introduction is a quick overview of different verbs and their respective cognitive expectations.

For the skill-based questions, the peer feedback form contains boxes that can be checked by the peer reviewer to indicated the presence, presence with error, or the absence of the required part of the response. This more closely reflects the nature of skill questions: either the responder has the skills or the responder does not. There is much less room for interpretation. Also, it is possible to provide a completely correct solution, so that becomes the expectation.

Day 2 (20 minutes, 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.

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.

If you decide to provide scores for the students' final responses, remember that a standard of excellence score (80%) requires students to build new connections between ideas and that a response that provides only exactly what the student was told is an acceptable-level response (50%).

Cognitive Expectations

Different verbs indicate different cognitive levels, as described in Bloom's taxonomy.

Knowledge	Comprehension and Application	Higher Mental Activities
In general, verbs such as *listing*, *describing*, *identifying*, *sorting*, *ranking*, *defining*, etc., are at the lowest cognitive level and are classified as Knowledge.	Verbs such as *comparing*, *applying*, *calculating*, *determining*, etc., are at a more difficult cognitive level and are classified as Comprehension and Application. In general, students need to be putting ideas together to get to this level. As a peer reviewer, you are thinking something like "The response provides this answer **and** links it to that."	Tasks such as *explain*, *evaluate*, *justify*, *analyze*, *assess*, *design*, etc., require a very high cognitive engagement and are classified as HMA. As a reviewer, you are looking for the response to contain statements followed by "because" or "since" so that the student has clearly addressed the relationship between the ideas.

Extensions

Once you and your students are comfortable with the cognitive tasks required by the directing verbs and understand the cognitive tasks associated with the horizontal bars, you can have the students build the bars based on the verbs when they get the question.

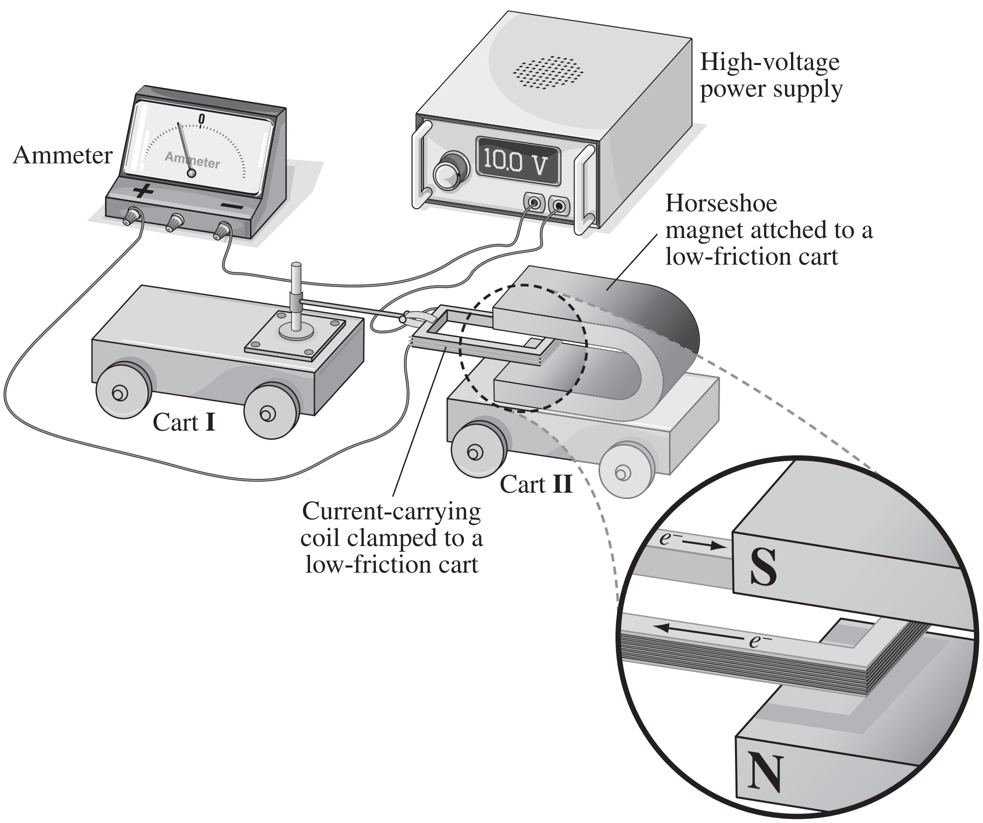
You can also take any of the written-response questions that you want to use on assessments for grades and convert them into something similar.

Use the following information to answer the next question.

A length of copper wire is wound onto a wooden frame to form a square coil of wire of N turns. The coil is clamped horizontally on top of a low-friction laboratory cart, Cart I, such that it projects beyond the front of the cart. When connected to a power supply an electric current, I, flows through the coil. The current is measured with an ammeter.

A horseshoe-shaped permanent magnet is clamped on top of a second, low-friction laboratory cart, Cart II. The positions of the two carts are adjusted so that the current-carrying coil is located between the poles of the horseshoe magnet, as shown below. The mass of Cart I, clamp and coil is 1.28 kg. The mass of Cart II and attached horseshoe magnet is 1.57 kg.

When the power supply is switched on, both carts are observed to move.



A teacher provides a group of students with the apparatus, as described above, and instructs the students to determine the minimum magnitude of the magnetic field between the poles of the horseshoe magnet.

The student's experimental design is to determine the time required for Cart I to travel a distance of 2.00 cm from rest. The students place a metre stick next to the carts and intend to use a stopwatch to measure the time interval. The students will use the data to calculate the acceleration of Cart I, and from that the magnetic force on Cart I. They also measure the width of the square coil of wire, to find the length of wire used.

Using the concepts of magnetic force on a current-carrying wire, Newton’s third law, and experimental design, **evaluate** the student’s experimental design. In your response,

- **sketch** arrows showing the direction and shape of the magnetic field between the poles of a horseshoe magnet
- **predict** whether the carts will move toward each other or move away from each other. **Explain** how the application of a hand rule supports the direction you have predicted
- **derive** an equation for the magnitude of the magnetic field between the poles of the horseshoe magnet in terms of the variables that the students plan to measure
- **evaluate** the students’ experimental design

Student Name____________________

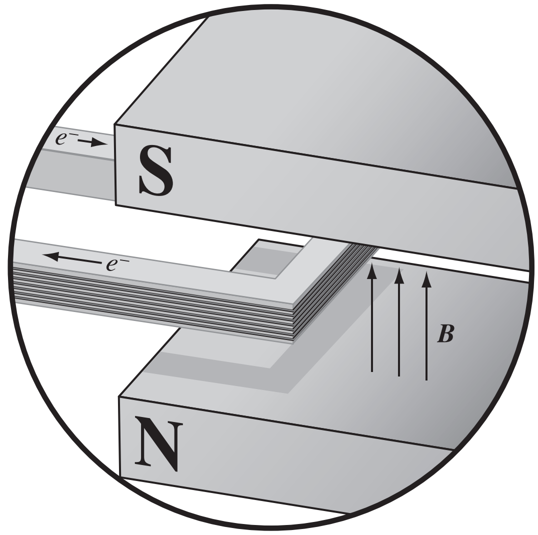
Peer Feedback—Electromagnetic Induction

Reviewer's Name____________________

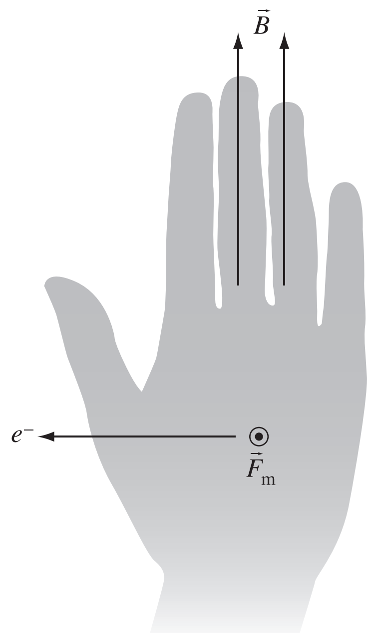
Program Links to Tasks in this Question	The horizontal bar indicates the scope required in the response. Place an "x" on the bar to indicate the level demonstrated in the response.	Looking Back
Sketch arrows showing the direction and shape of the magnetic field between the poles of a horseshoe magnet (B3.2k – much easier than full scope of outcome)	**Sketch** — Knowledge / 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…	**Changes that I am going to make** to my response…
Predict whether the carts will move toward each other or move away from each other (A1.2k – again, much easier than full scope of outcome)	**Predict** — Knowledge / 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…	**Changes that I am going to make** to my response…
Explain how the application of a hand rule supports the direction you have predicted (B3.7k, B3.8k, B3.2s)	**Explain** — Knowledge / 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…	**Changes that I am going to make** to my response…
Derive an equation for the magnitude of the magnetic field between the poles of the horseshoe magnet in terms of the variables that the students plan to measure (B3.8k, B3.3s)	**Derive** — Knowledge / 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…	**Changes that I am going to make** to my response…
Evaluate the students' experimental design (B3.1s)	**Evaluate** — Knowledge / 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…	**Changes that I am going to make** to my response…

Sample Response

As with all other magnetic fields, a North magnetic pole is simply the region of space which magnetic field lines are leaving. Conversely, a South magnetic pole is a region of space which magnetic field lines are entering. For the region between the North and South magnetic poles of the horseshoe magnet, the magnetic field lines will then be directed from the North magnetic pole toward the South magnetic pole.



The interaction between the magnetic effects of the electron motion and the horseshoe magnet results in a magnetic force acting on the coil and a reaction force acting on the horseshoe magnet. The direction of the magnetic force can be determined using a hand rule.



For this rule, with a flattened left hand for electron flow, the extended fingers point in the direction of the magnetic field, the extended thumb points in the direction of electron flow within the wire, and the palm of the hand will face in the same direction as the magnetic force acting on the current-carrying wire.

Accordingly, the current-carrying coil (and attached cart) will be forced to move to the right, toward the horseshoe magnet and Cart II. By Newton's third law, Cart II will also be forced to move to the left, toward Cart I. Cart I and Cart II move toward each other.

Since Cart I has an initial velocity of zero, the acceleration may be expressed in terms of distance and time. The net force acting on Cart I (in the absence of friction) is due to magnetic force. The magnetic force acting on one wire due to an external magnetic field is expressed as $\left|\vec{F}_{\text{m}}\right| = Il_{\perp}\left|\vec{B}\right|$, so for N wires, $\left|\vec{F}_{\text{m}}\right| = I\,Nl_{\perp}\left|\vec{B}\right|$.

$$\vec{d} = \vec{v}_{\text{i}}t + \frac{1}{2}\vec{a}t^2$$

since $\vec{v}_{\text{i}} = 0$

$$\vec{d} = \frac{1}{2}\vec{a}t^2$$

$$\vec{a} = \frac{2\vec{d}}{t^2}$$

$$\vec{F}_{\text{net}} = \vec{F}_{\text{m}}$$

$$m\vec{a} = \vec{F}_{\text{m}}$$

$$m\left(\frac{2\vec{d}}{t^2}\right) = \vec{F}_{\text{m}}$$

$$\vec{F}_{\text{m}} = I\,Nl_{\perp}\left|\vec{B}\right|$$

$$m\left(\frac{2\vec{d}}{t^2}\right) = I\,Nl_{\perp}\left|\vec{B}\right|$$

$$\left|\vec{B}\right| = \frac{2\vec{d}m}{NIl_{\perp}t^2}$$

Overall, the students' experimental design is flawed. To start with, the design lacks repeated trials and so the students' calculated magnitude will be subject to a great deal of uncertainty. Secondly, the students have interpreted low friction as "no friction," which is not likely for this experimental apparatus. A third major issue is that human reflex time to start and stop a stopwatch is likely to be a significant source of error. One last significant error is that the width of the coil is not the same as the length of wire contained within the magnetic field—the students would have been better off measuring the width of the horseshoe magnet.

General notes about the sample response and the expectations of the verbs in the question.

The description of the three mutually perpendicular vectors can be done in terms of perpendicular vectors. The use of a hand rule just makes the relative order of the vectors easier to keep straight—it is a *model* that we use to make predictions.

The complete explanation for the carts moving toward each other needs to clearly use Newton's third law. This law is very often misunderstood—students often have two forces acting on the same object rather than two forces acting on different objects.

The derivation of the equation needs to contain verbal or mathematical statements justifying why the formulas from the equation sheet are appropriate to this situation. This is the *explain* aspect of the program rather than the *determine* or *calculate* expectations of the old program.

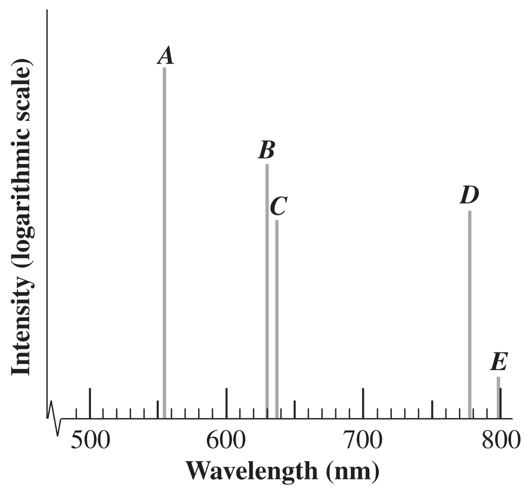
Finally, the evaluation requires a statement of *value*—is the procedure good or bad? Then the response needs to include supporting statements. It is not important for the students to be correct – they might say the procedure is good—but the support needs to be consistent and reasonably valid.

Use the following information to answer the next question.

Northern lights, visible in Alberta, are caused by electron transitions in excited atoms of oxygen.

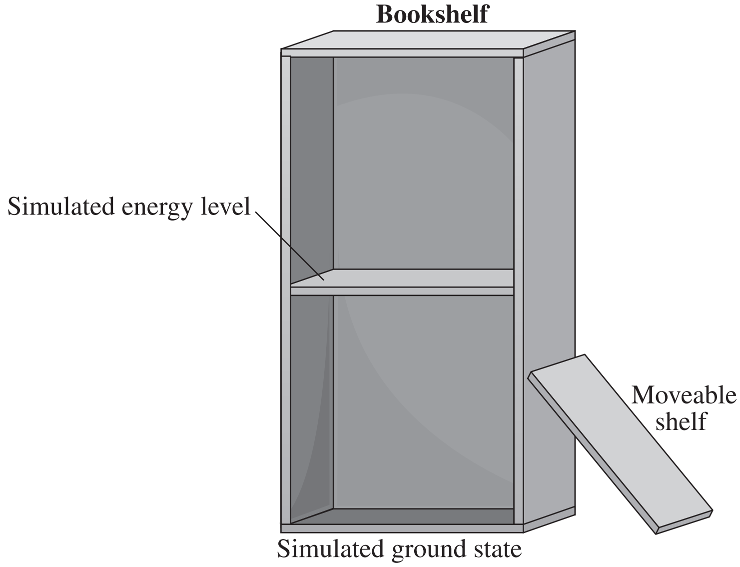
The following graph shows the relative intensity of five emission lines (*A* through *E*) for excited oxygen atoms.

Selected Emission Lines for Excited Oxygen Atoms



A teacher has a tall bookshelf in his classroom that has two adjustable shelves. He places one of the shelves within the bookcase to simulate an electron energy level, as shown below. He then challenges the students in his class to position the other shelf so that the bookshelf is a model of the electron energy levels in atomic oxygen that are involved in the production of the visible northern lights.

Bookshelf



Using the concepts of optical phenomena, the electromagnetic spectrum, atomic models, and conservation of energy, **evaluate** the use of a bookshelf to model atomic electron energy levels. In your response,

- **describe** a process that would separate different wavelengths of electromagnetic radiation. **Explain** how the process separates the different wavelengths

- **identify** the emission lines for oxygen atoms that are in the visible region of the electromagnetic spectrum and state their corresponding wavelengths. **Compare** the energies of the photons associated with each visible emission line

- **sketch** the positioning of the moveable shelf within the bookshelf to model the electron energy levels in atomic oxygen that are associated with the emission of visible light. **Explain** in terms of energy the relative positions of the shelves

- **draw** and **label** (with letter or wavelength) arrows on your arrangements of shelves showing electron transitions corresponding to the visible emission lines for oxygen atoms

- **evaluate** the use of a bookshelf to model electron energy levels

Student Name__________________________

Peer Feedback—Bookshelf Model

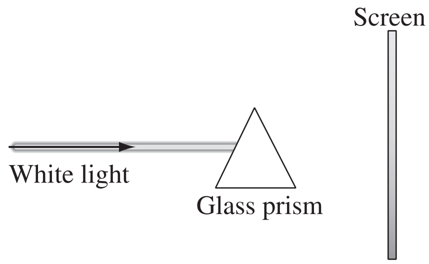
Reviewer's Name____________________

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 process that would separate the different wavelengths of electromagnetic radiation. **Explain** how the process separates the different wavelengths. (C1.1s, C1.6k, C1.8k)	Knowledge / Comprehension/Application / Higher Mental Activities **Describe** **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 emission lines for oxygen atoms that are in the visible region of the electromagnetic spectrum and **state** their corresponding wavelengths. **Compare** the energies of the photons associated with each visible emission line. (C1.2k, C1.3s, C2.1k)	Knowledge / Comprehension/Application / Higher Mental Activities **Identify** **State** **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…
Sketch the positioning of the moveable shelf within the bookshelf to model the electron energy levels in atomic oxygen that are associated with the emission of visible light. **Explain** in terms of energy the relative positions of the shelves. (C2.1s, D2.1k)	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…
Draw and **label** (with letter or wavelength) arrows on your arrangements of shelves showing electron transitions corresponding to the visible emission lines for oxygen atoms (D2.1s)	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…
Evaluate the use of a bookshelf to model electron energy levels (NS1 – STS)	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…

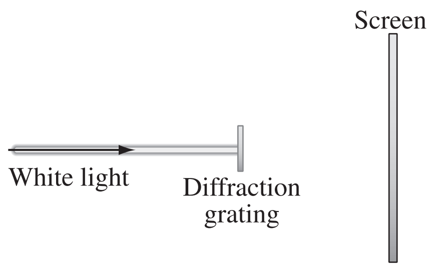
Sample Response

To separate the light you may use either a prism or a diffraction grating.

Light passing through a prism is refracted by differing amounts based on the incident wavelength, as described by Snell's law, $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2}$. Shorter wavelengths refract more than longer wavelengths and deviate from the original path by a greater amount, as shown below.



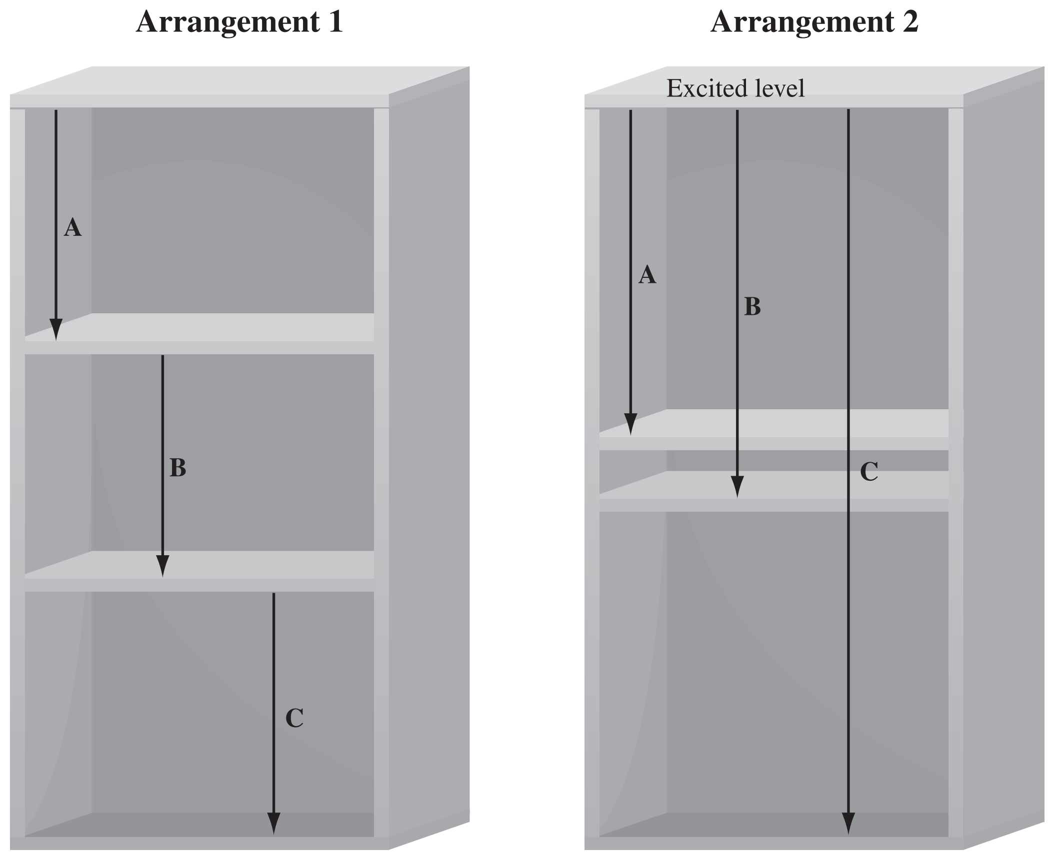
Light passing through a diffraction grating is diffracted by differing amounts based on incident wavelength, as described by $\lambda = \frac{d\sin\theta}{n}$. For a grating, longer wavelengths diffract more than shorter wavelengths and deviate from the original path by a greater amount, as shown below.



Visible wavelengths are between 400 nm and 700 nm, so for the given spectrum the emission lines that are in the visible range are *A* (557nm), *B* (630 nm) and *C* (636 nm). The other wavelengths are in the infrared section of the spectrum.

The larger the wavelength, the smaller the energy, as describe by $E = \frac{hc}{\lambda}$. So, a photon associated with the 557 nm emission line has the largest energy, followed by a photon associated with the 630 nm emission line, and the photon associated with the 636 nm emission line has the least amount of energy.

Emission spectra are explained in terms of an atomic model that has electrons in specific stable energy states. Electrons in higher energy states make transitions to lower energy states and emit specific photons. Each transition causes the emission of one photon. Two arrangements of shelves to model the production of the three spectral lines corresponding to visible light, *A*, *B*, and *C*, are shown below



Note to Teachers: The use of the verb *evaluate* is meant to cue the students that they are expected to not only pass a value judgment on this model (good/bad, acceptable/unacceptable, etc.) but to support that judgment with at least one valid argument.

The use of a bookshelf to model electron energy levels could be viewed as acceptable since it attempts to describe the energy of a photon as equivalent to the difference in energy between two stable energy states. Since the shelves are moveable it would also be possible to describe the spectral emissions for other parts of the electromagnetic spectrum or even of other excited atoms.

OR

The use of a bookshelf to model electron energy levels could be viewed as unacceptable since it describes electron location (shelf) as a fixed position in space rather than as a statistical probability state. The use of a fixed position (shelf) to describe electron location more closely matches outdated models, such as the Bohr model, than our current model. The ability to move smoothly between one shelf and another shelf also does not match the current concept of a quantum transition, according to which there are locations electrons cannot occupy.

Background Information on the Energy Levels of Oxygen Question

Unit D2 in the *Physics 20-30 Program of Studies, 2007*, mandates that students explain, qualitatively, the characteristics of, and the conditions necessary to produce, continuous line-emission and line-absorption spectra (D2.3k), predict the conditions necessary to produce line-emission and line-absorption spectra (D2.1s), and explain that scientific knowledge and theories develop through hypotheses, the collection of evidence, investigation and the ability to provide explanations (D2.1sts).

The Aurora, “Forbidden” Transitions and Metastable Oxygen

Early measurements of the Aurora proved that it was an atmospheric phenomenon. In 1790, Henry Cavendish used triangulation methods to estimate that the intense green light seen in the aurora originated in a region approximately 100 to 150 km above Earth’s surface. In 1886, Anders Angström used spectroscopic methods to study the auroral light, and determined the wavelength of the dominant green line to be 556.7 nm. Within a very short time other scientists had measured and reported the wavelengths of the other spectral lines associated with the red and blue light seen in auroral displays.

The fact that the auroral light could be resolved as a spectral line pattern, distinct from that of the solar spectrum, established the fact that the Aurora was not just reflected or diffracted sunlight as had been suggested by some scientists. By 1912, advances in photography and spectroscopy had allowed scientists to determine that the red and blue spectral lines for the aurora were due to nitrogen gas, the major component of Earth’s atmosphere. However, a great problem at the time was that the dominant green spectral line did not match any known source, either astronomical or atmospheric.

The emission spectrum of atomic oxygen that is typically seen in a laboratory setting is the result of a collection of excited atoms that make energy transitions to lower energy states. When an electron makes a transition from an excited energy state to a lower energy state, the photon that is released has an angular momentum associated with it. The excited and lower energy states must have a difference in angular momentum equal to that carried away by the photon. This may only happen if certain quantum mechanical restrictions are met. This requirement means that the number of spectral lines that may be observed is much less than would be expected if photons could be released by just any transition to a lower energy level.

The most probable type of transition that fulfills all of the quantum mechanical requirements associated with the release of a photon is an “electric dipole” transition (because the change in electron position relative to the nucleus is the quantum mechanical equivalent of the change for a classical oscillating electric dipole). This type of transition occurs on a time scale of less than 10^{-8} s.

In 1925, two Canadian physicists at the University of Toronto, John McLennan and Gordon Shrum, determined that the green spectral line of the aurora was associated with a metastable form of atomic oxygen. This metastable form of atomic oxygen undergoes energy level transitions that are not observed under normal, laboratory conditions.

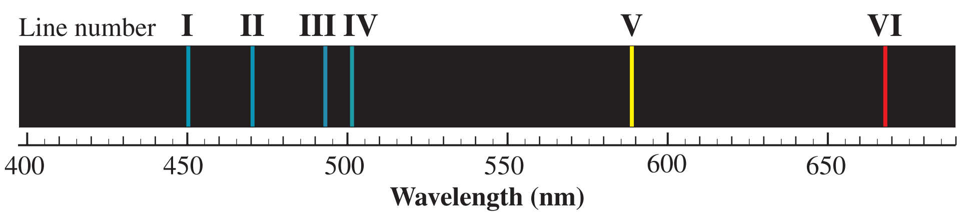
A metastable atom is one for which there are no possible energy level transitions that fulfill the requirements for electric dipole transitions. That is not to say that there are no possible energy level transitions, only that the transitions cannot occur (are "forbidden") by electric dipole radiation. There are transitions that can be made (magnetic dipole transitions and electric quadrupole transitions), but the probability of such transitions is very low. Under normal atmospheric conditions it is much more likely that a metastable atom will give up its energy via collision with another atom than by the release of a photon. However, at the altitude where the Aurora originates the atmosphere is very rarefied and the low probability of atomic collisions allows time for such transitions to occur. Consequently, spectral lines will be observed that are normally not observed, even under the best laboratory vacuum conditions.

Use the following information to answer the next question.

In a classroom activity, a teacher gives her students the following equipment.

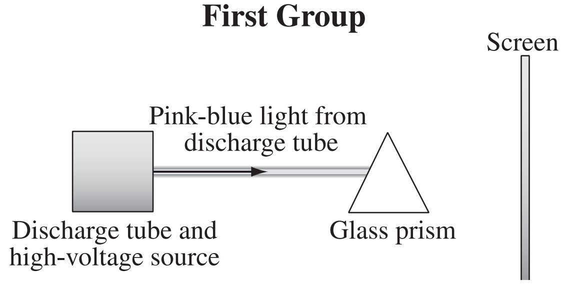
- A low-pressure helium gas discharge tube
- A high-voltage source
- Diffraction gratings
- Triangular glass prisms
- A screen
- A picture of the helium emission spectrum, shown below

The teacher connects the low-pressure discharge tube to the high-voltage source and turns off the lights in the room. The students observed pink-blue light emitted by the tube. One group of students is given the task of observing the emission spectrum of helium using a glass prism. A second group is to observe the spectrum using a diffraction grating.



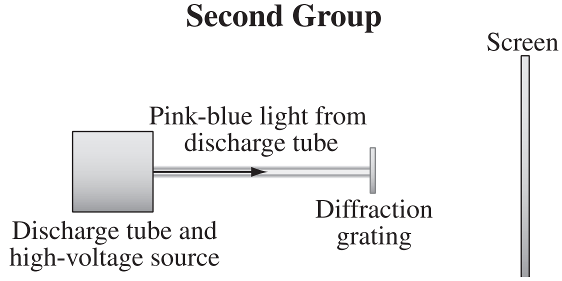
The students in the first group direct the light from the low-pressure helium gas discharge tube toward the prism, as illustrated below, and observe the spectrum produced on the screen.

First Group



The students in the second group direct the light from the low-pressure helium gas discharge tube toward the diffraction grating, as illustrated below, and observe the spectrum produced on the screen.

Second Group



Using the concepts of conservation of energy and the optical phenomena of refraction and diffraction, **analyze** the observations of the experiment. In your response,

- **trace** the energy conversions in the production of an emission spectrum. Begin with the electrical energy supplied to the low-pressure helium-gas discharge tube and end with the emission of electromagnetic radiation

- **explain** why an atomic model that requires electrons to occupy stable electron energy levels is necessary to account for the observation of emission spectra

- **predict** and **label** the locations of the lines numbered **I**, **V**, and **VI** on the screen, as observed by the first group of students

- **predict** and **label** the locations of the lines numbered **I**, **V**, and **VI** on the screen, as observed by the second group of students

- **explain** how you predicted the relative locations of these lines

Student Name________________________ *Peer Feedback—Refraction/Diffraction Comparison* 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
Trace the energy conversions in the production of an emission spectrum. Begin with the electrical energy supplied to the discharge tube and end with the emission of electromagnetic radiation (D2.3k, D2.1s)	Knowledge / Comprehension/Application / Higher Mental Activities **Trace** **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 why an atomic model that requires electrons to occupy stable electron energy levels is necessary to account for the observation of emission spectra (D2.4k)	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…
Predict and **label** the locations of the lines numbered **I**, **V**, and **VI** on the screen, as observed by the first group of students (C1.6k, C1.12k,C1.2s)	Knowledge / Comprehension/Application / Higher Mental Activities **Predict** **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 and **label** the locations of the lines numbered **I**, **V**, and **VI** on the screen, as observed by the second group of students (C1.8k, C1.12k, C1.2s, C1.3s)	Knowledge / Comprehension/Application / Higher Mental Activities **Predict** **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…
Explain how you predicted the relative locations of these lines (C1.6k, C1.8k, C1.1s, C1.3s)	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…

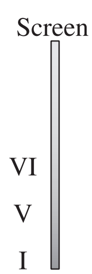
Sample response

Electrical energy is transferred to electrons in the helium atoms, causing the electrons to undergo transitions to higher energy levels. As these electrons undergo transitions to lower energy levels, they emit photons that have energy equal to the difference in energy of the energy levels. These photons constitute the electromagnetic radiation emitted by the discharge tube. Within a collection of atoms, the excited state the atoms reach will vary so that as they return to lower energy states, different wavelengths are emitted. Also, several different paths can be followed as an atom goes to a lower energy state. This would produce a variety of emitted wavelengths. The energy of an emitted photon matches the change in energy of the atom.

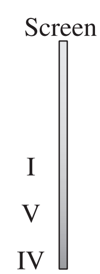
In classical physics, stable electron energy levels are necessary to account for emission spectra because of the requirement that electrons undergoing centripetal acceleration as they orbit the nucleus must continuously emit electromagnetic radiation (EMR). The loss in energy created by the emission of EMR would result in a continuously changing orbit of the electron, eventually leading to the electron colliding with the nucleus. Observations do not provide evidence that this happens, so it became necessary to modify the model of the atom so that the electron is not described as orbiting the nucleus. Early models were modified to predict that there are certain, very specific orbits that were non-radiative (stationary states). Later models describe electrons as being wavelike, and as forming stable, standing wave patterns at certain positions around the atom. Since electrons are no longer described as accelerating particles, the need for continuous emission of EMR is not an issue.

Line position as observed by:

First Group of Students (Prism)



Second Group of Students (Grating)



When passing through the prism, the red light (line VI) refracts the least because of its longer wavelength. Blue light (line I) refracts the most because of its shorter wavelength. The greater refraction by the blue light causes line I to be projected the furthest from the centre of the screen.

When passing through the diffraction grating, the red line (VI) diffracts the most because of its longer wavelength and blue light diffracts the least. This causes the red line to be produced the furthest from the centre of the screen.

General notes about the sample response and the expectations of the verbs in the question.

The conservation of energy discussion will lend itself to reinforcing the students' widely held misconception that all the energy moves from one type of energy to another type of energy based on their Science 10 experiences. In the quantum world, this may be true; in the macro world this is definitely not true. Exploring this idea AFTER the students have completed their responses by challenging the students to decide if all the electrons get excited to the same state or return to the same lower energy level could be used to refine the students' understanding of energy.

The role of observation in the evolution of atomic models is something that historically many students have struggled with. Students really want to be taught what is correct so that they don't have to keep learning; science is the process of getting closer to a model that matches the world better than the last model. Students need to understand that physics is building models, that models have strengths and weaknesses, and future models should address the weaknesses. When you are looking at the student responses, you need to see words such as *because* or *since* or *which means* because these words indicate that the students are building connections between ideas rather than just stating facts.

Predicting and labelling are both very cognitively easy. Explaining why certain colours appear where they do requires the students to link ideas. Be sure that they are providing real explanations rather than statements of truths.

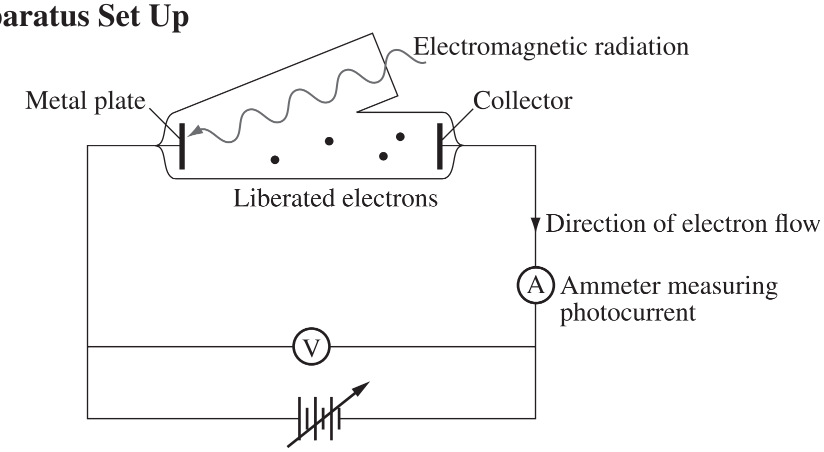
Use the following information to answer the next question.

Students complete the following investigation to determine the work function of a metal plate.

Materials

- Photocathode
- Variable voltage source
- Voltmeter
- Ammeter
- Variable electromagnetic radiation (EMR) source

Schematic of Apparatus Set Up



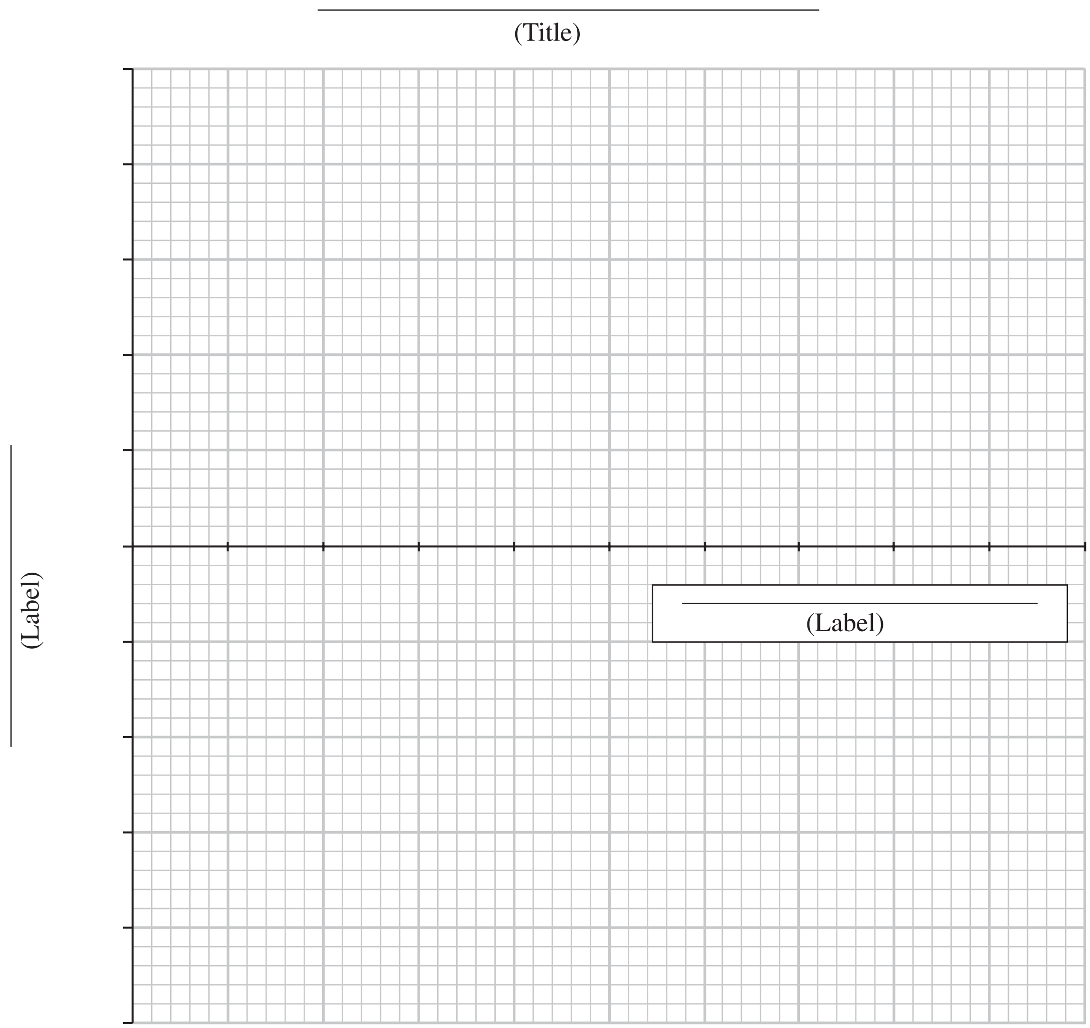
Procedure

1 Set the variable voltage source to zero.
2 Direct EMR onto the metal plate and increase the frequency of the EMR until a current is detected by the ammeter.
3 Increase the voltage supplied by the voltage source until the current drops to zero.
4 Record the incident frequency and the stopping voltage.
5 Repeat steps 2 through 4 for several higher frequencies.

Observation Chart

Frequency of EMR (10^{14} Hz)	**Stopping Voltage (V)**
6.0	0.38
7.0	0.80
8.0	1.31
9.0	1.63
10.1	2.01

Using graphical analysis and both the *x*-intercept and *y*-intercept, **determine** the work function of the photocathode. In your response, **provide** a graph of stopping voltage as a function of frequency, **determine** the *x*-intercept and *y*-intercept of your graph, and **relate** each of the intercepts algebraically to a physics equation.



Student Name________________________

Peer Feedback—Graphing

Reviewer's Name________________________

Paper-and-Pencil Graphing Convention	Peer Feedback			Calculator Active Graphing Convention	Peer Feedback			Mathematical Treatment	Peer Feedback		
	Present and Correct	**Present with Error(s)***	**Absent**		**Present and Correct**	**Present with Error(s)***	**Absent**		**Present and Correct**	**Present with Error(s)***	**Absent**
The title is in the form "responding variable as a function of manipulated variable"				The title is in the form "responding variable as a function of manipulated variable"				All necessary formulas are present			
The axes are labelled with the variable, including powers of 10 if required, and units				How the data are entered into the calculator is clearly communicated, including powers of 10 and units				All substitutions are shown.			
The scales are such that the data, when plotted, cover a majority of the graph **and** that reading values from the line of best fit is convenient				Window settings are provided				Values used are on the line of best fit			
All the data points are plotted				The sketch of the calculator window shows the locations of the data points and the line of best determined by the appropriate regression				The relationship between the equation for a line and the relevant physics is explicit			
The line of best fit, either a line or a curve, provides the best approximation of the trend of the data given the context of the data				The regression used and the order in which the data was used and the results of the regression are provided				The final answer is stated with appropriate significant digits and units			

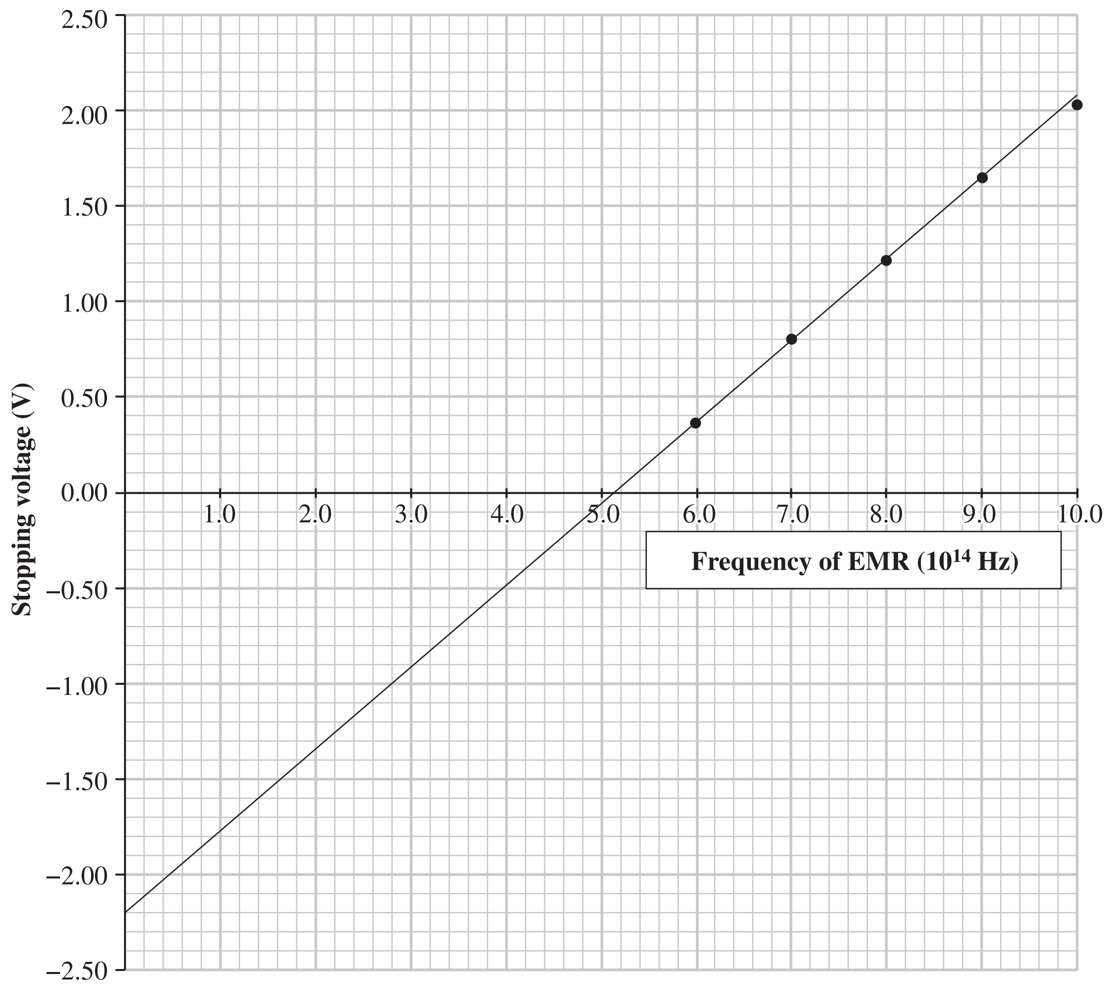
Changes that I will make based on Peer Feedback.

*Note to Peer Reviewers: Provide details of the error(s) that you identified.

Sample response

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

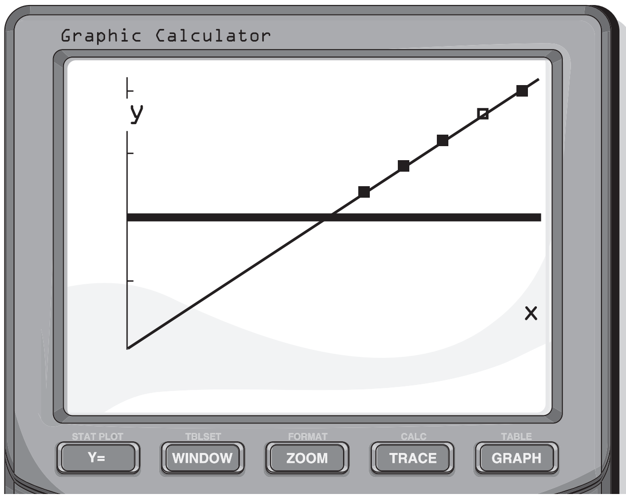
Stopping Voltage as a Function of EMR Frequency



x-int = 5.18×10^{14} Hz y-int = –2.20 V

Calculator-Active Graph

Stopping Voltage as a Function of Frequency



Where Stopping Voltage (V_{stop}) is entered into L2 (V) and Frequency (f) is entered into L1 (10^{14} Hz)

Window Setting:
$\{x \mid 0, 1.04 \times 10^{15}\}$
$\{y \mid -2.066, 2.1876\}$

Then, the linear regression $ax + b$ on L1, L2 gives
$a = 4.00 \times 10^{-15}$
$b = -1.99$

the y-intercept = –1.99
the x-intercept = 5.05×10^{14} using the trace function along $y = 0$

Mathematical Treatment:

Based on conservation of energy, $E_i = E_f$

This means $E_{photon} = E_{k_{max}} + W$ where $E_{kmax} = V_{stop}q_e$ and $E_{photon} = hf$

Solving for V_{stop} gives $V_{stop} = \frac{hf}{q_e} - \frac{W}{q_e}$

Matching this to $y = mx + b$,
gives $b = -W/q_e$ or solving for the work function
$W = -bq_e$
$W = -(-2.20 \text{ V})(1.60 \times 10^{-19} \text{ C})$
$W = 3.52 \times 10^{-19}$ J

Using the calculator-active values,
$W = -(-1.99 \text{ V})(1.60 \times 10^{-19} \text{ C})$
$W = 3.18 \times 10^{-19}$ J

The x-intercept occurs when the y value is zero ($V_{stop} = 0$),

Which gives: $0 = \frac{hf}{q_e} - \frac{W}{q_e}$ which simplifies to $W = hf_0$ (which is where this formula comes from)

So, $W = hf_0$

$W = (6.63 \times 10^{-34}\ \text{J·s})(5.18 \times 10^{-14}\ \text{Hz})$

$W = 3.43 \times 10^{-19}\ \text{J}$

Using the calculator-active values,

$W = (6.63 \times 10^{-34}\ \text{J·s})(5.05 \times 10^{-14}\ \text{Hz})$

$W = 3.35 \times 10^{-19}\ \text{J}$

Finding the average of the two values to minimize error gives

$W_{ave} = \frac{3.43 + 3.52}{2} \times 10^{-19}\ \text{J} = 3.48 \times 10^{-19}\ \text{J}$ or $W = 3.27 \times 10^{-19}\ \text{J}$

Note: SD may vary depending on data points selected.

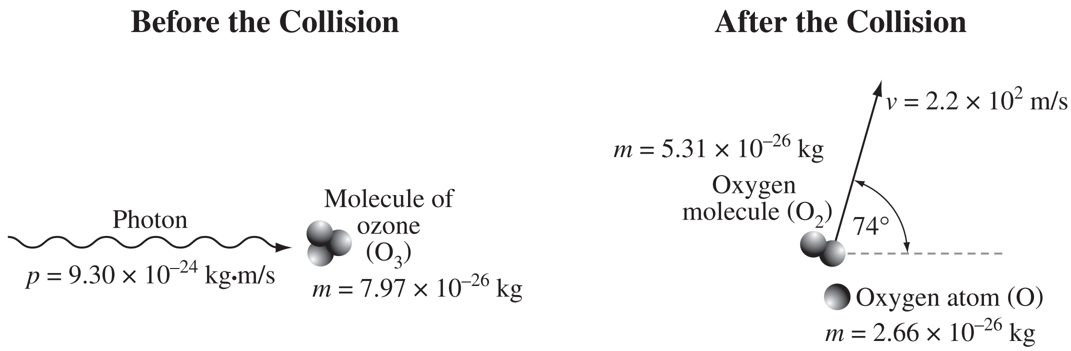
Notes to Teachers: A line of best fit will usually not go through the first and last plotted points. Sometimes it will go through the origin, but not always, and certainly not in this situation. Students need practice in estimating the line of best fit and should also have experience with lines of best fit that are curved.

In reading values to use for the slope, students should be encouraged to use on-line points rather than data points, and points that are far apart. The calculation of slope is another opportunity to explore error of measurement and significant digits in a setting that clearly affects the precision of the students' final answer.

Grade 12 students should be able to identify the physics principle being used, and algebraically manipulate the physics equations that are appropriate to the principle to isolate the variable being plotted on the vertical axis. They should then be able to match the algebra to the equation for a line to justify the use of the slope or the use of an intercept. (The use of the slope and proper delta notation is mandated in each unit of both Physics 20 and Physics 30.)

Use the following information to answer the next question.

Ozone (O_3) in the upper atmosphere protects life on Earth by absorbing dangerous photons of ultraviolet electromagnetic radiation produced by the Sun. When such a photon collides inelastically with an initially stationary ozone molecule, the molecule is broken apart into an oxygen molecule (O_2), and an oxygen atom (O), as shown below.



Determine the velocity of the oxygen atom after the collision. As part of your response, **sketch** an arrow showing the direction of the oxygen atom's motion after the collision, **sketch** a vector addition diagram consistent with the vector analysis method you are choosing, and **state** all necessary physics principles and formulas.

Student Name_______________________

Peer Feedback—Two Dimensional Vector Skills

Reviewer's Name_____________________

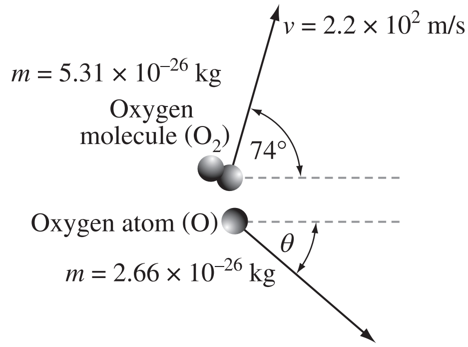
Paper-and-Pencil Graphing Convention	Peer Feedback			Mathematical Treatment	Peer Feedback		
	Present and Correct	**Present with Error(s)***	**Absent**		**Present and Correct**	**Present with Error(s)***	**Absent**
Direction is explicitly addressed: • sign convention is defined • in situations in which the directions of the vectors are not given, the response must contain an explicit use of physics to support the direction (for example, like charges repel; therefore the forces are in such-and-such direction, or the direction of the magnetic field is from N to S, etc.)				The physics principle related to the solution is explicitly communicated (for example, conservation of momentum, work done = change in the system's kinetic energy, equilibrium means $F_{net} = 0$)			
A situational diagram showing the directions of the forces is present (for example, for a momentum question an arrow for each moving object is given; for a forces question a FBD is given				All formulas are present			
A vector addition diagram is present				All substitutions are shown			
Vector conventions are followed: • Vectors are drawn as arrows pointing in the direction of the vector • Arrows are labelled • The angle(s) label(s) appear at the tail of the vectors				The final answer is consistent with the vector addition diagram given			
The response is presented in an organized manner				The final answer is stated with appropriate significant digits and units.			

Changes that I will make based on Peer Feedback.

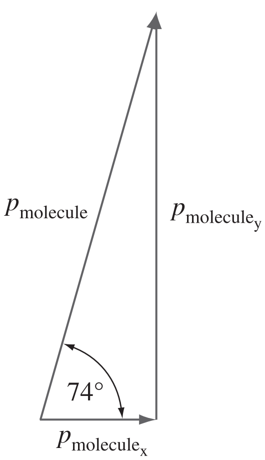
*Note to Peer Reviewers: Provide details of the error(s) that you identified.

Sample response

Velocity of oxygen atom after collision:



Method 1—Components



Components of molecule's momentum after the collision:

$$\left| p_{\text{molecule}_x} \right| = (\cos\theta)mv = (\cos 74°)(5.31 \times 10^{-26}\ \text{kg})(2.2 \times 10^{2}\ \text{m/s})$$

$$\left| p_{\text{molecule}_x} \right| = 3.2199 \times 10^{-24}\ \text{kg·m/s}$$

$$\left| p_{\text{molecule}_y} \right| = (\sin\theta)mv = (\cos 74°)(5.31 \times 10^{-26}\ \text{kg})(2.2 \times 10^{2}\ \text{m/s})$$

$$\left| p_{\text{molecule}_y} \right| = 1.1229 \times 10^{-23}\ \text{kg·m/s}$$

Adding *x*-components

$$\sum p_{x_i} = \sum p_{x_f}$$

$$p_{\text{photon}_{x_i}} = p_{\text{molecule}_{x_f}} + p_{\text{atom}_{x_f}}$$

$$p_{\text{atom}_{x_f}} = p_{\text{photon}_{x_i}} - p_{\text{molecule}_{x_i}}$$

Adding *y*-components

$$\sum p_{y_i} = \sum p_{y_f}$$

$$p_{\text{photon}_{y_i}} = 0 = p_{\text{molecule}_{y_f}} + p_{\text{atom}_{y_f}}$$

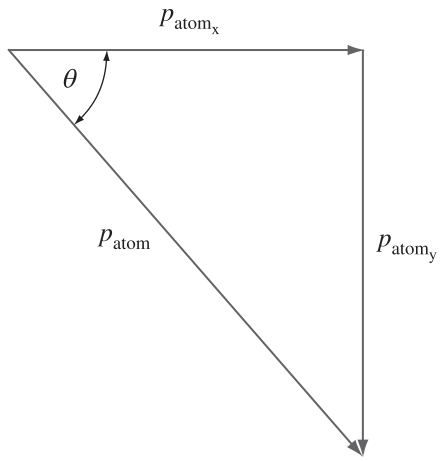
$$p_{\text{atom}_{y_f}} = -p_{\text{molecule}_{y_f}}$$

$$p_{\text{atom}_{y_f}} = -1.1229 \times 10^{-23}\ \text{kg·m/s}$$

$$p_{\text{atom}_{x_f}} = 9.30 \times 10^{-24}\ \text{kg·m/s} - 3.2199 \times 10^{-24}\ \text{kg·m/s}$$

$$p_{\text{atom}_{x_f}} = 6.08 \times 10^{-24}\ \text{kg·m/s}$$

Final vector diagram and resultant:



$$\left|\vec{p}_{\text{atom}}\right|^2 = \left|\vec{p}_{\text{atom}_x}\right|^2 + \left|\vec{p}_{\text{atom}_y}\right|^2$$

$$\left|\vec{p}_{\text{atom}}\right| = \sqrt{(6.08 \times 10^{-24}\ \text{kg·m/s})^2 + (-1.1229 \times 10^{-23}\ \text{kg·m/s})^2}$$

$$\left|\vec{p}_{\text{atom}}\right| = 1.28 \times 10^{-23}\ \text{kg·m/s}$$

$$\tan\theta = \frac{\left|p_{\text{atom}_y}\right|}{\left|p_{\text{atom}_x}\right|}$$

$$\theta = \tan^{-1}\left(\frac{1.1229 \times 10^{-23}\ \text{kg·m/s}}{6.08 \times 10^{-24}\ \text{kg·m/s}}\right)$$

$$\theta = 62°$$

$$\vec{p}_{\text{atom}} = m\vec{v}$$

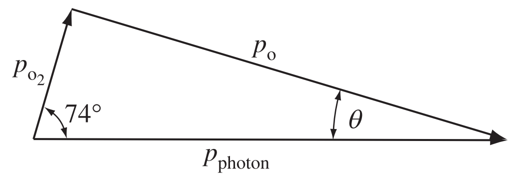
$$v = \frac{p_{\text{atom}}}{m}$$

$$v = \frac{1.28 \times 10^{-23}\ \text{kg·m/s}}{2.66 \times 10^{-26}\ \text{kg}}$$

$$v = 4.8 \times 10^2\ \text{m/s}$$

The velocity of the electron is 4.8×10^2 m/s, 62° to the right of the photon's original direction.

Method 2—Cosine Law



$\left| p_{molecule_x} \right| = mv$

$\left| p_{molecule_x} \right| = (5.31 \times 10^{-31}\ \text{kg})(2.2 \times 10^{2}\ \text{m/s})$

$\left| p_{molecule_x} \right| = 1.1682 \times 10^{-23}\ \text{kg·m/s}$

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

$\left| \vec{p}_{atom} \right|^2 = \left| \vec{p}_{molecule} \right|^2 - 2\left| \vec{p}_{molecule} \right| \left| \vec{p}_{photon} \right| \cos\theta$

$\left| \vec{p}_{atom} \right|^2 =$

$(1.168 \times 10^{-23}\ \text{kg·m/s})^2 + (9.30 \times 10^{-24}\ \text{kg·m/s})^2 - 2(1.1682 \times 10^{-23}\ \text{kg·m/s})(9.30 \times 10^{-24}\ \text{kg·m/s})(\cos 74°)$

$\left| \vec{p}_{atom} \right| = 1.28 \times 10^{-23}\ \text{kg·m/s}$

$\vec{p}_{atom} = m\vec{v}$

$v = \frac{p_{atom}}{m}$

$v = \frac{1.28 \times 10^{-23}\ \text{kg.m/s}}{2.66 \times 10^{-26}\ \text{kg}}$

$v = 4.8 \times 10^{2}\ \text{m/s}$

To get the angle:

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

$\frac{\left| \vec{p}_{molecule} \right|}{\sin\theta} = \frac{\left| \vec{p}_{atom} \right|}{\sin 74^\circ}$

$\sin\theta = \frac{(\sin 74^\circ)(1.1682 \times 10^{-23}\ \text{kg.m/s})}{(1.28 \times 10^{-23}\ \text{kg.m/s})}$

$\theta = 62°$

The velocity of the electron is 4.8×10^{2} m/s, 62° to the right of the photon's original direction.

Notes to Teachers: Many students draw their vector addition diagrams as triangles rather than as vector addition. This is not acceptable.

Many students are very competent with the book-keeping method of analyzing two-dimensional situations. Although this method is valid, it is not included here because some of these students do not really understand 2-D vectors and vector addition; they have replaced understanding with calculator competency.

The use of sine law and cosine law is not mandated, so students are not required to use this method. However, for some students, this method makes sense and they have the foundation for it. These students should not be held back.

Finally, the use of scaled vector addition diagrams is an excellent way of checking if the students have an authentic understanding of vectors and vector addition. It is also a way of making 2-D analysis accessible for the students who struggle with calculators but understand the physics.

Illustrative Example of Bookshelf Model

The following pages contain a student's initial response, the completed peer feedback form, and he student's final response.

Commentary

Initial Response:

The initial response addresses each part of the question but not at the cognitive level required. The student uses *diffract* instead of *refract* in part 1.

The student uses an incorrect value, 10^{-14}, for Planck's constant with incorrect units in part 2.

The student provides an explanation for the positions of the shelves in part 3.

The student provides an evaluation with two characteristics of why this model is good.

Peer Feedback:

The peer feedback identifies each of these weaknesses (except the units on *h*).

The looking back portion shows the student responding to the feedback.

Final Response:

The final response is much better than the initial response, with spelling and physics errors fixed (except units on h) and more details provided in the higher cognitive tasks.

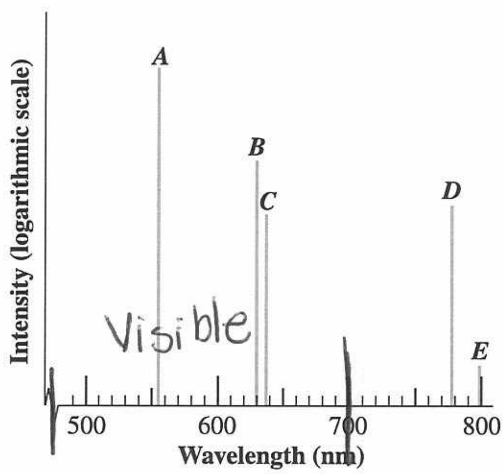
C1 Initial Response

Use the following information to answer the next question.

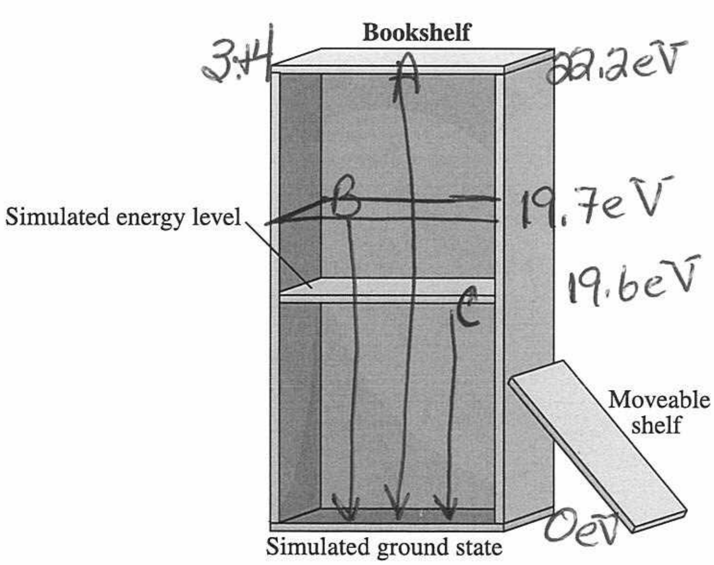
Northern lights, visible in Alberta, are caused by electron transitions in excited atoms of oxygen.

The following graph shows the relative intensity of five emission lines (*A* through *E*) for excited oxygen atoms.

Selected Emission Lines for Excited Oxygen Atoms



A teacher has a tall bookshelf in his classroom that has two adjustable shelves. He places one of the shelves within the bookcase to simulate an electron energy level, as shown below. He then challenges the students in his class to position the other shelf so that the bookshelf is a model of the electron energy levels in atomic oxygen that are involved in the production of the visible northern lights.



5) A bookshelf is good, because the energy levels are the same for a given element. An object can be moved from a top shelf directly to the bottom or placed on any of the other shelves just as an electron can in the atom.

Using the concepts of optical phenomena, the electromagnetic spectrum, atomic models, and conservation of energy, **evaluate** the use of a bookshelf to model atomic electron energy levels. In your response,

1 • **describe** a process that would separate different wavelengths of electromagnetic radiation. **Explain** how the process separates the different wavelengths

2 • **identify** the emission lines for oxygen atoms that are in the visible region of the electromagnetic spectrum and state their corresponding wavelengths. **Compare** the energies of the photons associated with each visible emission line

3 • **sketch** the positioning of the moveable shelf within the bookshelf to model the electron energy levels in atomic oxygen that are associated with the emission of visible light. **Explain** in terms of energy the relative positions of the shelves

4 • **draw** and **label** (with letter or wavelength) arrows on your arrangements of shelves showing electron transitions corresponding to the visible emission lines for oxygen atoms

5 • **evaluate** the use of a bookshelf to model electron energy levels

1. Shine visible white light through a prisim. The prism has a different refrection index # than air, and thus the different wavelengths of white light will defract at different amounts and the spectrum of visible light colours will be produced.

2. Visible: 400nm - 700nm A (560nm) B (630nm) C (635nm)

$$E = \frac{hc}{\lambda}$$

$$= \frac{(4.14 \times 10^{-14}\ J.s)(3 \times 10^{8}\ m/s)}{5.60 \times 10^{-9}\ m}$$

$E_A = 22.2\ eV$ $E_B = 19.7\ eV$ $E_C = 19.6\ eV$

$E_A > E_B > E_C \rightarrow$ shorter λ = higher E

Student Name C1

Peer Feedback—Bookshelf Model

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 process that would separate the different wavelengths of electromagnetic radiation. **Explain** how the process separates the different wavelengths. (C1.1s, C1.6k, C1.8k)	Knowledge — Comprehension/Application — Higher Mental Activities **Describe** [x at Knowledge] **Explain** [x at Comprehension/Application] **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 explanation, but confuses refraction/diffraction …	**Changes that I am going to make** to my response… The prisim refracts light not defrect
Identify the emission lines for oxygen atoms that are in the visible region of the electromagnetic spectrum and **state** their corresponding wavelengths. **Compare** the energies of the photons associated with each visible emission line. (C1.2k, C1.3s, C2.1k)	Knowledge — Comprehension/Application — Higher Mental Activities **Identify** [x at Knowledge] **State** [x at Knowledge] **Compare** [x at Comprehension/Application] **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… ~~Excellent response~~ 10^{-15} not 10^{-14} in h Good otherwise	**Changes that I am going to make** to my response… -Not screw up Plank's constant
Sketch the positioning of the moveable shelf within the bookshelf to model the electron energy levels in atomic oxygen that are associated with the emission of visible light. **Explain** in terms of energy the relative positions of the shelves. (C2.1s, D2.1k)	Knowledge — Comprehension/Application — Higher Mental Activities **Sketch** [x at Knowledge] **Explain** [x at Comprehension/Application] **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 sketches, but….. you need to explain why you put the shelves there	**Changes that I am going to make** to my response… -more explanation
Draw and **label** (with letter or wavelength) arrows on your arrangements of shelves showing electron transitions corresponding to the visible emission lines for oxygen atoms (D2.1s)	Knowledge — Comprehension/Application — Higher Mental Activities **Draw** [x at Knowledge] **Label** [x at Knowledge] **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… Excellent drawing + labelling	**Changes that I am going to make** to my response…
Evaluate the use of a bookshelf to model electron energy levels (NS1 – STS)	Knowledge — Comprehension/Application — Higher Mental Activities **Evaluate** [x at 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… Good explanation…. maybe a little more in-depth	**Changes that I am going to make** to my response… - more details

C1 Edited Response

1. Shine visible white light through a prism. The prism has a different refractive index number than air, and thus the different wavelengths of the white light refract at different rates. Thus a spectrum of visible light will be produced.

2. Visible ≐ 400nm - 700nm
∴ Visible A (560 nm) B (630 nm) C (635nm)

$E = \frac{hc}{\lambda}$ $E = \frac{hc}{\lambda}$ $E = \frac{hc}{\lambda}$

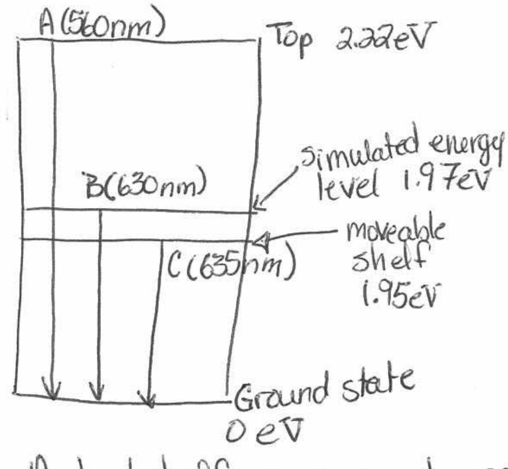
$E = \frac{(4.14 \times 10^{-15} J \cdot s)(3 \times 10^{8} m/s)}{5.60 \times 10^{-7} m}$ $E = \frac{hc}{6.30 \times 10^{-7} m}$ $E = \frac{hc}{6.35 \times 10^{-7} m}$

$E_A = 2.22 eV$ $E_B = 1.97 eV$ $E_C = 1.95 eV$

- shorter wavelength = higher energy as proven by calculations

$E_A > E_B > E_C$

3/4



- The moveable shelf will be placed just below the simulated shelf. This is because the energy levels are so close, and the ground state is 0 eV so the top of the shelf will be the highest energy level.

5. A bookshelf is a good representation of electron energy levels. The shelfs stay stationary for a given element, and thus it is good. The shelf shows how an object can be moved directly from the top to the bottom or on different increments just as a model electron energy levels.