

Solutions: Section 1 (Multiple Choice)

Questions 1–45: Single-Choice Items

- 1. B**—The mass of argon is greater. Thus, at the same temperature, argon has the same kinetic energy but a slower average speed. This shifts the curve to the left. Since the number of moles is the same, the peak of the argon graph must be higher to accommodate the same number of atoms.
- 2. D**—The exit velocity is proportional to the water pressure at the hole, which is proportional to the depth of the water: $P = P_0 + \rho gh$.
- 3. D**—The point source model shows us that the larger the wavelength, the greater the bending of the wave around the corner. We can also see this in the equation for diffraction: $\sin \theta = \frac{m\lambda}{d}$. As the wavelength gets smaller, the diffraction bending angle also gets smaller. Visible light has a very small wavelength and only bends a tiny amount around corners.
- 4. C**—Only electrons can move in the metal spheres. Protons (positive charges) are stuck in the nuclei of atoms and cannot move. In the presence of the positively charged rod, the three-sphere system will polarize with excess electrons moving toward the positively charged rod. Answer choice A shows no charge polarization. Choice B shows each individual sphere polarized, which cannot happen since the conductors are in contact and act as one system. Choice D shows protons moving, which also cannot happen.
- 5. D**—Electric field lines are perpendicular to the isolines and point from higher potential to lower potential. The average electric field strength is

$E = \frac{\Delta V}{\Delta r}$. Therefore, the electric field at point A will be stronger than at point B.

6. **C**—The force from sphere 1 on sphere 3 is $\frac{1}{2} F$ to the left. The force from sphere 2 on sphere 3 is $2 F$ to the left. The sum is $(5/2) F$.
7. **B**—The current is the same; therefore, the higher the resistance, the greater the electric potential. Use the resistance equation to find the relative magnitude of the three resistors: $R = \frac{\rho L}{A}$.
8. **D**—Originally only bulb A is lit, and it experiences all the emf of the battery. When the switch is opened, the emf of the battery is split evenly between the bulbs. $P = \frac{V^2}{R}$; therefore, the power dissipation by bulb A is one-quarter of the original value.
9. **C**—Special relativity tells us that when two observers are moving relative to each other, they will not necessarily agree on length and time. This becomes evident when we get up near the speed of light. We start to easily notice the effect around $0.1 c$ and faster. The only constant that all observers will agree on is the speed of light.
10. **C**—The original velocity is toward the top of the page. The force on the proton is out of the page. Therefore, by the right-hand rule, the magnetic field is directed to the left.
11. **B**—Newton's third law.
12. **B**—The three resistors in the bottom right corner are in parallel. Since they all have the same resistance and the same electric potential across them, they must also have the same current. Ammeter #3 is the sum of the currents in the top two resistors and will be twice as large as ammeter #4.
13. **B**—The three resistors in parallel add up to a resistance of $\frac{1}{3} R$. Adding these in series with the resistor in the main line, we get $\frac{4}{3} R$.

14. **D**—The data in the table suggest that gas pressure and volume are inversely related: $P \propto \frac{1}{V}$. This is also seen in the Ideal Gas model: $P = \frac{nRT}{V}$. Therefore, plotting P on the vertical axis and $1/V$ on the horizontal axis will produce a straight line from which the number of moles could be calculated knowing that the slope will equal nRT .
15. **C**—The ranking will be based on the $P \times V$ value: $T_C > T_B = T_D > T_A$
16. **B**—Both paths start and end at the same point. Therefore, the initial and final temperatures are the same, as are the initial and final thermal energies. Process 1 has a higher average pressure for the same volume change. Another way to think about it is to compare the area under the curves. Graph 1 has more area underneath and, therefore, a larger magnitude of work.
17. **B**—The weight of the blocks is balanced by the buoyancy force. Since the blocks are half submerged, their densities are half that of water:

$$\begin{aligned}
 F_g &= F_b \\
 (mg)_{\text{block}} &= (\rho V g)_{\text{water}} \\
 (\rho V g)_{\text{block}} &= (\rho V g)_{\text{water}} \\
 (\rho V)_{\text{block}} &= \left(\rho \left(\frac{1}{2} V_{\text{block}} \right) \right)_{\text{water}} \\
 \rho_{\text{block}} &= \frac{1}{2} \rho_{\text{water}}
 \end{aligned}$$

18. **D**—Using the conservation of mass/continuity equation, we see that the water must be slower at the hydrant than exiting the nozzle:

$$A_1 v_1 = A_2 v_2$$

The area of the hose is proportional to the diameter squared:

$$\pi r_1^2 v_1 = \pi r_2^2 v_2$$

$$\pi \left(\frac{8\text{cm}}{2} \right)^2 v_1 = \pi \left(\frac{2\text{cm}}{2} \right)^2 18 \frac{\text{m}}{\text{s}}$$

This gives us a velocity in the hose of 1.125 m/s.

Using conservation of energy/Bernoulli's equation and assuming the exit pressure is atmospheric,

$$\left(P + \rho gy + \frac{1}{2} \rho v^2 \right)_1 = \left(P + \rho gy + \frac{1}{2} \rho v^2 \right)_2$$

$$\left(P + 0 + \frac{1}{2} (1,000 \text{ kg/m}^3) (1.125 \text{ m/s})^2 \right)_1$$

$$= \left(100,000 \text{ Pa} + (1,000 \text{ kg/m}^3) (10 \text{ m/s}^2) (6 \text{ m}) \right.$$

$$\left. + \frac{1}{2} (1,000 \text{ kg/m}^3) (18 \text{ m/s})^2 \right)_2$$

- 19. A**—Gravity is proportional to the product of the two masses, and the electric force is proportional to the product of the two charges. Since the mass of an electron is on the order of 10^{-31} kg, and the charge is on the order of 10^{-19} C, the electric force will be much larger than the gravitational force. In addition, the universal gravitational constant is much smaller than the Coulomb's law constant. This makes the gravitational force between the electrons negligible compared to the electric force.
- 20. B**—The charge of Psevdísium is smaller than the electron charge, which calls this particle's existence into doubt. Within the level of uncertainly listed, the charge of Alithísium is ten times the charge of the electron. We would expect the charge to be a whole integer multiple of the

electron charge. The mass of Alithísium is listed as an energy equivalent. This is perfectly acceptable: $E = mc^2$.

21. **C**—Electric field vectors are perpendicular to the equipotential lines. The pattern of the electric field vectors indicates that both charges are the same sign. Additionally, there is no zero potential line separating the two charges, indicating that they have the same sign.
22. **D**—It is not possible to separate a north pole from a south pole. All magnets are dipoles. When you break a magnet in half, you get two weaker magnets. If they stayed the same magnitude as the original, we would be violating conservation of energy.
23. **C**—By the right-hand rule, the magnetic force on the proton is to the left. Originally, the electric and magnetic forces were equal. Since the velocity has increased, the magnetic force is now larger than the electric force that is to the right.
24. **D**—The diaphragm vibrates back and forth along the axis of the magnet, changing the magnetic field strength through the coil area.
25. **C**—The law of reflection is not influenced by the water. Snell's law of refraction depends on the indices of refraction of the two materials. The speed of light changes less going from water to lens than going from air to lens. This means there will be less refraction in water, making the focal length larger.
26. **B**—Electromagnetic waves are transverse, with both the E- and B-fields oscillating perpendicular to the direction of motion and each other.
27. **D**—The lens equation can be rearranged to produce a straight line:

$$\frac{1}{s_i} = (-1)\frac{1}{s_o} + \frac{1}{f}$$

$$y = mx + b$$

Thus, if we plot $1/s_o$ on the x -axis and $1/s_i$ on the y -axis, we should get a

graph with a slope of -1 and an intercept of $1/f$. The image distance is $x_2 - x_1$, and the object distance is $x_0 - x_1$.

- 28. B**—When the angle of the prism decreases, the right side of the prism becomes more vertical, and the angle of incidence with the normal becomes smaller. This creates less refraction and the distance (x) increases. Look at the extreme case when θ becomes zero. Then the angle of incidence is zero, and there is no refraction at all. The beam will pass straight through the “prism” because it has become flat like a window, and the distance (x) becomes infinite.
- 29. C**—The particle is most likely to be found at the highest positive/negative amplitude location of Ψ as a function of x . The particle will not be found at locations -15 nm and 0.0 nm.
- 30. C**



Solve for A and Z . $A = 32$ and $Z = 16$. Knowing that alpha particles have two protons and four nucleons, we can divide 32 by 4 or divide 16 by 2 to find out that we need 8 alpha particles to balance the equation.

- 31. B**—When the metal block is lifted out of the water, the buoyancy force between the block and the water disappears. This makes the spring scale reading go up by 70 g and the balance reading go down by 70 g. Note that mass of the block is 190 g. Therefore, the spring scale reading must be 190 g when the block is lifted out of the water!
- 32. C**—In process 3, the work done is zero: $W = 0$. The temperature and the internal kinetic energy of the gas are increasing. Therefore, thermal energy must be entering the gas: $\Delta U = Q$.
- 33. C**

$$K_{\text{average of the gas}} = \frac{3}{2}k_B T \text{ and } K = \frac{1}{2}mv^2$$

The helium is moving at half the speed and has four times the mass of hydrogen. This means they both have the same average kinetic energies and the same temperatures:

$$K_{\text{helium}} = \frac{1}{2}(4m_{\text{hydrogen}})\left(\frac{1}{2}v_{\text{hydrogen}}\right)^2$$

$$= \frac{1}{2}m_{\text{hydrogen}}v_{\text{hydrogen}}^2 = K_{\text{hydrogen}}$$

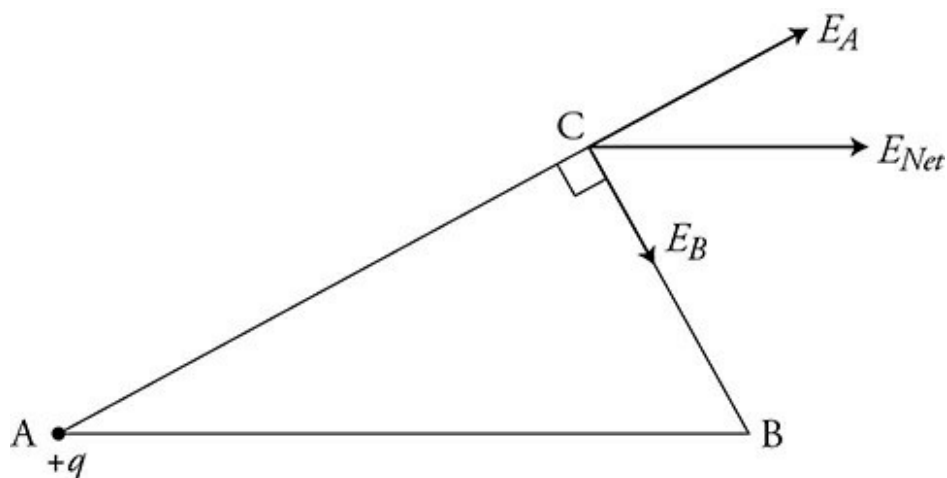
Objects with the same temperature are in thermal equilibrium and do not transfer any net thermal energy between them.

- 34. C**—Adding heat to the gas from the resistor will increase the kinetic energy and temperature of the gas. The kinetic energy of the gas is proportional to the velocity squared:

$$E_{\text{added to gas from resistor}} = \Delta K_{\text{average of the gas}} = \frac{1}{2}mv^2$$

Thus, the average velocity of the gas is proportional to the square root of the energy added to the gas (E).

- 35. D**—Without knowing the exact locations, it is impossible to know the exact electric field strength. Since electric field is proportional to $\frac{1}{r^2}$, the electric field strength varies in strength in the three regions.
- 36. C**—For the electron to receive a force to the left, the electric field must be pointing to the right. The electric field from the charge at vertex B must be smaller in magnitude than the field produced by the charge at vertex A. To accomplish this, the charge at point B must be negative and smaller than $|+q|$.



37. **A**—Near the edges of the capacitor, the electric field is still pointing in the same direction but is weaker than between the two plates.
38. **B**—The reading in ammeter 1 never changes because the potential difference and resistance in that line does not change. The capacitor behaves like a wire when uncharged and like an open switch when fully charged. This behavior changes the current through ammeter 2 as time passes.
39. **D**— $P = \frac{V^2}{R}$. The slope of the right graph will equal the reciprocal of the resistance.
40. **B**—Use the right-hand rule for magnetic fields around current-carrying wires.
41. **A**—The image is upright and smaller. This means the image is virtual, the image distance is negative, and the mirror must be diverging/convex.

$$M = \frac{1}{2} = \frac{-s_i}{s_o} = \frac{-s_i}{12 \text{ cm}}$$

$$s_i = -6 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o}$$

$$\frac{1}{f} = \frac{1}{-6 \text{ cm}} + \frac{1}{12 \text{ cm}}$$

$$f = -12 \text{ cm}$$

42. **C**—The amplitude is 3 mV/m, and the time period is 0.5 ns. Using the wave equation, we get

$$\begin{aligned} E &= A \cos\left(\frac{2\pi t}{T}\right) = 3 \cos\left(\frac{2\pi t}{0.5}\right) = 3 \cos(4\pi t) \\ &= 3 \cos(12.6t) \end{aligned}$$

43. **A**—The frequency remains the same. The wavelength of light is directly proportional to the speed of light in the substance. Light travels faster in water than through glass; therefore, $\lambda_w > \lambda_g$.
44. **D**—The electrostatic repulsion of the protons is much stronger than the gravitational attraction of the nucleons. Thus, we need a stronger force to hold the nucleus together. Scientists call this the nuclear strong force.
45. **B**—Ohmic materials will have a constant ratio of current to potential difference. This shows up on a graph as a straight line.

Questions 46–50: Multiple-Correct Items

(You must indicate both correct answers; no partial credit is awarded.)

46. **C and D**—Four capacitors connected in series result in a capacitance

one-quarter the size of the individual capacitors. $C = \frac{\kappa\epsilon_0 A}{d}$. To get a single capacitor with one-quarter the capacitance, we need to get a factor of four in the denominator.

- 47. B and D**—The sum of the forces must equal zero. Therefore, the buoyancy force upward must equal gravity downward minus the tension upward. Buoyancy force is ρVg , and the volume of the block is $a^2 (h_1 - h_2)$.
- 48. A and D**—The Ideal Gas model ($PV = nRT$) shows us that gas pressure is directly related to gas temperature ($P \propto T$). This is seen in the straight line data represented in the graph. The slope of this graph will be equal to $\frac{nR}{V}$. Since the volume of the gas is given, the number of moles—and thus, the number of atoms—in the gas can be calculated using the slope. The x -intercept represents the temperature of the gas when the volume reaches zero. This point is absolute zero. The area of a PV diagram would represent work. We cannot calculate the force from the pressure because we do not know the surface area of the container. We are only given the volume.
- 49. A and C**—Sphere A is negative, and sphere B is positive. The rod polarizes the system that consists of the two spheres, pulling excess electrons to the left and leaving the right side with an excess positive charge of equal magnitude.
- 50. A and D**—Be careful! Make sure you are paying attention to which of these is a magnetic field and which is an electric field. Electric forces are along the axis of the field. E-fields push positive charges in the direction of the field. Negative charges are pushed in the opposite direction of the E-field. Magnetic forces abide by the right-hand rule. Only moving charges experience forces from B-fields.

Solutions: Section 2 (Free Response)

Your answers will not be word-for-word identical to what is written in this key. Award points for your answer as long as it contains the correct physics explanation *and* as long as it does not contain incorrect physics or contradict the correct answer.

Question 1

Part (A) 5 points total for a well-constructed and easy to read explanation that contains the following:

1 point—The amount of air inside the bubble remains the same during ascent.

1 point—The external pressure from the water on the bubble decreases as the bubble rises.

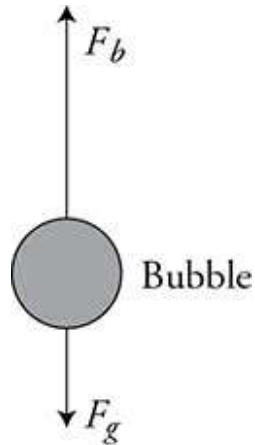
1 point—The bubble increases in volume as it moves upward.

1 point—As the bubble volume increases, the buoyancy force increases, but the gravity force on the bubble remains constant.

1 point—The bubble accelerates upward at an increasing rate as it ascends.

Part (B)

1 point—For buoyancy force upward and gravity force downward. Buoyancy must be drawn larger than gravity. If extra vectors are drawn, this point is not awarded.



Part (C)

1 point—The atoms inside the gas collide with and bounce off the water molecules. This causes a change in momentum of the gas atoms. This generates an equal and opposite force between the water and gas that keeps the bubble from collapsing.

Part (D)

1 point—For the correct relationship between the pressure at the surface of the water and at a depth D : $P_D = P_s + \rho g D$.

1 point—For the correct application of the ideal gas law and the correct final expression:

$$P_S V_S = P_D V_D$$

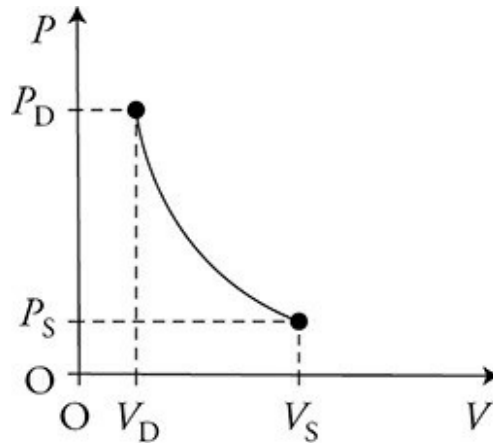
$$P_S V_S = (P_s + \rho g D) V_D$$

$$V_S = \frac{(P_s + \rho g D) V_D}{P_s}$$

Part (E)

(i)

1 point—The sketch should have the shape of an adiabatic process, with an upward concave curve similar to that for an inverse relationship. The initial and ending points should be marked as seen in the figure. Pressure decreases and volume increases.



(ii)

No point is awarded for checking the blank “Less than $P_D V_D$.” Points are awarded for the justification as follows:

1 point—The process is an adiabatic expansion. There is no heat transfer between the water and the bubble. Therefore: $Q = 0$, and $\Delta U = W$.

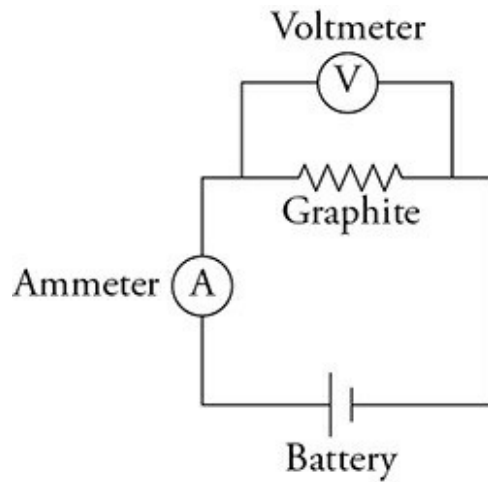
1 point—Since the work is negative as the bubble expands, the internal energy of the bubble must also decrease. Therefore, the temperature and the PV value must also decrease.

Question 2

Part (A)

(i)

1 point—Minimum equipment: wires, voltmeter, and ammeter. Note that the equipment that is listed must be used in the lab procedure.



(ii)

1 point—There are several ways to draw this. The key is that the ammeter is in series with the battery and the graphite. The voltmeter must be in parallel with the graphite to measure the correct potential difference. The graphite should be drawn as a resistor and the entire schematic needs to be labeled.

(iii)

1 point—Procedure:

1. Connect the graphite, ammeter, and battery in series.
2. Connect the voltmeter in parallel with the graphite.
3. Measure the current and voltage.
4. Repeat for several lengths of graphite.

(iv)

1 point—Since the current and voltage are measured for the graphite specifically, the internal resistance of the emf source is irrelevant.

Part (B)

(i)

1 point—Trials: 1, 6, 9, 11, 12, and 13 are the best because they give the

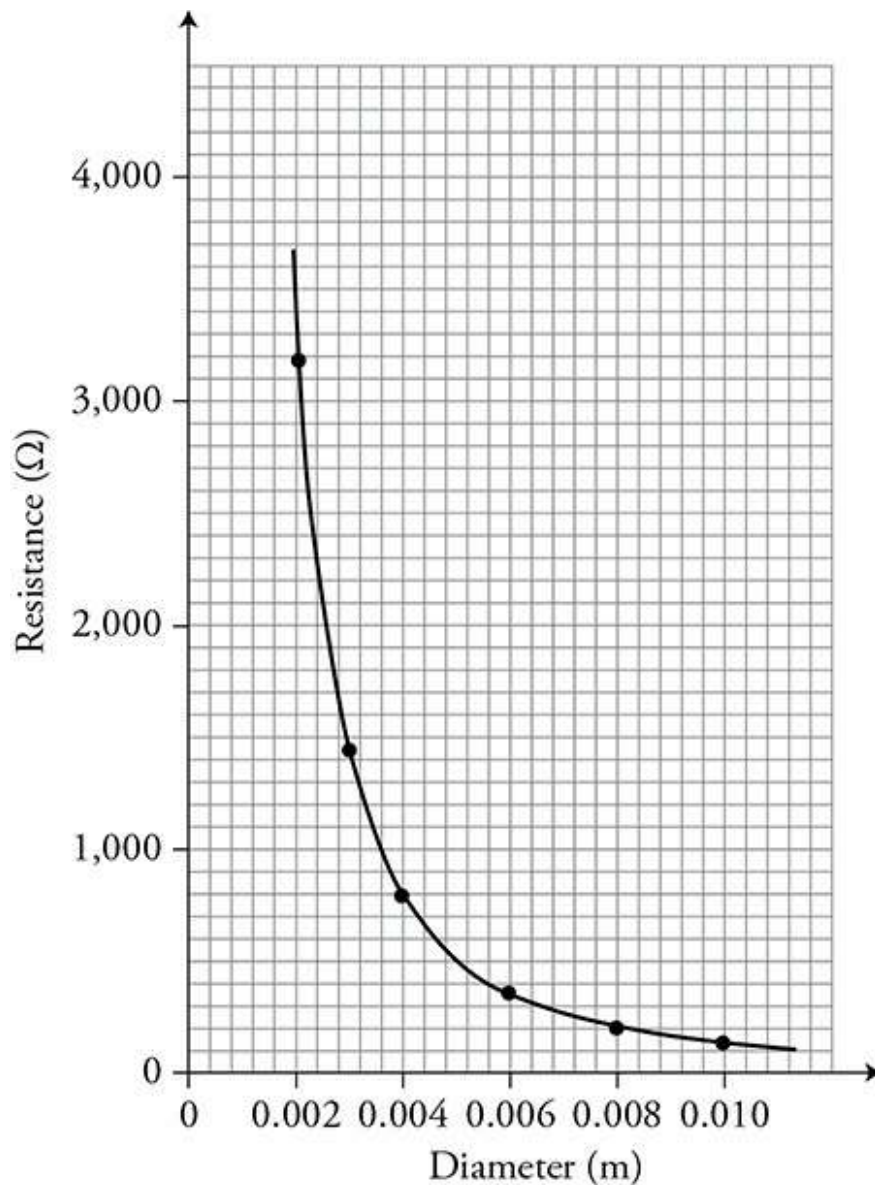
widest quantity and spread of data for a constant length segment of Play-Doh with differing diameters.

1 point—The resistance is missing and needs to be calculated. (See the table.)

Trial	Diameter (m)	Length (m)	Current (A)	Voltage across Play-Doh (V)	Resistance (Ω)
1	0.002	0.1	0.003	9.0	3,200
2	0.002	0.2	0.001	9.0	
3	0.002	0.3	0.001	9.0	
4	0.002	0.4	0.001	9.0	
5	0.002	0.5	0.001	9.0	
6	0.003	0.1	0.006	9.0	1,400
7	0.003	0.2	0.003	9.0	
8	0.003	0.3	0.002	9.0	
9	0.004	0.1	0.011	9.0	800
10	0.004	0.2	0.006	9.0	
11	0.006	0.1	0.025	8.9	350
12	0.008	0.1	0.045	8.9	200
13	0.010	0.1	0.069	8.8	130

(ii)

1 point—Data point must be correctly plotted. The axes must be correctly labeled. The graph should be a curve.



(iii)

1 point—For a statement that the resistance appears to be inversely related to the diameter (or the diameter squared).

(iv)

1 point—To determine if the relationship between resistance and diameter is inverse (or inverse squared), we need to graph R vs $1/d$ (or R vs $1/d^2$) and see if this graph produces a straight line.

(v)

1 point—The changing water content of Play-Doh could change the resistivity of the material and the resistance-diameter relationship, which damages the validity of the lab. It is a variable that is not held constant and calls the validity of the experiment into question.

Question 3

Part (A)

There are two ways to construct this energy level diagram. Both are shown below.

1 point—For converting the wavelengths of light in energy in electron volts.

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

$$248 \text{ nm} = 5 \text{ eV}, 400 \text{ nm} = 3.1 \text{ eV}, 650 \text{ nm} = 1.9 \text{ eV}$$

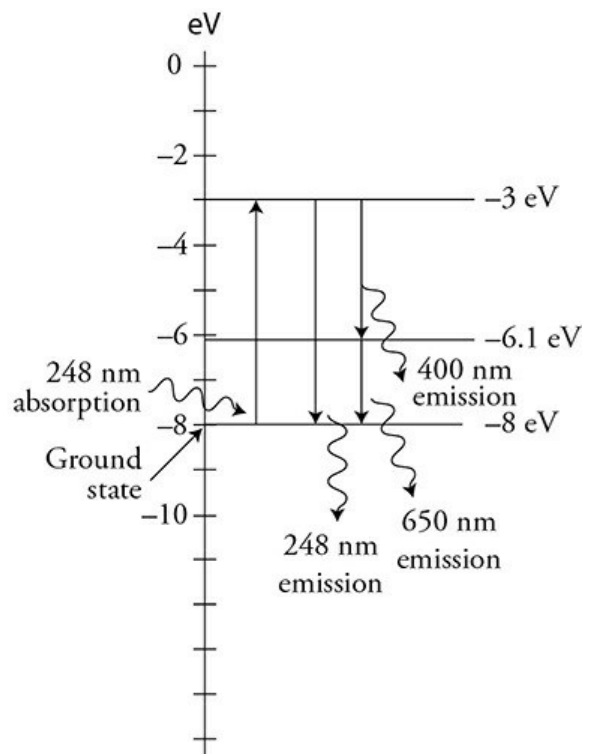
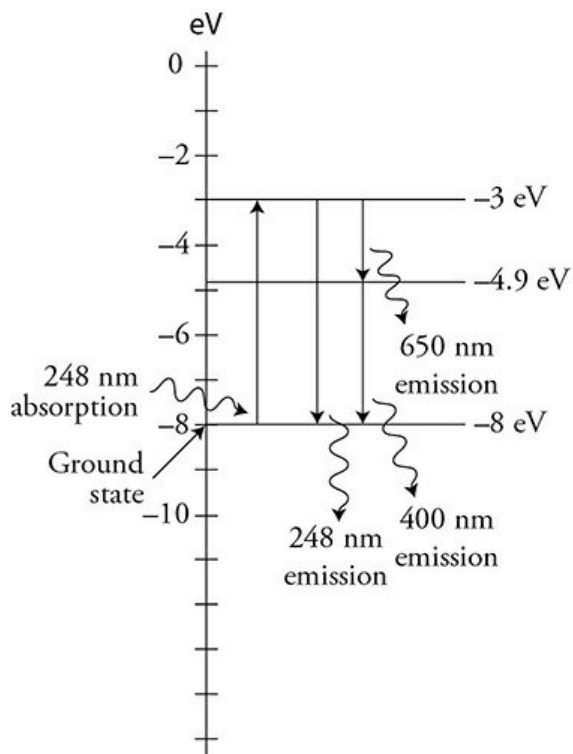
1 point—For drawing energy levels at both -8 eV and -3 eV . (See figure below.)

1 point—For drawing an additional energy level at either -4.9 eV or -6.1 eV . (See figure below.)

1 point—For drawing an arrow upward from the -8 eV energy level to the -3 eV energy level to indicate the absorption of the 248 nm photon. (See figure below.)

1 point—For drawing three downward arrows as shown in the diagram below and indicating the emission of the 248 nm , 400 nm , and 650 nm photons.

Note: Only one of the diagrams below needs to be drawn by the student.



Part (B)

1 point—For indicating that the 400 nm photon is below the threshold energy (work function) needed to eject an electron.

1 point—For indicating that the 650 nm photon has even less energy than the 400 nm photon.

Part (C)

(i)

1 point—For converting the electron energy from eV into joules of kinetic energy and then into an electron velocity.

$$\text{Electron kinetic energy} = (2.71 \text{ eV})(1.6 \times 10^{-19} \text{ J/eV}) = 4.34 \times 10^{-19} \text{ J}$$

$$K = \frac{1}{2} m_e v^2$$

$$v = \sqrt{\frac{2K}{m_e}} = 9.76 \times 10^5 \text{ m/s}$$

1 point—For calculating the de Broglie wavelength.

$$\lambda = \frac{h}{p} = \frac{h}{m_e v} = 7.46 \times 10^{-10} \text{ m}$$

(ii)

1 point—For indicating that an interference pattern will form with appropriate justification. Here is an example explanation:

The electrons will form an interference pattern, as the waves are on the same order of magnitude and smaller than the opening spacing. The equation

$\sin \theta = \frac{m\lambda}{d}$ shows us that the ratio $\frac{\lambda}{d}$ needs to be less than 1 for an

interference pattern to form. Any larger ratio will cause the angle θ to be larger than 90 degrees, and no pattern will form. This means the wavelength must be smaller than the spacing, but not too small or the angle will be so small that the pattern will be too small to see.

Question 4

Part (A)

1 point—Student A is correct that particles 2 and 3 have no net force acting on them while between the charged plates. This is evident in the fact that they travel in a straight line through the charged plate.

AND

Student A is correct in stating that particle 2 is neutral as it travels in a straight line through the magnetic field. Knowing that a charged particle will experience a force while passing through a magnetic field, particle 2 must be uncharged.

1 point—Student B is correct in stating that particle 3 must have a charge,

since a moving charged particle will experience a force when passing through a magnetic field. Student B is also correct in stating that the path implies a negative charge. According to the right-hand rule for a charged particle in a magnetic field, the direction of force on a moving charged particle will be perpendicular to both the magnetic field and the direction of positive charge motion. Using this right-hand rule, we find a circular path directed upward for a positive charge, thus the downward curve of particle 3 suggests a negative charge.

AND

Student B is correct in stating that the bottom plate must be negatively charged. Since particle 3 is negative as previously stated, the negative charge will experience a downward force from the magnetic field. In order to maintain a straight line and thus no acceleration, particle 3 must experience an upward force to balance the downward force. This can be achieved only if the bottom plate repels the negative charge upward, indicating that the bottom plate is negatively charged.

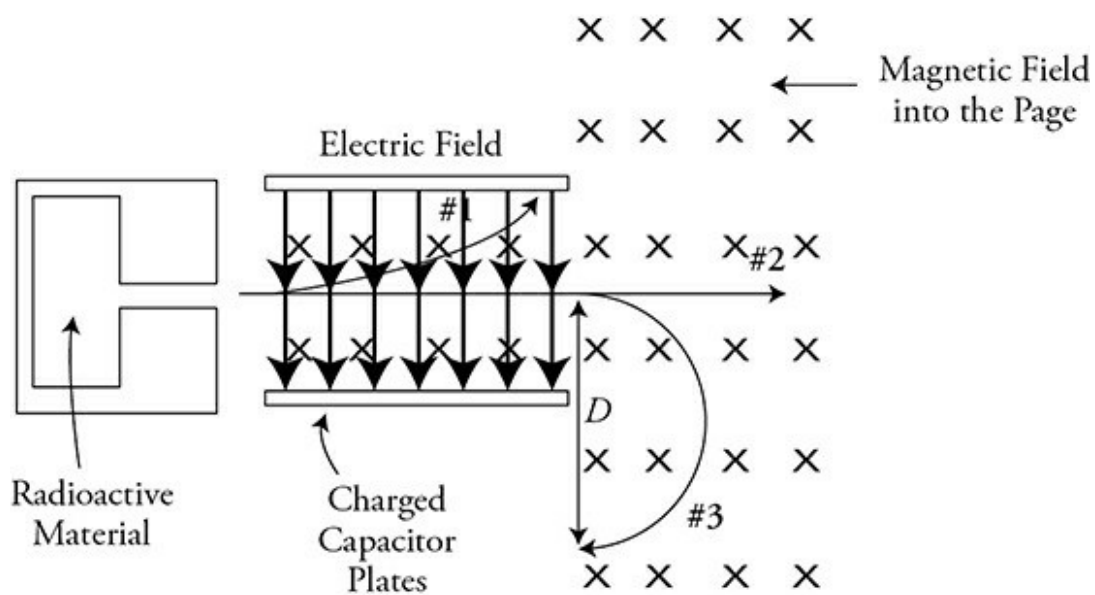
Part (B)

1 point—Student A is incorrect in stating that particle 3 is neutral as evidenced by the fact that it experiences a force exerted by the magnetic field and arcs downward as soon as it leaves the electric field between the charged plates.

1 point—Student C is incorrect in stating that particle 1 is positively charged. Although the direction of the magnetic force on a positive charge would be upward, the bottom plate is negative and the top plate is positive. Thus, the electric force on particle 1 is downward. It is not possible to tell from the given information what the charge of particle 1 is. We can only say for sure that particle 1 has a net charge.

Part (C)

1 point—For indicating that the electric field is pointing directly downward between the plates and uniform in strength.



Part (D)

1 point—For finding the velocity of particle 3 using the magnetic and electric forces between the plates:

$$F_M = F_E$$

$$qvB = Eq$$

$$v = \frac{E}{B}$$

1 point—For setting the magnetic force equal to the centripetal force in the magnetic field:

$$F_B = m \frac{v^2}{r}$$

1 point—For the correct expression for charge to mass ratio:

$$F_B = m \frac{v^2}{r}$$

$$qvB = m \frac{v^2}{\left(\frac{D}{2}\right)}$$

$$qB = 2m \frac{v}{D}$$

$$\frac{q}{m} = \frac{2v}{BD}$$

Substituting in the equation for velocity from above:

$$\frac{q}{m} = \frac{2E}{B^2 D}$$

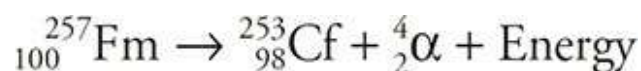
Part (E)

1 point—For clearly explaining that only multiples of the electron charge can be used to find the possible masses of particle 3.

Example: The mass can be found by dividing the charge by the charge to mass ratio (q/m). However, we know that particles come only in multiples of the electron charge. So, dividing the multiple of the electron charge by the charge to mass ratio will give us a set of possible masses for particle 3.

Part (F)

1 point—For the correct nuclear equation showing Californium as the end product with the correct atomic number and atomic mass number:



1 point—For a correct expression of masses and utilizing $E = mc^2$:

$$m_{\text{Fm}} - m_{\text{Cf}} - m_{\alpha} = \Delta mc^2$$

$$\Delta m = \frac{m_{\text{Fm}} - m_{\text{Cf}} - m_{\alpha}}{c^2}$$

1 point—For a correct velocity of the Californium nucleus:

$$P_1 = P_2$$

$$0 = P_2$$

$$m_{\text{Cf}} v_{\text{Cf}} = m_{\alpha} v_{\alpha}$$

$$(253\text{u})v_{\text{Cf}} = (4\text{u})(2 \times 10^7 \text{ m/s})$$

$$v_{\text{Cf}} = 316,000 \text{ m/s}$$

How to Score Practice Exam 1

The practice exam cut points are based on historical exam data and will give you a ballpark idea of where you stand. The bottom line is this: If you can achieve a 3, 4, or 5 on the practice exam, you are doing great and will be well prepared for the real exam in May. This is the curve I use with my own students, and it has been a good predictor of their actual exam scores.

Multiple-Choice Score: Number Correct _____ (50 points maximum)

Free-Response Score: Problem 1 _____ (12 points maximum)
 Problem 2 _____ (10 points maximum)
 Problem 3 _____ (10 points maximum)
 Problem 4 _____ (12 points maximum)
 Free-Response Total: _____ (44 points maximum)

Calculating Your Final Score

Final Score = $(1.136 \times \text{Free-Response Total}) + (\text{Multiple-Choice Score})$

Final Score: _____ (100 points maximum)

Round your final score to the nearest point.

Raw Score to AP Grade Conversion Chart

Final Score on
Practice Exam

AP Grade

70–100

5

4

Outstanding! Keep up the good work.

55–69

40–54

3

Great job! Practice and review to secure a score of 3 or better.

25–39

2

Almost there . . . concentrate on your weak areas to improve your score.

0–24

1

Don't give up! Study hard and move up to a better grade.