AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour and 30 minutes
Number of Questions
40
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 40 multiple-choice questions. Pages containing equations and other information are also printed in this booklet. Calculators, rulers, and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work.

Because this section offers only four answer options for each question, do not mark the (E) answer circle for any question. If you change an answer, be sure that the previous mark is erased completely.

For questions 1 through 36, select the single best answer choice for each question. After you have decided which of the choices is best, completely fill in the corresponding circle on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent	Ⓐ ● Ⓒ Ⓓ Ⓔ

For questions 131 through 134, select the two best answer choices for each question. After you have decided which two choices are best, completely fill in the two corresponding circles on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
New York is a (A) state (B) city (C) country (D) continent	● ● Ⓒ Ⓓ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on Section I is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

Form I
Form Code 4OBP4-S

84

AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	$1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}\text{ kg} = 931\text{ MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}\text{ J·s} = 4.14 \times 10^{-15}\text{ eV·s}$
	$hc = 1.99 \times 10^{-25}\text{ J·m} = 1.24 \times 10^{3}\text{ eV·nm}$
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}\text{ C}^2/\text{N·m}^2$
Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}\text{ N·m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}\text{ N/m}^2 = 1.0 \times 10^{5}\text{ Pa}$

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. In all situations, positive work is defined as work done on a system.
III. The direction of current is conventional current: the direction in which positive charge would drift.
IV. Assume all batteries and meters are ideal unless otherwise stated.
V. Assume edge effects for the electric field of a parallel plate capacitor unless otherwise stated.
VI. For any isolated electrically charged object, the electric potential is defined as zero at infinite distance from the charged object

AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_n\right|$

$a_c = \frac{v^2}{r}$

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

$\Delta \vec{p} = \vec{F}\,\Delta t$

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

$\Delta E = W = F_{\|} d = F d \cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(\omega t) = A\cos(2\pi f t)$

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp} F = r F \sin\theta$

$L = I\omega$

$\Delta L = \tau \Delta t$

$K = \frac{1}{2} I \omega^2$

$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$

a = acceleration
A = amplitude
d = distance
E = energy
F = force
f = frequency
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed

$U_s = \frac{1}{2} k x^2$

$\Delta U_g = mg\,\Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$

$\vec{E} = \frac{\vec{F}_E}{q}$

$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$

$\Delta U_E = q\Delta V$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$\left|\vec{E}\right| = \left|\frac{\Delta V}{\Delta r}\right|$

$\Delta V = \frac{Q}{C}$

$C = \kappa\varepsilon_0 \frac{A}{d}$

$E = \frac{Q}{\varepsilon_0 A}$

$U_C = \frac{1}{2} Q \Delta V = \frac{1}{2} C (\Delta V)^2$

$I = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho \ell}{A}$

$P = I\,\Delta V$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = separation
t = time
U = potential (stored) energy
V = electric potential
v = speed
κ = dielectric constant
ρ = resistivity
θ = angle
Φ = flux

$\vec{F}_M = q\vec{v} \times \vec{B}$

$\left|\vec{F}_M\right| = \left|q\vec{v}\right|\left|\sin\theta\right|\left|\vec{B}\right|$

$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$\left|\vec{F}_M\right| = \left|I\vec{\ell}\right|\left|\sin\theta\right|\left|\vec{B}\right|$

$\Phi_B = \vec{B} \cdot \vec{A}$

$\Phi_B = \left|\vec{B}\right|\cos\theta\left|\vec{A}\right|$

$\mathcal{E} = -\frac{\Delta \Phi_B}{\Delta t}$

$\mathcal{E} = B\ell v$

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = \frac{m}{V}$

$P = \frac{F}{A}$

$P = P_0 + \rho gh$

$F_b = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho {v_1}^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho {v_2}^2$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$

$PV = nRT = Nk_BT$

$K = \frac{3}{2}k_BT$

$W = -P\Delta V$

$\Delta U = Q + W$

A = area
F = force
h = depth
k = thermal conductivity
K = kinetic energy
L = thickness
m = mass
n = number of moles
N = number of molecules
P = pressure
Q = energy transferred to a system by heating
T = temperature
t = time
U = internal energy
V = volume
v = speed
W = work done on a system
y = height
ρ = density

MODERN PHYSICS

$E = hf$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$E = mc^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$\lambda = \frac{v}{f}$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

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

$|M| = \left|\frac{h_i}{h_o}\right| = \left|\frac{s_i}{s_o}\right|$

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
s = distance
v = speed
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

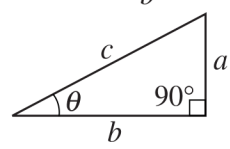
Rectangular solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



PHYSICS 2

Section I

Time—1 hour and 30 minutes

50 Questions

Note: To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

1. Two waves are created in air and move toward outer space. Wave *X* cannot travel in the vacuum of outer space, but wave *Y* can. What types of waves are *X* and *Y*?

	Wave *X*	Wave *Y*
(A)	Electromagnetic	Mechanical
(B)	Electromagnetic	Electromagnetic
(C)	Mechanical	Mechanical
(D)	Mechanical	Electromagnetic

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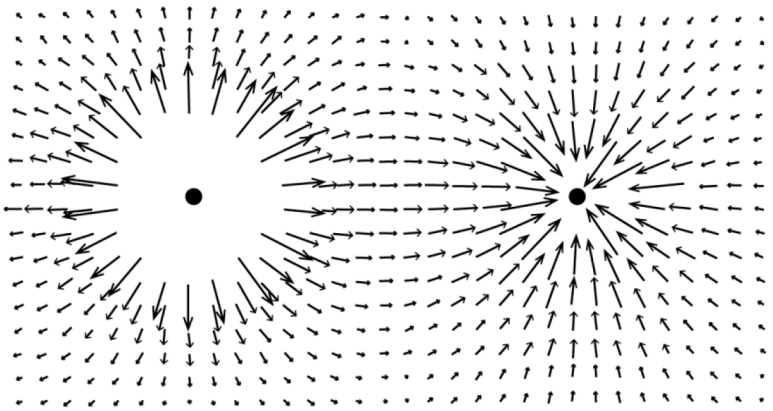

2. Which of the following is a correct description of the field diagram shown above?

(A) It shows field vectors for two particles with charges of opposite sign and about the same magnitude, and it could also represent their gravitational field if they have about the same mass.

(B) It shows field vectors for two particles with charges of opposite sign and about the same magnitude, but it could not represent their gravitational field.

(C) It shows field vectors for two particles with charges of the same sign and about the same magnitude, and it could also represent their gravitational field if they have about the same mass.

(D) It shows field vectors for two particles with charges of the same sign and about the same magnitude, but it could not represent their gravitational field.

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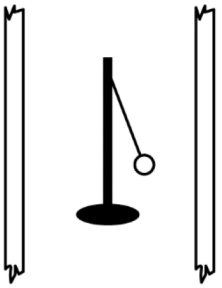
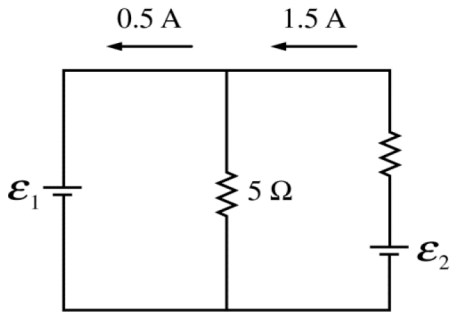


Note: Figure not drawn to scale.

3. Some students are trying to determine whether the radius of a metal sphere affects the amount of charge that it can hold. The students have metal spheres of different radii and known masses that can be attached to a stand by a string, as shown above. The stand is midway between a set of large plates that are connected to a battery to create a nearly uniform electric field in the region between them and near their centers. The students rub a rod with cloth and touch it to each sphere to charge the sphere, and they observe the deflection of the sphere as it is attracted to one plate. They keep adding charge to each sphere until they cannot observe any change in deflection. Which of the following data will give them information that is useful for quantitatively comparing the amount of charge on each sphere?

(A) The number of times they rub the cloth back and forth on the rod
(B) The number of times they touch the rod to the sphere
(C) The string's angle of deflection
(D) The string's direction of deflection



4. What are the value and the direction of the current through the 5 Ω resistor in the circuit shown above?

(A) 1.0 A toward the top of the page
(B) 1.0 A toward the bottom of the page
(C) 2.0 A toward the top of the page
(D) 2.0 A toward the bottom of the page

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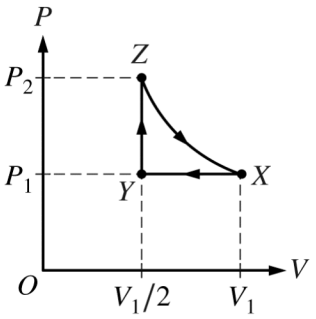
Questions 5-7 refer to the following material.



A closed chamber filled with a gas that is modeled as ideal has a movable piston of area A. The graph above of pressure P as a function of volume V shows three processes that make up cycle $XYZX$ through which the gas is taken. Process ZX is isothermal.

5. During which process is no work done on or by the gas?

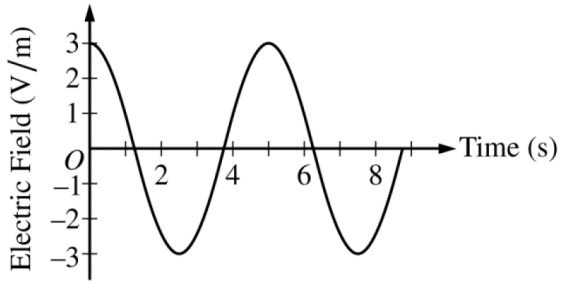
(A) XY
(B) YZ
(C) ZX
(D) Work was done on or by the gas during every process.

6. What is the force exerted on the piston by the gas during process XY ?

(A) P_1V_1
(B) $P_1V_1/2$
(C) P_1A
(D) $P_1A/2$

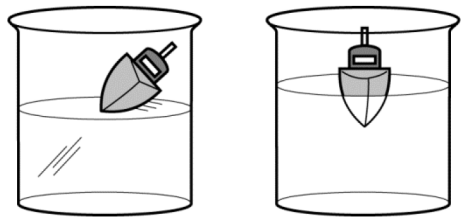
7. During which process is the amount of work done on the gas equal to the amount of energy that the gas exchanges with its surroundings through heating or cooling?

(A) XY
(B) YZ
(C) ZX
(D) None of the processes; the amount of work done on the gas is always greater than the amount of energy that the gas exchanges with its surroundings through heating or cooling.



8. The graph above represents the magnitude E of the electric field at a point in space as a function of time t. Which of the following is a correct equation for the field if E is in V/m and t is in s?

(A) $E = 3\cos(2\pi t/5)$
(B) $E = 3\cos(2\pi t/3)$
(C) $E = 5\cos(2\pi t/5)$
(D) $E = 5\cos(2\pi t/3)$



9. A toy boat sits atop a cylinder of ice in a beaker, as shown above on the left. A normal force is exerted on the boat by the surface of the ice. Later the ice has melted, and the boat floats while partially submerged in the water, as shown on the right. A buoyant force is exerted on the boat by the water. Which of the forces, if either, is greater and why?

(A) The normal force is greater because molecules in solids exert larger interatomic forces on other objects than molecules in liquids do.
(B) The buoyant force is greater because more molecules of water are in contact with the boat, so the net interatomic force between the water and the boat is greater.
(C) The forces are equal because each molecule of ice in contact with the boat exerts the same interatomic force on the boat as each molecule of water in contact with the boat.
(D) The forces are equal because in both cases the net interatomic force exerted by the ice or water on the boat and the gravitational force on the boat balance.

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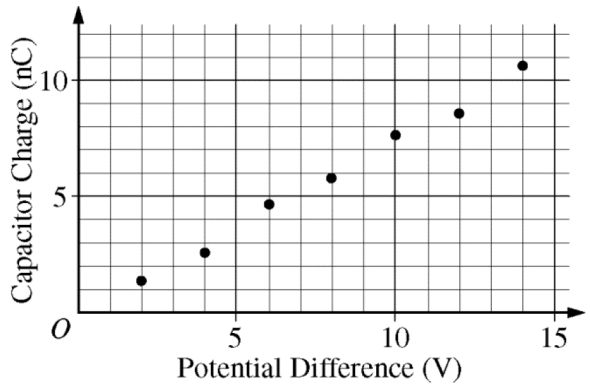
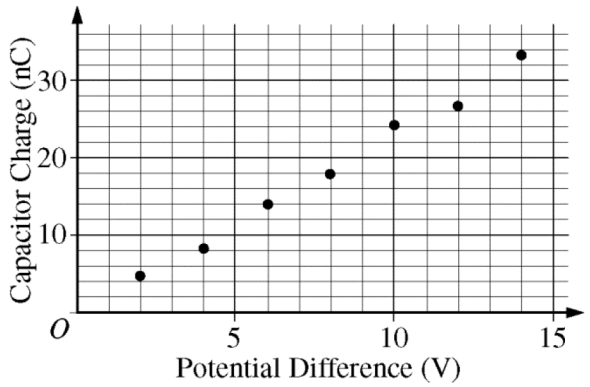


Graph 1: Capacitor with Air



Graph 2: Capacitor with Dielectric

10. A capacitor initially has only air between its plates. The charge on the capacitor as a function of applied potential difference is measured, and the results are shown in graph 1 above. The capacitor is discharged, a dielectric material is inserted between the plates, and the charge as a function of applied potential difference is measured again. The results are shown in graph 2. Which of the following is equal to the dielectric constant of the material inserted into the capacitor?

(A) The slope of graph 1 divided by the slope of graph 2
(B) The slope of graph 2 divided by the slope of graph 1
(C) The vertical intercept of graph 1 divided by the vertical intercept of graph 2
(D) The vertical intercept of graph 2 divided by the vertical intercept of graph 1

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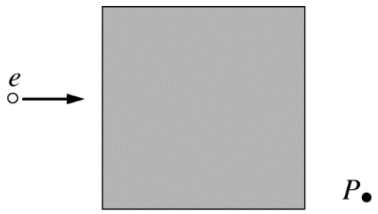
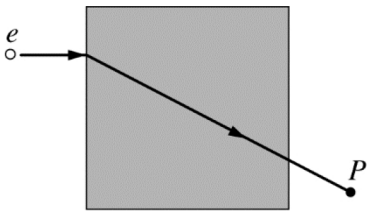
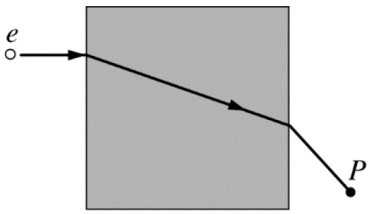
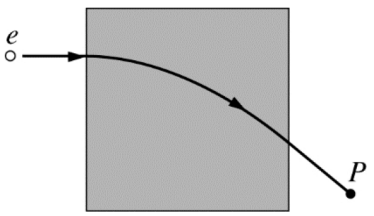
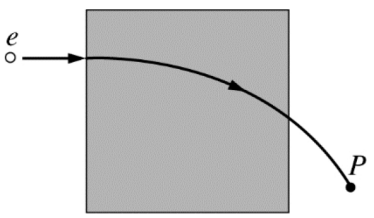


11. An electron is moving to the right, as shown in the figure above. It passes through the shaded region, which contains a magnetic field directed into the page. The electron travels along a path that takes it through point *P*. The gravitational force on the electron is negligible. Which of the following is a possible path of the electron?

(A)


(B)


(C)


(D)


Object Distance from Lens	Orientation of Image	Type of Image	Size of Image Compared to Object
5 cm	Upright	Virtual	Larger
10 cm	Upright	Virtual	Larger
15 cm	Inverted	Real	Larger
25 cm	Inverted	Real	Smaller

12. A student uses a convex lens to create images and collects the data shown above. The focal length of the lens is in which of the following ranges?

(A) 0–5 cm
(B) 5–10 cm
(C) 10–15 cm
(D) 15–25 cm

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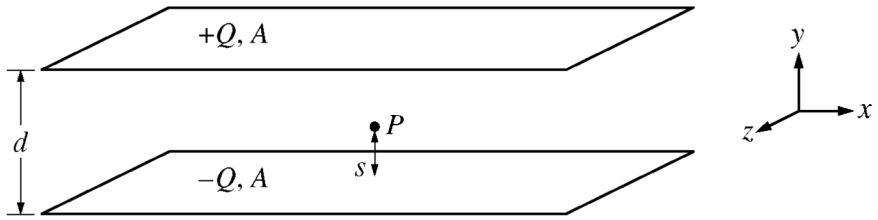
Questions 13-15 refer to the following material.



Two conducting plates of area A are separated by a distance d, as shown above. The upper plate has a net charge of $+Q$ and the lower plate has a net charge of $-Q$. Point P is located a distance s above the center of the lower plate and closer to the lower plate than the upper plate. Assume the plate dimensions are very large compared to d and all gravitational forces are negligible.

13. Which of the following indicates the direction of the electric field at point P and the reason it has that direction?

(A) The electric field is in the $+x$ direction because the charges are equal and opposite.
(B) The electric field is in the $-y$ direction because point P is farther from the positively charged plate.
(C) The electric field is in the -y direction because electric fields point away from positive charge and toward negative charge.
(D) The electric field is in the $+y$ direction because electric fields point away from negative charge and toward positive charge.

14. Assume the magnitude of the electric field at point P is 5.0×10^4 N/C. What is the magnitude and direction of the force on an electron at point P due to the electric field?

(A) 3.1×10^{23} N in the same direction as the electric field
(B) 3.1×10^{23} N in the direction opposite to the electric field
(C) 8.0×10^{-15} N in the same direction as the electric field
(D) 8.0×10^{-15} N in the direction opposite to the electric field

15. If the magnitude of the electric field at point P is 5.0×10^4 N/C and the distance between the plates is 0.80 mm, what is the electrical potential difference between the plates?

(A) 40 V
(B) 62.5 V
(C) 4000 V
(D) 6250 V

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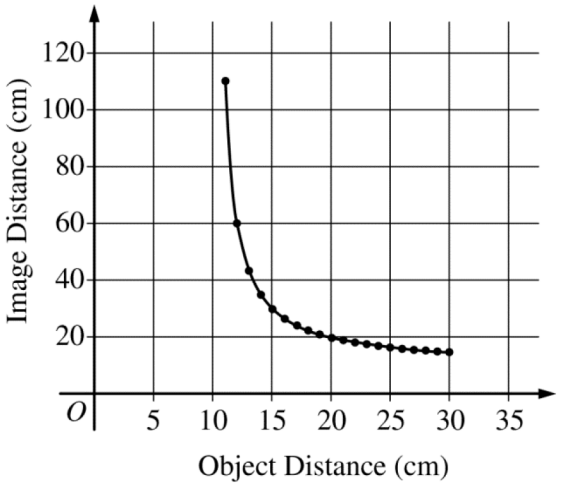
$$^{238}_{92}\mathrm{U} + X \rightarrow {}^{239}_{92}\mathrm{U}$$

$$^{239}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} + Y + \overline{\nu}$$

$$^{239}_{93}\mathrm{Np} \rightarrow {}^{239}_{94}\mathrm{Pu} + Y + \overline{\nu}$$

16. The three reactions shown above, with unidentified particles X and Y, occur in the manufacturing process of plutonium. What particles do X and Y represent?

	X	Y
(A)	$^{1}_{0}\mathrm{n}$	α
(B)	γ	β^{-}
(C)	γ	α
(D)	$^{1}_{0}\mathrm{n}$	β^{-}



17. Some students collect data to determine the focal length of a concave mirror. Using a small candle as the object, they move a piece of white cardboard until they see a focused image of the candle flame on it. The students measure the distances of the candle and the image from the mirror. A graph of the data is shown above. Which of the following is closest to the focal length of the mirror?

(A) 10 cm
(B) 15 cm
(C) 20 cm
(D) 30 cm

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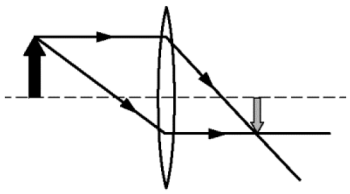
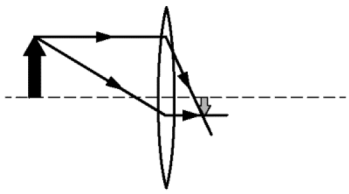
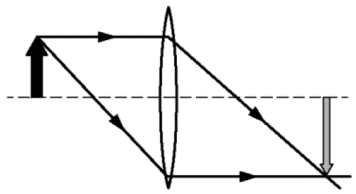


Lens 1



Lens 2



Lens 3

18. A student is comparing three lenses of the same size and shape that are made of different materials. A small object, represented by the thick black arrow, is held on one side of each lens. The ray diagrams above show the formation of the image, represented by the gray arrow, for each lens. Which of the following correctly ranks the index of refraction n of the lenses?

(A) $n_1 > n_2 > n_3$

(B) $n_2 > n_1 > n_3$

(C) $n_3 > n_1 > n_2$

(D) $n_3 > n_2 > n_1$

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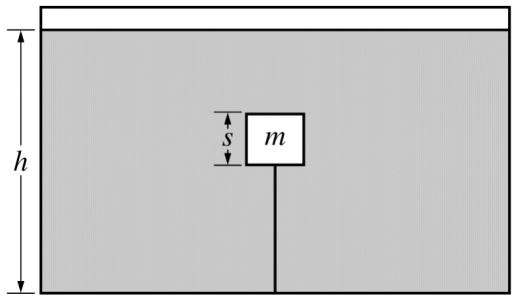
Questions 19-20 refer to the following material.



A cube of mass m with sides of length s is completely submerged in a tank of fluid of density ρ and held in place by a string attached to the bottom of the tank, as shown above. The height of the fluid is h, and the string has a nonzero tension F_T.

19. Which of the following indicates how the density of the cube compares with the density of the fluid and provides correct evidence for the comparison?

(A) The fact that the cube is completely submerged is evidence that the density of the cube is greater than the density of the fluid.

(B) The fact that the cube is completely submerged is evidence that the density of the cube is less than the density of the fluid.

(C) The fact that there is tension in the string is evidence that the density of the cube is greater than the density of the fluid.

(D) The fact that there is tension in the string is evidence that the density of the cube is less than the density of the fluid.

20. Which of the following is a correct expression for the density of the cube?

(A) $\left(\rho s^3 g + F_T\right) / s^3 g$

(B) $\left(\rho s^3 g - F_T\right) / s^3 g$

(C) $\left(F_T + mg\right) / s^3 g$

(D) $\left(F_T - mg\right) / s^3 g$

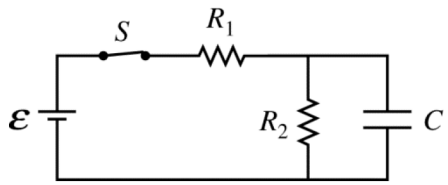
21. About 1×10^{-29} kg of mass is lost when an atom of a certain isotope of plutonium, Pu-239, undergoes a single alpha decay. A small sample is composed of 3×10^{19} Pu-239 atoms. If all the nuclei in the sample undergo alpha decay, the energy released is most nearly

(A) 9×10^{-13} J

(B) 9×10^{-2} J

(C) 3×10^{7} J

(D) 3×10^{21} J



22. The circuit shown above includes a battery, two resistors, and a capacitor with values as labeled. The current through the battery is I. Which of the following is a correct equation for potential differences in the circuit a long time after the switch is closed?

(A) $\mathcal{E} - IR_1 - IR_2 = 0$

(B) $\mathcal{E} + IR_1 + IR_2 = 0$

(C) $\mathcal{E} - IR_1 - IR_2 - C\mathcal{E} = 0$

(D) $\mathcal{E} - IR_1 - IR_2 + C\mathcal{E} = 0$

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23. The figure above represents three identical closed containers holding the same number of moles of different gases at the same temperature. From left to right, the gases are in order from smallest molar mass (H_2) to largest molar mass (O_2). Modeling the gases as ideal, which gas, if any, has the greatest internal energy?

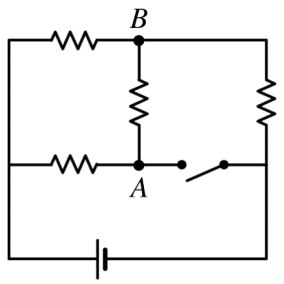
(A) H_2
(B) N_2
(C) O_2
(D) All have the same internal energy.

24. A plutonium nucleus of mass M is at rest when it spontaneously emits a high-energy photon of frequency f. After the decay, the photon moves off in one direction and the nucleus recoils with speed v in the opposite direction. The nucleus' mass decreases by an amount Δm. Which of the following equations correctly represents the conservation of energy in the decay?

(A) $(\Delta m)c^2 = \frac{1}{2}(M - \Delta m)v^2 + hf$
(B) $(\Delta m)c^2 = \frac{1}{2}(M - \Delta m)v^2 - hf$
(C) $Mc^2 = \frac{1}{2}(M - \Delta m)v^2 + hf$
(D) $Mc^2 = \frac{1}{2}(M - \Delta m)v^2 - hf$

25. A student wants to increase the temperature of an ideal gas in a cylinder that is initially at room temperature. The cylinder has a movable piston with negligible friction. Which of the following correctly indicates an action the student could take to increase the temperature of the gas, and why the temperature increases?

(A) Pull the piston out rapidly. The gas will expand violently and increase in temperature.
(B) Pull the piston out slowly. The gas will have time to absorb energy from the surroundings by heating as it expands.
(C) Push the piston in rapidly. The temperature of the gas will increase because no energy will be transferred to the surroundings by cooling.
(D) Push the piston in slowly. The gas will have time to absorb energy from the surroundings by heating as it is compressed.



26. The circuit shown above contains four identical resistors connected to a battery and a switch. Which of the following correctly describes the direction of the current, if any, between points A and B when the switch is open and when it is closed?

	Switch Open	Switch Closed
(A)	From B to A	From B to A
(B)	From B to A	From A to B
(C)	From A to B	No current
(D)	From A to B	From B to A

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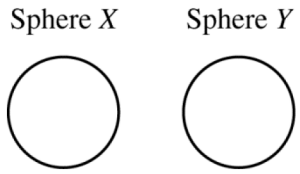
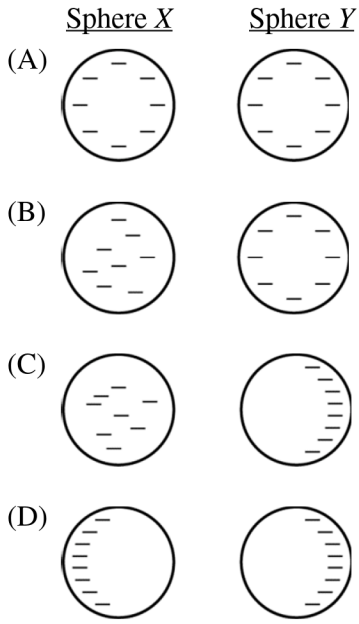


27. Small solid sphere X is made of an insulating material and has negative charge distributed throughout its volume. Small solid sphere Y is made of a conducting material and is also negatively charged. The spheres are initially far apart and are then brought near each other, as shown above. Which of the following cross sections best represents the charge distribution on the two spheres when they are near each other?



Current Through Bulb (A)	Intensity of Light from the Bulb $\left(\mathrm{W/m^2}\right)$
5	74
10	298
15	675
20	1200
40	4800

28. A student wishes to determine if a particular lightbulb is an ohmic resistor. The student assumes that the intensity of light from the bulb is directly proportional to the power it dissipates. The student measures the light intensity at one location near the bulb and the current through the bulb as the voltage across the bulb is varied. The data are shown above. Based on the data, is the bulb ohmic, and why?

(A) No, because the power is a linear function of the current.
(B) No, because the power is a quadratic function of the current.
(C) Yes, because the power is a linear function of the current.
(D) Yes, because the power is a quadratic function of the current.

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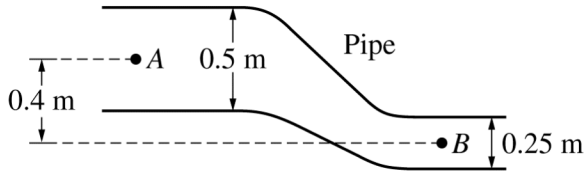
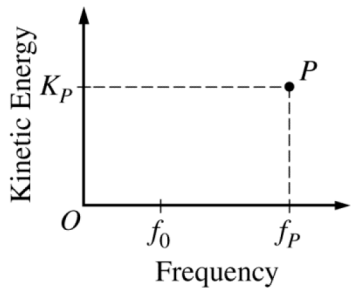


29. An ideal fluid with density $960\ \text{kg/m}^3$ fills the pipe shown in the side view above and flows through it. The pipe has a circular cross section, and the speed of the fluid at point A is $0.6\ \text{m/s}$. The difference in the pressure of the fluid at points A and B is most nearly

(A) 1.2×10^3 Pa
(B) 2.6×10^3 Pa
(C) 3.8×10^3 Pa
(D) 6.4×10^3 Pa

30. Student 1 brings a negatively charged rod with an insulating handle near to but not touching an uncharged metal sphere and finds that the objects attract. She wants the sphere to be repelled by the rod. Student 2, who is uncharged, suggests that this can be accomplished if he touches the sphere. Which of the following indicates whether this will work, and if so, gives a procedure that will cause the repulsion?

(A) Yes, Student 2 could touch the sphere while the rod is held near it, because that would make the sphere negatively charged.
(B) Yes, Student 2 could touch the sphere while the rod is kept far away, because that would make the sphere negatively charged.
(C) Yes, Student 2 could touch the sphere while the rod is kept far away, because that would make the sphere positively charged.
(D) No, there is no way that having Student 2 touch the sphere will work.



31. When light of frequency f_P is incident on a metal with threshold frequency fo, electrons are ejected with maximum kinetic energy K_P. This is represented in the graph above by point P. How would the location of point P on the graph change if the intensity of the same light source were increased?

(A) P would not move.
(B) P would move vertically up.
(C) P would move horizontally to the right.
(D) P would move diagonally up and to the right.

32. A student is doing an experiment in which monochromatic light passes through a double slit, creating a pattern of dark and bright lines on a nearby screen. The student has a red light and a green light. The student also has two sets of slits, one with a small separation between the slits and one with a large separation. Which of the following lists the color and slit separation that will create the pattern with the greatest separation between the bright lines?

	Color	Slit Separation
(A)	Green	Large
(B)	Green	Small
(C)	Red	Large
(D)	Red	Small

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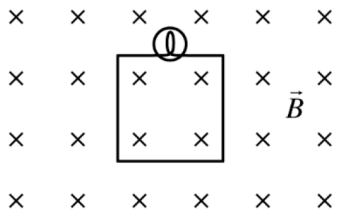

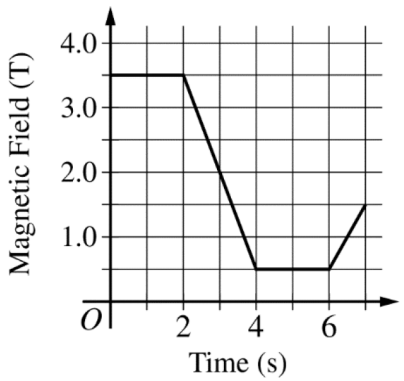

33. A circuit containing only a lightbulb is placed in a uniform magnetic field $\vec{B}$ directed into the page, as shown above on the left. The variation of the magnetic field as a function of time is shown in the graph. During which of the following intervals will the bulb be brightest?

(A) 0-2 s
(B) 2-4 s
(C) 4-6 s
(D) 6-7 s

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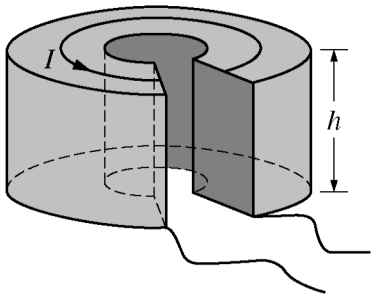
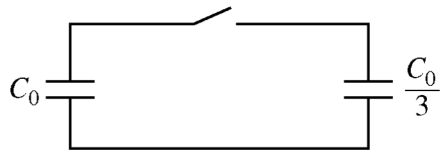
34. Electronic transitions between the $n = 2$ and $n = 4$ energy levels of a hydrogen atom are associated with the emission or absorption of photons of visible light of frequency f. Which of the following statements about the electronic transition from the $n = 1$ to the $n = 4$ energy level of hydrogen must be true as a consequence of energy conservation?

(A) A photon with a frequency greater than f must be absorbed by the atom.
(B) A photon with a frequency greater than f must be emitted by the atom.
(C) A photon with a frequency smaller than f must be absorbed by the atom.
(D) A photon with a frequency smaller than f must be emitted by the atom.



35. A piece of a thick ring of metal with height h and resistance R is connected to a battery, creating a uniform current I throughout the piece of ring, as shown in the figure above. A second piece of a ring has height $2h$ but is otherwise identical to the first piece. The second piece of ring is connected to the battery in the same way as the first piece. What is the resistance of the second piece?

(A) $R/4$
(B) $R/2$
(C) $2R$
(D) $4R$



36. A capacitor with capacitance C_0 has a charge Q_0. It is then connected in a circuit with a switch and an initially uncharged capacitor with capacitance $C_0/3$, as shown in the figure above. What are the final charges on the capacitors a long time after the switch is closed?

	Charge on C_0	Charge on $C_0/3$
(A)	$\frac{Q_0}{2}$	$\frac{Q_0}{2}$
(B)	$\frac{Q_0}{3}$	$\frac{2Q_0}{3}$
(C)	$\frac{3Q_0}{4}$	$\frac{Q_0}{4}$
(D)	$\frac{2Q_0}{3}$	$\frac{Q_0}{3}$

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Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in each case and then fill in the corresponding circles that begin with number 131 on page 3 of the answer sheet.

131. Conducting rod *A* will be given a positive charge in a procedure that uses some or all of the following steps in an appropriate order.

Step W: Rod *A* is connected to ground.

Step X: Negatively charged rod *B* is brought near, but does not touch, rod *A*.

Step Y: The connection between ground and rod *A* is removed.

Step Z: Rod *B* is moved away.

Which of the following lists sufficient steps in an order that will give rod *A* a positive charge? Select two answers.

(A) W, X, Y
(B) W, X, Z
(C) W, X, Y, Z
(D) W, X, Z, Y

132. Which of the following accurately describe how the kinetic energy of atoms in a sample of monatomic ideal gas changes when the temperature is increased? Select two answers.

(A) The kinetic energy of each individual atom in the gas increases.
(B) The kinetic energy of each individual atom in the gas may increase or decrease.
(C) The average kinetic energy of the whole sample of atoms increases.
(D) The kinetic energy of some individual atoms increases, but the average kinetic energy of the whole sample of atoms does not change.

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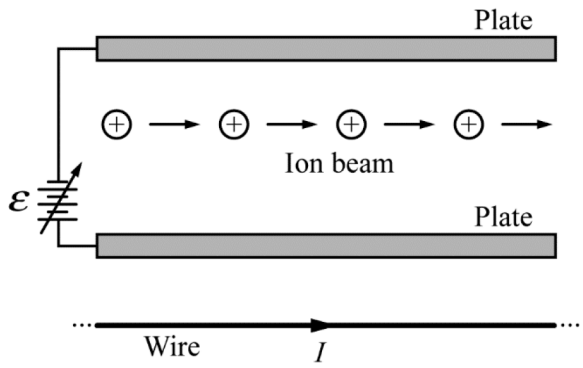

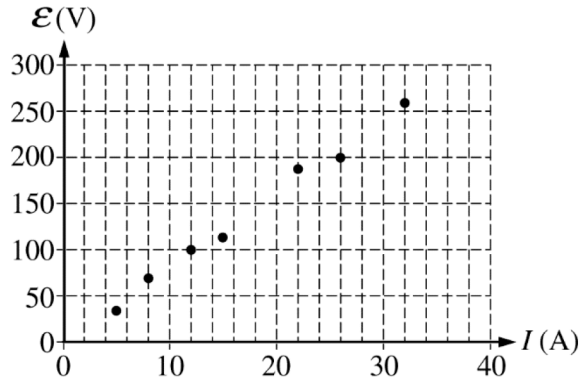

133. A beam of identical positively charged ions moves from left to right between two parallel plates, as shown in the figure on the left above. A wire is located below the plates and parallel to the ion beam. The distance between the plates, the length of the plates, and the distance between the ion beam and the wire are known. A current I in the wire deflects the ion beam from a straight path. The potential difference ε across the plates is then adjusted to return the beam to the straight path. The graph above plots the potential difference across the plates as a function of the current in the wire. Which of the following can be determined from the slope of the graph? Select two answers.

(A) The mass of an ion in the beam if the charge on the ion is known
(B) The average speed of the ions in the beam
(C) The amount of charge on an ion in the beam if the mass of the ion is known
(D) The time an ion spends between the plates

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134. One way to model the allowed states of a hydrogen atom is to treat the atom's single electron as a standing wave with a wavelength λ. Which of the following could be the radius of the orbit of the electron in such a model? Select two answers.

(A) $2\lambda/\pi$

(B) $\lambda/4\pi$

(C) $\lambda/2\pi$

(D) $\lambda/2$

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GO ON TO THE NEXT PAGE.

END OF SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET.**

AP® Physics 2: Algebra-Based Exam

SECTION II: Free Response

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour and 30 minutes
Number of Questions
4
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Suggested Time
Approximately 25 minutes each for questions 2 and 3 and 20 minutes each for questions 1 and 4
Weight
Approximate weights:
Questions 2 and 3: 27% each
Questions 1 and 4: 23% each

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
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Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4OBP4-S

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AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	$1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. In all situations, positive work is defined as work done on a system.
III. The direction of current is conventional current: the direction in which positive charge would drift.
IV. Assume all batteries and meters are ideal unless otherwise stated.
V. Assume edge effects for the electric field of a parallel plate capacitor unless otherwise stated.
VI. For any isolated electrically charged object, the electric potential is defined as zero at infinite distance from the charged object

AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_n\right|$

$a_c = \frac{v^2}{r}$

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

$\Delta \vec{p} = \vec{F}\,\Delta t$

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

$\Delta E = W = F_{\|} d = F d \cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(\omega t) = A\cos(2\pi f t)$

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp} F = r F \sin\theta$

$L = I\omega$

$\Delta L = \tau \Delta t$

$K = \frac{1}{2} I \omega^2$

$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$

a = acceleration
A = amplitude
d = distance
E = energy
F = force
f = frequency
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed

$U_s = \frac{1}{2} k x^2$

$\Delta U_g = mg\,\Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$

$\vec{E} = \frac{\vec{F}_E}{q}$

$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$

$\Delta U_E = q\Delta V$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$\left|\vec{E}\right| = \left|\frac{\Delta V}{\Delta r}\right|$

$\Delta V = \frac{Q}{C}$

$C = \kappa\varepsilon_0 \frac{A}{d}$

$E = \frac{Q}{\varepsilon_0 A}$

$U_C = \frac{1}{2} Q \Delta V = \frac{1}{2} C (\Delta V)^2$

$I = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho \ell}{A}$

$P = I\,\Delta V$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = separation
t = time
U = potential (stored) energy
V = electric potential
v = speed
κ = dielectric constant
ρ = resistivity
θ = angle
Φ = flux

$\vec{F}_M = q\vec{v} \times \vec{B}$

$\left|\vec{F}_M\right| = \left|q\vec{v}\right|\left|\sin\theta\right|\left|\vec{B}\right|$

$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$\left|\vec{F}_M\right| = \left|I\vec{\ell}\right|\left|\sin\theta\right|\left|\vec{B}\right|$

$\Phi_B = \vec{B} \cdot \vec{A}$

$\Phi_B = \left|\vec{B}\right|\cos\theta\left|\vec{A}\right|$

$\mathcal{E} = -\frac{\Delta \Phi_B}{\Delta t}$

$\mathcal{E} = B\ell v$

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = \frac{m}{V}$

$P = \frac{F}{A}$

$P = P_0 + \rho gh$

$F_b = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho {v_1}^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho {v_2}^2$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$

$PV = nRT = Nk_BT$

$K = \frac{3}{2}k_BT$

$W = -P\Delta V$

$\Delta U = Q + W$

A = area
F = force
h = depth
k = thermal conductivity
K = kinetic energy
L = thickness
m = mass
n = number of moles
N = number of molecules
P = pressure
Q = energy transferred to a system by heating
T = temperature
t = time
U = internal energy
V = volume
v = speed
W = work done on a system
y = height
ρ = density

MODERN PHYSICS

$E = hf$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$E = mc^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$\lambda = \frac{v}{f}$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

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

$|M| = \left|\frac{h_i}{h_o}\right| = \left|\frac{s_i}{s_o}\right|$

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
s = distance
v = speed
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

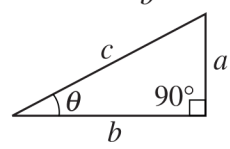
Rectangular solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



PHYSICS 2

Section II

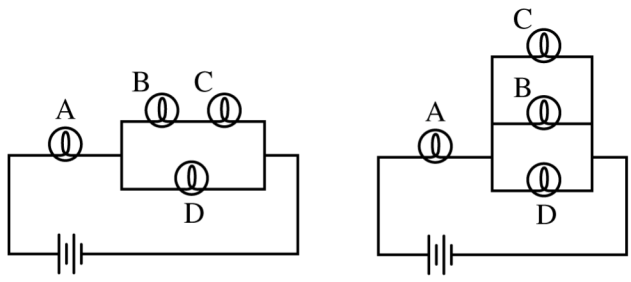
Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

1. (10 points, suggested time 20 minutes)

   A student is performing some lab experiments with batteries, ohmic resistors, capacitors, and some identical ohmic lightbulbs.



Circuit 1 Circuit 2

   (a) The student first connects four lightbulbs and an ideal battery as shown above in circuit 1 and observes the brightness of each lightbulb. The student then moves lightbulb C to obtain circuit 2. In a coherent, paragraph-length response, describe how the brightnesses of lightbulbs A and D in circuit 2 compare to their brightnesses in circuit 1. Support your claims with appropriate physics principles.

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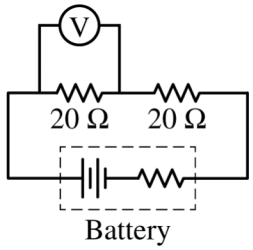
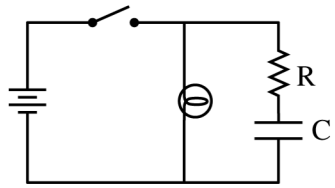


(b) The student thinks that one of the available batteries has a nonnegligible internal resistance. The student measures the potential difference across the battery as 9 V when it is not connected to any other circuit elements. The student then connects the circuit shown above, where the battery is represented by the circuit elements in the dashed box. The voltmeter indicates that the potential difference across one resistor is 4 V. Calculate the internal resistance of the battery.

(c) One of the lightbulbs is now connected with an ideal battery, an open switch, a resistor R and an initially uncharged capacitor C, as shown below. The resistance of the lightbulb and the resistor are about the same. The switch is then closed and left closed for a long time. Describe how, if at all, the brightness of the lightbulb changes during the time the switch remains closed, and explain why.



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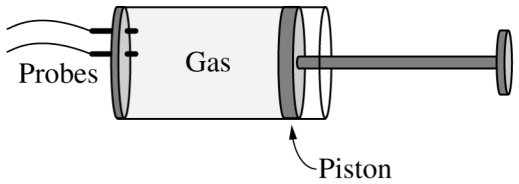


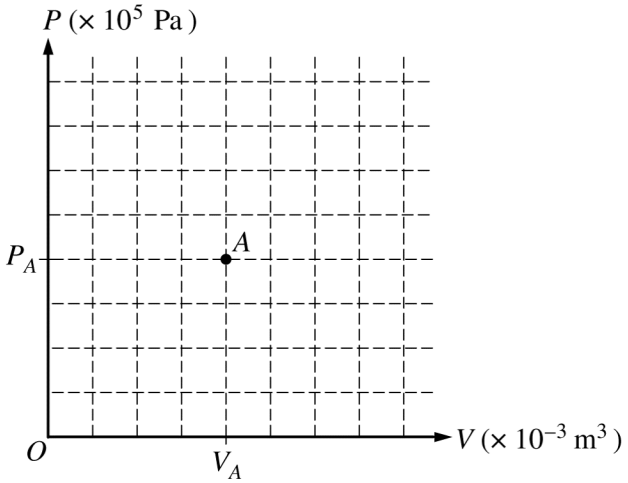
2. (12 points, suggested time 25 minutes)

A cylinder with a movable piston contains a sample of ideal gas. A temperature probe and a pressure probe are inserted into the cylinder, as shown above. The sample of gas is taken through a three-step cycle, *ABCA*.

- In process *AB*, the volume is decreased to $1/4$ its original value while constant pressure is maintained.
- In process *BC*, the gas expands back to its original volume isothermally.
- In process *CA*, the gas returns to its original state without any work being done on or by the gas.

(a)

i. On the axes below, draw a graph of pressure *P* as a function of volume *V* for the three-step process *ABCA*, labeling states *B* and *C*. The pressure and volume of state *A* are P_A and V_A, respectively. Label the axes with the values of pressure and volume for states *B* and *C* in terms of P_A and V_A.



ii. For process *BC*, is energy added to the gas by heating or removed from the gas by cooling? Support your claim using physics principles.

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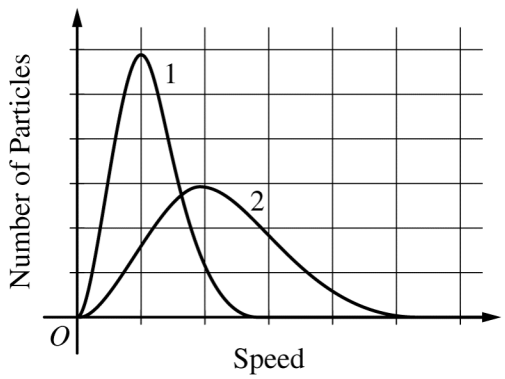
(b) For process *CA*, is the net flow of energy into the gas or out of the gas? Explain your reasoning using physics principles. Describe one method by which this flow of energy could be accomplished in the laboratory.

(c) Curves 1 and 2 below show the distributions of particle speeds when the sample of gas is in two of the states, with curve 1 a state that occurs before curve 2 as the gas goes through the cycle. Which states correspond to curve 1 and 2? Support your claim using physics principles.



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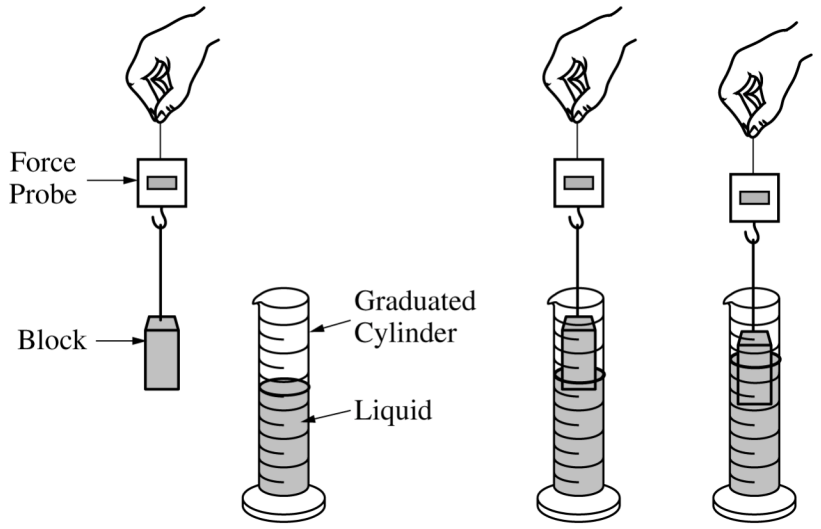

3. (12 points, suggested time 25 minutes)

Two groups of students are given samples of the same unknown liquid and are asked to identify the liquid. The first group decides to do this by determining its density ρ_L. The students pour a volume V_i of the liquid into a graduated cylinder. They then hang a long solid block of mass m, from a force probe and lower the block partially into the liquid, as shown above. The students record the reading on the force probe and the volume reading V_f on the graduated cylinder for various amounts of the block lowered into the liquid.

(a)

i. On the square below, which represents the block, draw and label the forces (not components) that are exerted on the block when it is stationary and partially submerged in the liquid. Each force must be represented by a distinct arrow starting on, and pointing away from, the square.

ii. Derive an equation for the force probe reading F_p in terms of ρ_L, m_b, V_i, V_f, and physical constants, as appropriate.

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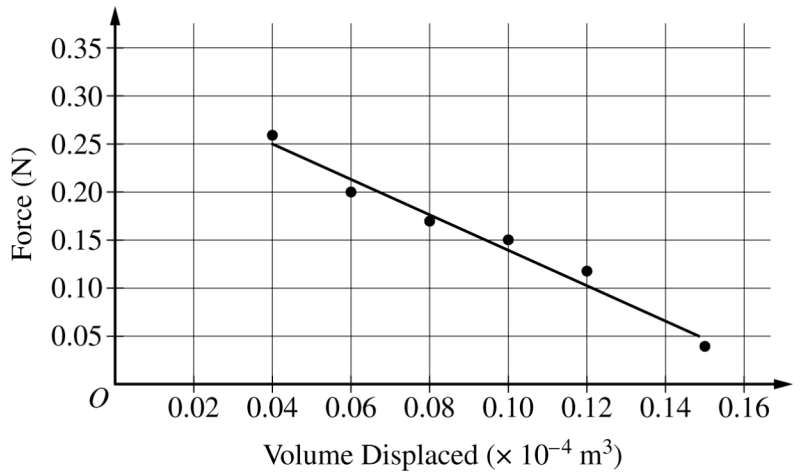
GO ON TO THE NEXT PAGE.

The data the students collected and the graph they plotted are shown below. The initial volume V_i of liquid in the cylinder is 1.00×10^{-4} m^3.

Volume Reading V_f $\left(\times 10^{-4}\ \text{m}^3\right)$	1.04	1.06	1.08	1.1	1.12	1.15
Volume Displaced ΔV $\left(\times 10^{-4}\ \text{m}^3\right)$	0.04	0.06	0.08	0.10	0.12	0.15
Force Probe Reading (N)	0.26	0.20	0.17	0.15	0.12	0.04



(b)

i. State the physical meaning of the slope of the line and its intercept with the vertical axis.

ii. Use the graph to calculate the density of the liquid.

Question 3 continues on the next page.

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The students in the second group decide to determine the index of refraction of the liquid. They have a laser pointer and a transparent, thin-walled rectangular container to hold the liquid. They also have access to common laboratory equipment.

(c) Describe an experimental procedure this group could use to determine the index of refraction of the unknown liquid. In your description include the measurements to be taken. Also include the corresponding equipment needed. Sketch a diagram showing the experimental setup with labels corresponding to the measurements you indicated. Describe how the measurements will be used to calculate the index of refraction of the liquid.

Write procedure here.

Draw labeled diagram here.

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GO ON TO THE NEXT PAGE.

4. (10 points, suggested time 20 minutes)

The allowed energy levels of a hypothetical atom have principal quantum numbers n = 1, 2, 3, and 4 and energies of -8 eV, -5 eV, -2 eV, and -1 eV.

(a)

i. Draw the energy-level diagram for the atom. Label each level with the appropriate energy and principal quantum number.

ii. Calculate the frequency of a photon that will excite the atom from its ground state to the $n = 3$ state.

iii. A photon of wavelength 124 nm is incident on the atom and causes an electron in the ground state to be ejected from the atom. Neglecting relativistic effects, calculate the speed of the electron.

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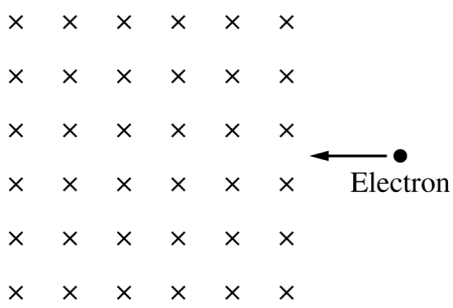
(b) The ejected electron then enters a region of space that contains a constant, uniform magnetic field directed into the plane of the page. The electron is moving to the left in the plane of the page when it enters the field.



i. On the figure above, draw a possible path for the electron as it travels through the region of the magnetic field. Describe what happens to the speed of the electron as it passes through the field, and explain why this happens.

ii. To make the electron travel in a straight line to the left through the magnetic field, an electric field can be applied in the region. What is the direction of the required electric field? Justify your choice based on physics principles.

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STOP

END OF EXAM

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.**

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE FRONT COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**