Name:_____

Answer Sheet for AP Physics 2: Algebra-Based

Practice Exam, Section I

No.	Answer
1	
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No.	Answer	
21		
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35		
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131		
132		
133		
134		

AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice

2019

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 4PBP4-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 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 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 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

$\tau = r_\perp F = rF\sin\theta$

$L = I\omega$

$\Delta L = \tau\,\Delta t$

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

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

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

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

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

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

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

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

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

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

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

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

$PV = nRT = Nk_BT$

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

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

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

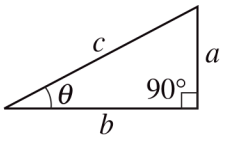
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

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

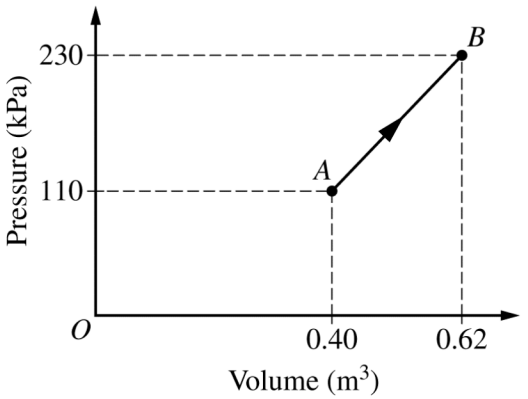
40 Questions

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. Radioactive element X has a half-life of approximately 50 days. Radioactive element Y has a half-life of approximately 100 days. A 0.8 g sample of element X and a 0.8 g sample of element Y are weighed and examined. Some time later, both samples are measured again and 0.2 g of element X remains. How much of element Y remains?

   (A) 0.1 g
   (B) 0.2 g
   (C) 0.4 g
   (D) 0.8 g



2. A sample of a gas is in a container with a movable piston. Only one action is performed to take the gas from state *A* to state *B* via the process shown in the above graph of pressure as a function of volume. Which of the following could be the one action?

   (A) Gas molecules were removed from the container.
   (B) Thermal energy was added to the gas.
   (C) The piston was pulled out.
   (D) The gas was allowed to freely expand.

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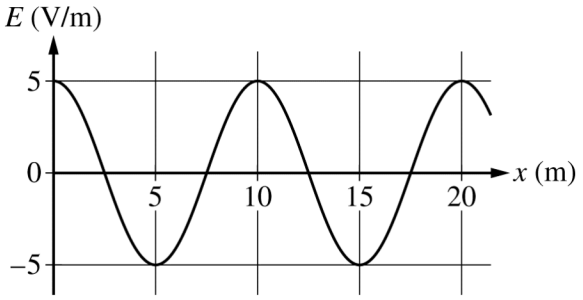


3. The graph above shows the electric field E of an electromagnetic wave as a function of position x at a particular instant. Which of the following equations, where all quantities are assumed to have units consistent with the graph, best represents the graph?

(A) $E = 10\cos(2\pi x/10)$

(B) $E = 10\cos(2\pi x/5)$

(C) $E = 5\cos(2\pi x/10)$

(D) $E = 5\cos(2\pi x/5)$

4. Some students observe that a hollow metal sphere hanging on an insulating string is attracted to a positively charged rod. They decide that this is evidence that the sphere could also be charged. The answer to which of the following questions might determine whether they are correct?

(A) Is the sphere still attracted when the positively charged rod is placed on the other side of the sphere?

(B) Is the sphere repelled by a negatively charged rod?

(C) Is the attraction of the sphere to the rod weaker when the distance between them is increased?

(D) Is the attraction of the sphere to the rod stronger when the charge on the rod is doubled?

5. Two identical containers, X and Y, each contain one mole of an ideal monatomic gas. The atoms in container X have a higher average kinetic energy than those in container Y. The containers are thermally insulated from the external environment and placed into thermal contact with each other at time $t = 0$. Which of the following accurately describes the interactions between containers X and Y?

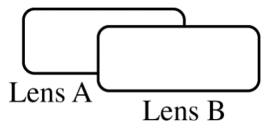
(A) The net result is that energy is transferred from container X to container Y.

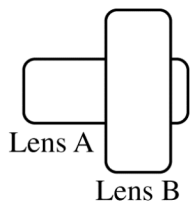
(B) The amount of energy transferred between the containers depends on the type of atoms each contains.

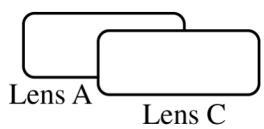
(C) After equilibrium is reached, the atoms in container X will still have a different average kinetic energy than those in container Y.

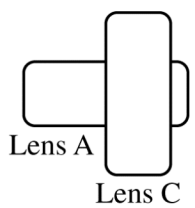
(D) All the atoms in container X slow down, and all the atoms in container Y speed up.

6. A student has three sunglass lenses. Lenses A and B have identical polarization patterns, and lens C is not polarized. Which of the following arrangements of lenses would have the most light blocked where the lenses overlap?

(A)


(B)


(C)


(D)


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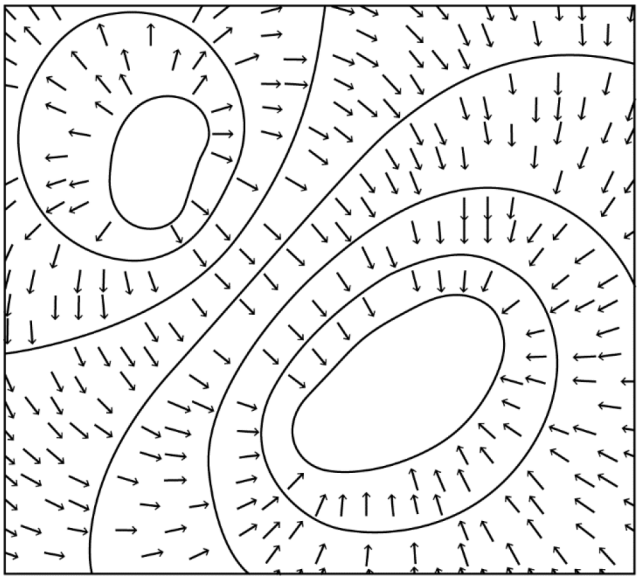

7. Some students drew the figure above as a representation that could be either a topographic (elevation) map, with the arrows representing the direction of downward slope, or electric equipotentials and electric field direction near some charged particles. Which of the following correctly describes what is inside the empty regions for each representation?

	Topographic Map	Electric Potentials and Field
(A)	Peak at upper left; valley at lower right	Negative charge at upper left; positive charge at lower right
(B)	Peak at upper left; valley at lower right	Positive charge at upper left; negative charge at lower right
(C)	Valley at upper left; peak at lower right	Negative charge at upper left; positive charge at lower right
(D)	Valley at upper left; peak at lower right	Positive charge at upper left; negative charge at lower right

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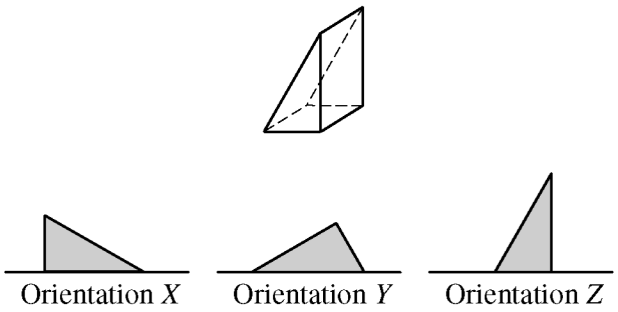
Questions 8-9 refer to the following material.

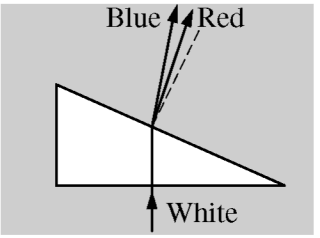


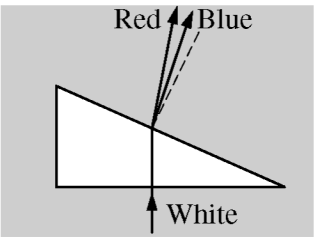
A hollow prism in the shape of a right triangle is shown in the figure above. The prism is filled with a liquid and can be placed in any of the three orientations shown.

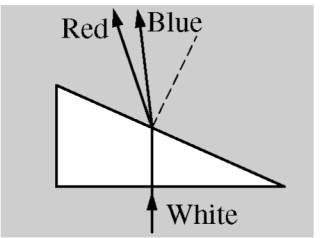
8. The liquid-filled prism is placed in a large tank containing a different liquid and sinks to the bottom of the tank. F_X is the magnitude of the buoyant force exerted on the prism by the liquid in the tank when the prism is in orientation X. F_Y and F_Z are the buoyant forces for orientations Y and Z. Which of the following correctly ranks the three buoyant forces?

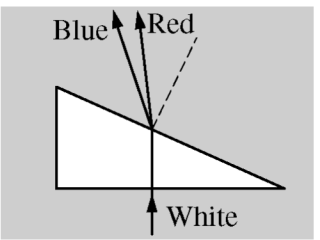
   (A) $F_Y < F_X < F_Z$
   (B) $F_Z < F_X < F_Y$
   (C) $(F_X = F_Y) < F_Z$
   (D) $F_X = F_Y = F_Z$

9. The prism is emptied of liquid. It is then submerged in another liquid with refractive indexes of 1.3 for red light and 1.4 for blue light. A beam of white light enters the prism. Which of the diagrams below shows the paths of red and blue light rays as they exit the prism?

(A)


(B)


(C)


(D)


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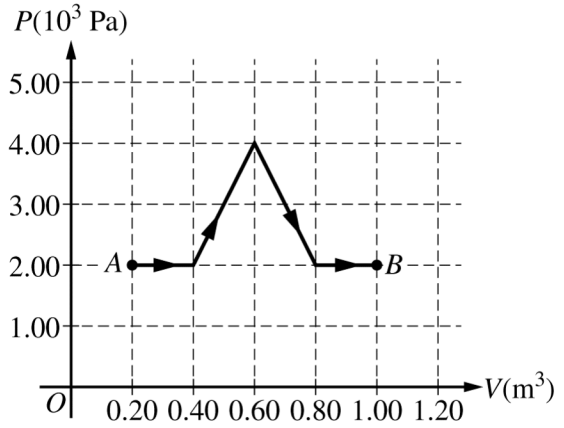
10. A proton moving to the right in the plane of the page with speed v enters a magnetic field of magnitude B directed toward the top of the page. What is the direction of the initial magnetic force that is exerted on the proton?

(A) Toward the top of the page
(B) Into the page
(C) Out of the page
(D) No direction, because there is no magnetic force on the proton



11. A simple ideal gas is enclosed in a cylinder with a movable piston. The gas is initially in state A at a temperature of 190 K and is taken from state A to state B along the path shown in the graph above of pressure P as a function of volume V. What is the temperature of the gas in state B ?

(A) 38 K
(B) 190 K
(C) 380 K
(D) 950 K

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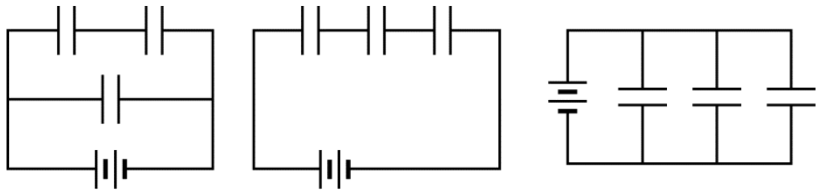


12. The figures above show three circuits, each containing the same battery and identical capacitors. Which circuit has the largest stored charge when it reaches steady state?

(A) X
(B) Y
(C) Z
(D) All three store the same charge.

---

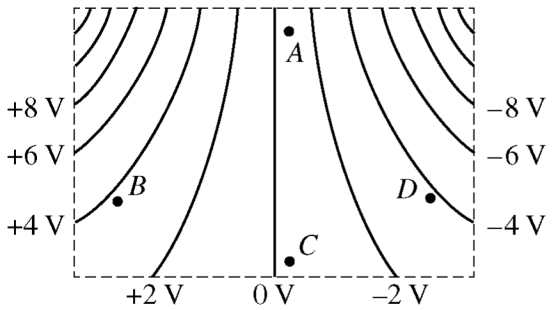
13. A fixed quantity of an ideal monatomic gas is enclosed in a container of fixed volume. Which of the following is true and helps explain why a decrease in the temperature of the gas results in a decrease in its pressure?

(A) The speed of each of the molecules decreases, so the molecules all exert less force on the container when they collide with it.

(B) The average speed of the collection of gas molecules decreases, so on average the molecules exert less force on the container when they collide with it.

(C) The speed of only the fastest molecules decreases, so the molecules have fewer collisions with the container.

(D) The speeds of the molecules are more evenly distributed across all possible values, so the molecules have fewer collisions with the container.



14. The figure above shows lines of equal electric potential in a region of space in the plane of the page. At which labeled point is the magnitude of the electric field greatest?

(A) *A*
(B) *B*
(C) *C*
(D) *D*

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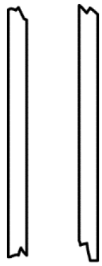


15. A student is doing experiments involving magnetic fields with the two long wires shown above, which are in the plane of the page. The student connects the ends of the left wire to a battery, creating a current in the wire toward the bottom of the page. What is the direction of the magnetic field at the location of the right wire?

(A) Out of the page
(B) Into the page
(C) Toward the left
(D) Toward the right

16. A proton and an electron are held a short distance apart and released from rest. The only nonnegligible forces on the particles are the electrostatic forces they exert on each other. Which of the following statements is true?

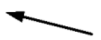
(A) The magnitude of the electrostatic force exerted on the proton by the electron is greater than that exerted on the electron by the proton.
(B) The magnitude of the acceleration of the proton is less than the magnitude of the acceleration of the electron.
(C) The proton must move a larger distance to have the same magnitude change in potential energy as the electron.
(D) The proton must move the same distance to have the same change in speed as the electron.

17. Three charged particles are near each other but isolated from other objects. Particle L has a charge of $+2.0\ \mu C$ and is located $4.0\ cm$ above the origin on the positive y-axis. Particle M has a charge of $-4.0\ \mu C$ and is located $8.0\ cm$ directly below particle L. Particles L and M are fixed in place. Particle N has a charge of $-1.0\ \mu C$ and is released from rest at 3.0 cm from the origin on the positive x-axis. Which of the following shows the initial direction of motion of particle N ?

(A) 

(B) 

(C) 

(D) 

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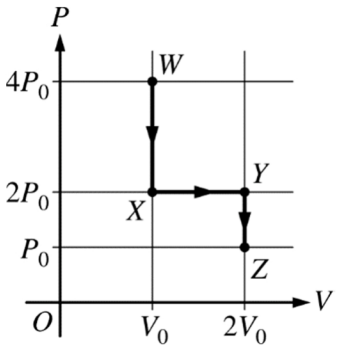
Questions 18-20 refer to the following material.



A monatomic ideal gas in a sealed container is taken from state W to state Z through intermediate states X and Y, as shown in the above graph of pressure P as a function of volume V.

18. What is the total work done on the gas as it goes from state W to state Z ?

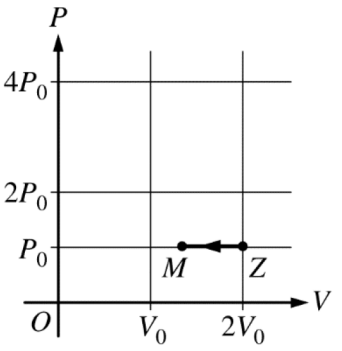
(A) 0
(B) $-P_0V_0$
(C) $-2P_0V_0$
(D) $-4P_0V_0$

19. The internal energy of the gas in state X is the same as that in which other state?

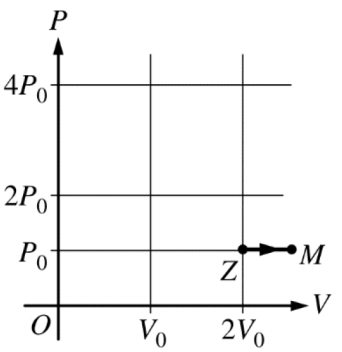
(A) W
(B) Y
(C) Z
(D) None of the other states

20. The gas is now taken from state Z to state M via an isovolumetric process in which its temperature increases. Which of the following graphs could represent this process?

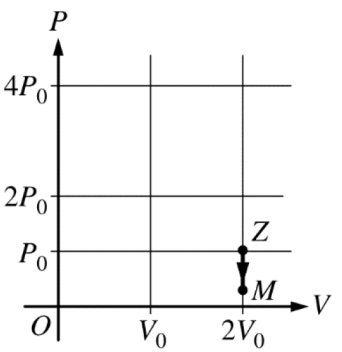
(A)



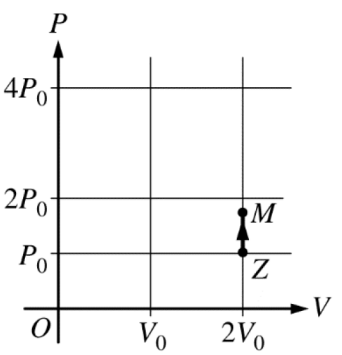
(B)



(C)



(D)



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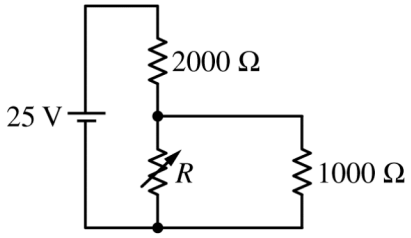
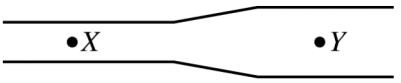


21. In the circuit shown above, R is a variable resistor. What resistance must R have so that the voltage across the $1000\,\Omega$ resistor is 5.0 V?

(A) 400 Ω
(B) 500 Ω
(C) 1000 Ω
(D) 5000 Ω



22. Water flows from left to right through the horizontal section of pipe shown above. At point X the speed of the water is $4\ \text{m/s}$, and at Y it is $2\ \text{m/s}$. The density of water is $1000\ \text{kg/m}^3$. What is the difference in water pressure between points X and Y?

(A) Zero
(B) 1000 Pa
(C) 2000 Pa
(D) 6000 Pa

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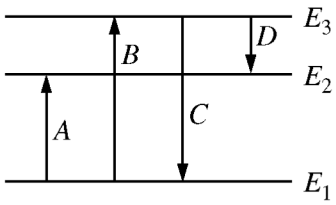
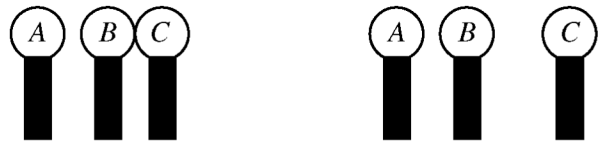


23. The figure above is an energy-level diagram for a hypothetical atom. The four transitions shown include the absorption of red light and the absorption of blue light. Which transition corresponds to the absorption of red light?

(A) *A*
(B) *B*
(C) *C*
(D) *D*



24. The figures above represent three metal spheres on insulating stands. Initially sphere *A* has charge $+Q$, and spheres *B* and *C* are uncharged. Spheres *B* and *C* are in contact when sphere *A* is brought near sphere *B* but does not touch it, as shown on the left. Sphere *C* is then separated from sphere *B*, as shown on the right. Which of the following best describes the final charges on spheres *B* and *C*?

	Sphere *B*	Sphere *C*
(A)	Positive	Uncharged
(B)	Positive	Negative
(C)	Uncharged	Positive
(D)	Negative	Positive

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25. Which of the following helps explain why the buoyant force exerted on an object submerged in a fluid on Earth is always directed upward?

(A) The buoyant force forms a Newton's third law pair with the force of gravity on the object.

(B) The fluid pressure exerts a force that balances the weight of the object, which means pressure is only exerted upward on the object.

(C) Fluid pressure is exerted on all surfaces of an object and increases with depth. The horizontal forces due to the pressure cancel, but the vertical forces do not.

(D) The surface tension between fluid molecules tends to resist the object moving downward through the surface of the fluid. This resistive force causes a net force upward.

θ_i (degrees)	θ_r (degrees)
0	0
16	10.8
32	20.4
48	30.1
64	37.9
80	39.8

26. A student measures the incident angle θ_i and the refracted angle o, of a beam of light that travels through air and then enters a material of unknown index of refraction. The student's data for several angles are shown in the table above. Which of the following procedures should the student follow so that the slope of a best-fit line will be the index of refraction of the material?

(A) Graph θ_r as a function of θ_i.

(B) Graph θ_i as a function of θ_r.

(C) Graph $\sin\theta_r$ as a function of $\sin\theta_i$.

(D) Graph $\sin\theta_i$ as a function of $\sin\theta_r$.

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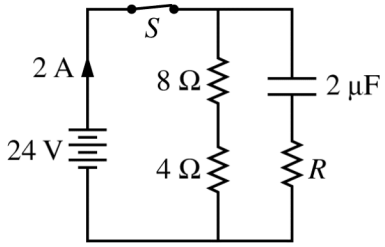

27. In the circuit above, the current through the battery a long time after switch S is closed is 2 A. What is the resistance of resistor R ?

(A) 6 Ω
(B) 10 Ω
(C) 12 Ω
(D) The resistance of resistor R cannot be determined from information about the steady state.

28. A student holds a lens 40 cm from an object and observes an enlarged image on a screen on the opposite side of the lens. Which of the following could be the type of lens and its focal length?

	Type of Lens	Focal Length
(A)	Diverging	30 cm
(B)	Diverging	50 cm
(C)	Converging	30 cm
(D)	Converging	50 cm

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Questions 29-31 refer to the following material.

Cosmic rays bombard Earth's upper atmosphere, creating subatomic particles called muons, which then stream toward the surface of Earth at nearly the speed of light. The muon is not a nucleon. It is an unstable fundamental particle with most properties the same as those of an electron but with a larger mass. In a frame of reference at rest with respect to the muon, the muon decays with a half-life of approximately 2.2×10^{-6} s.

29. The number of muons that reach Earth's surface without decaying is higher than would be expected from the known half-life for muon decay. The measured discrepancy arises because the muons are moving close to the speed of light. Which of the following is a consequence of the high speed of the muons and best explains the measured discrepancy?

    (A) Time intervals as measured in Earth's rest frame are different from time intervals measured in the rest frame of a muon, so more muons reach Earth's surface.
    (B) The size of a muon as measured on Earth is different from the size measured in the rest frame of a muon, so it is easier for a muon to reach Earth's surface
    (C) The mass of a muon as measured on Earth is different from the mass measured in the rest frame of a muon, so the acceleration due to gravity is different.
    (D) Energies of muons as measured on Earth are different from the energies measured in the rest frame of a muon, so different interactions occur with the atmosphere.

30. Which of the following could be the decay products of a negatively charged muon?

    (A) An electron and a positron
    (B) A neutron and an electron
    (C) Two electrons and a proton
    (D) An electron, a neutrino, and an antineutrino

31. In the most common form of muon decay, the total mass of the measured products is found to be much less than the mass of the muon. Which of the following best explains the measured discrepancy in mass?

    (A) The energy equivalent of the lost mass is transferred to the products, so they have a greater total potential energy than the muon had.
    (B) The energy equivalent of the lost mass is transferred to the products, so they have a greater total kinetic energy than the muon had.
    (C) Relativistic effects cause the total muon energy to be measured as larger and the total product energy to be measured as smaller than the same measurements in the reference frame of the particles.
    (D) Relativistic effects cause the muon mass to be measured as larger and the product masses to be measured as smaller than the same measurements in the reference frame of the particles.

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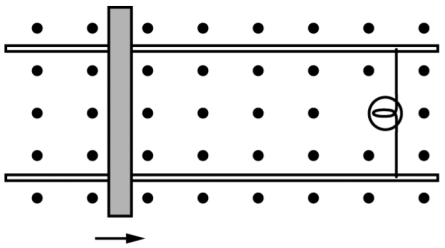

Top View



Side View

32. The system in the figure above consists of a conducting bar moving with negligible friction along a pair of stationary parallel conducting rails that are connected to a lightbulb, forming a circuit. The rails are slightly tilted from horizontal, and the system is in a uniform magnetic field B that is perpendicular to the plane of the rails and pointing up. As the bar slides downward along the rails, a current is induced that causes the bulb to light. Which of the following statements is true about the energy in the system or the forces exerted on the sliding bar?

(A) The gravitational potential energy of the circuit-magnetic field-Earth system is converted only to kinetic energy of the sliding bar.
(B) The gravitational potential energy of the circuit-magnetic field-Earth system increases due to the work done by the magnetic field on the moving bar.
(C) The motion of the bar is determined by the magnetic force due to the induced current and a component of the force of gravity, which are in the same direction.
(D) The motion of the bar is determined by the magnetic force due to the induced current and a component of the force of gravity, which are in opposite directions.

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33. Which type of electromagnetic radiation, visible light $\left(\lambda \approx 10^{-6}\ \text{m}\right)$ or microwaves $\left(\lambda \approx 10^{-2}\ \text{m}\right)$, exhibits more diffraction when interacting with everyday objects, and why?

(A) Visible light, because there is more visible light emitted from everyday objects than there are microwaves.
(B) Visible light, because its waves have a higher energy than microwaves do.
(C) Microwaves, because they are easier to produce than visible light waves, since visible light preferentially behaves like photons.
(D) Microwaves, because their wavelength is longer than that of visible light.

34. A container is filled with an ideal gas at a high gauge pressure and sealed with a cork of radius R that has been inserted into a circular opening of radius R. The force exerted on the cork by the gas has magnitude F. If the radii of the opening and cork are increased to $2R$, what will be the magnitude of the new force exerted on the cork by the gas?

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

Voltmeter Reading (V)	Ohmmeter Reading (Ω)
9.9	100
9.8	50
9.1	10
8.3	5
6.7	2

35. A student has a nonideal 10 V battery, some resistors, a voltmeter, and an ohmmeter and wants to determine the internal resistance of the battery and whether the resistors are ohmic. The student uses the ohmmeter to measure the resistance of each resistor. The student then connects the voltmeter across the battery terminals and one at a time connects each resistor to the battery. The table above shows the student's data. Which of the following indicates what can be concluded about the battery and resistors?

(A) The internal resistance of the battery is negligible, and the resistors are nonohmic.
(B) The internal resistance of the battery is negligible, and the ohmic nature of the resistors cannot be confirmed using only one potential difference measurement each.
(C) The internal resistance of the battery is about $1\ \Omega$, and the resistors are ohmic.
(D) The internal resistance of the battery is about $1\ \Omega$, and the ohmic nature of the resistors cannot be confirmed using only one potential difference measurement each.

36. An object is placed 25.0 cm in front of a convex mirror with a radius of curvature of 30.0 cm. Where is the image located?

(A) 9.38 cm behind the mirror
(B) 13.6 cm behind the mirror
(C) 37.5 cm in front of the mirror
(D) 150 cm in front of the mirror

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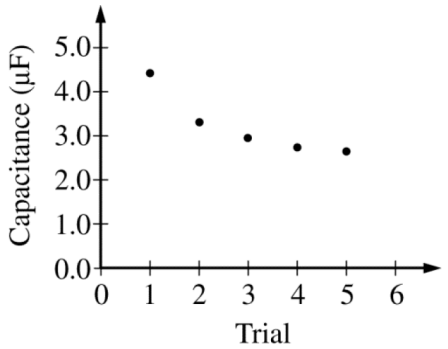
Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in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



131. A student conducts an experiment to investigate the relationship between the geometry of a capacitor and its capacitance. The student can adjust both the area and separation of the capacitor plates. The capacitance is measured using the capacitance setting on a digital multimeter. The student conducts five trials, numbering them in order from 1 to 5, and creates the graph of capacitance as a function of trial number shown above. Which of the following describes how the capacitor geometry could have been changed between successive trials to generate this data? Select two answers.

(A) Both the plate area and separation were increased.

(B) The plate area was increased, and the plate separation was held constant.

(C) The plate area was held constant, and the plate separation was increased.

(D) The plate area was increased, and the plate separation was decreased.

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132. In scenario 1, a test charge is placed at location P in an external electric field. In scenario 2, the test charge is removed and a new test charge with a slightly different charge is placed at location P.

Which of the following quantities will be the same in both scenarios? Select two answers.

(A) The electric potential energy of the test charge-field system

(B) The electric potential at location P

(C) The electric field at location P

(D) The electric force exerted on the test charge

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133. Which of the following proposed reactions are allowed by the law of conservation of electric charge? Select two answers.

(A) $n \rightarrow p^{+} + e^{-} + \nu$

(B) ${}^{3}_{1}\mathrm{H} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{7}_{4}\mathrm{Be} + \gamma$

(C) ${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$

(D) ${}^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{89}\mathrm{Ac} + e^{-} + \nu$

134. Which of the following data can be used to calculate the focal length of a thin converging lens? Select two answers.

(A) The distance from the lens to the object and the distance from the lens to the image

(B) The distance from the lens to the object and the magnification and orientation of the image

(C) The distance from the lens to the object and the height and orientation of the image

(D) The distance from the lens to the image and the height and orientation of the image

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AP® Physics 2: Algebra-Based Exam

SECTION II: Free Response

2019

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 4PBP4-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 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 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 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

$\tau = r_\perp F = rF\sin\theta$

$L = I\omega$

$\Delta L = \tau\,\Delta t$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

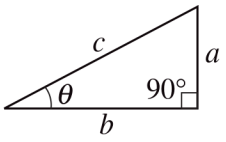
Rectangular solid
$V = \ell wh$

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 group of students is asked to design a heater for an indoor swimming pool using an electrically insulated current-carrying wire. The energy from the wire heats the water. The heater should deliver 10 kW of power to the water in the pool.

   (a) The students use wire that has a cross-sectional area of $1.3 \times 10^{-5}\ \text{m}^2$ and a resistivity of $3.0 \times 10^{-6}\ \Omega\text{•m}$. They have access to a 240 V power supply. Calculate the length of the wire needed to construct the heater.

   (b) The wire is completely submerged in the water, and the heater is turned on. After a while, both the water and the air above it are noticeably warmer.

      i. Identify and describe both the primary process that transfers energy through the wire's electrical insulation and the primary process that transfers energy through the water.

      Electrical Insulation

      Water

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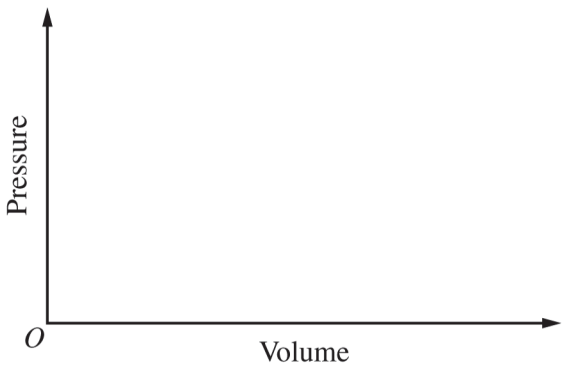
ii. The door to the pool area is open, and the air outside is colder than the air in the pool area. The heater must remain on to maintain a constant water temperature that is greater than the air temperature in the pool area. Explain how the first and second laws of thermodynamics can be applied to show that this must occur.

The door to the pool area is then closed so that energy transfer and air transfer into and out of the area are negligible. After some time the air in the pool area becomes warmer.

(c) On the graph below, sketch the thermodynamic process that the air in the pool area undergoes as it becomes warmer. Compare the amount Q of energy transferred to the air by heating to the change ΔU in the air's internal energy.

Sketch the Process



Compare Q and ΔU

(d) When the temperature of the room is 276 K, the air pressure is 1.0×10^5 Pa. Calculate the force exerted by the air in the room on a door that measures 2.0 m by 0.90 m when the temperature of the room is 310 K.

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2. (12 points, suggested time 25 minutes)

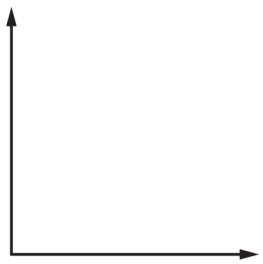
Students use a lightbulb, a screen, and a meterstick to determine the focal length of a concave mirror from a graph.

(a)

i. Describe a procedure that could be used to collect appropriate data and the measurements to be taken.

- Label the axes below with the quantities to be graphed.
- Draw a clearly labeled diagram of the experimental setup.
- Describe the procedure and indicate the quantities to be measured.

Label the Axes



Describe the Procedure

Draw a Diagram

ii. Describe how the focal length can be determined from the graph.

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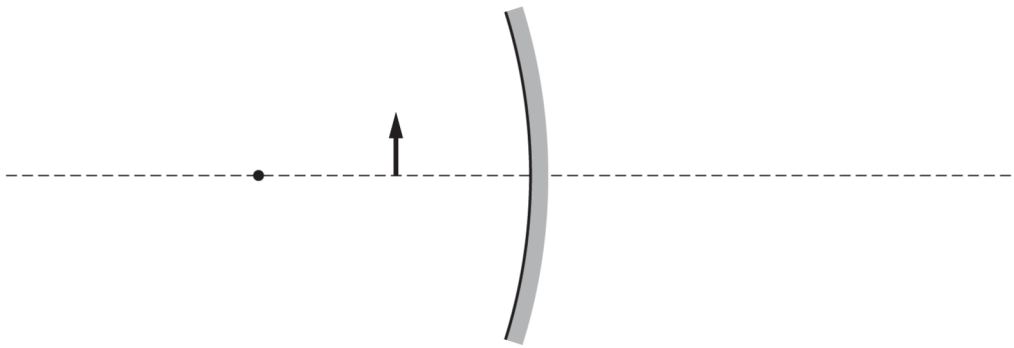
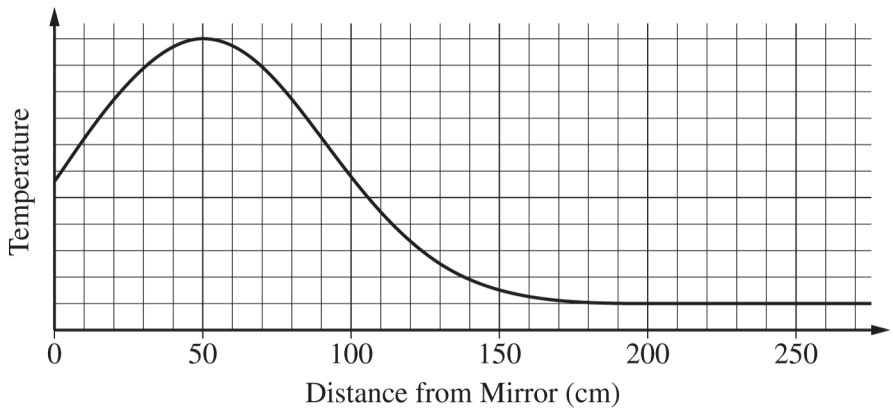
(b) The figure below represents one arrangement of a concave mirror and an object. The dot represents the focal point of the mirror and the arrow represents the object. Draw a ray diagram to illustrate the formation of the image that includes at least two rays and the resulting image.



(c) Some students take the concave mirror outside and hold it with the concave side facing the Sun. The students want to locate the image of the Sun. They measure the temperature of the air in front of the mirror along the principal axis and graph the air temperature as a function of distance from the mirror. The graph below is their best-fit curve to the data.



i. Based on the curve, at what distance from the mirror would you expect to find the image of the Sun?

ii. Use a relevant equation to explain how your response to (c)(i) relates to the focal length of the mirror.

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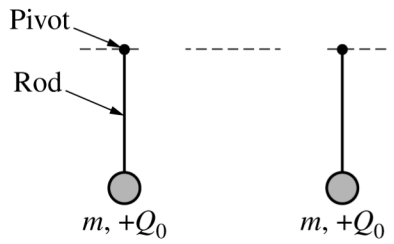

Figure 1

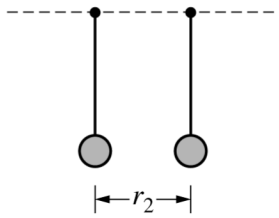

Figure 2

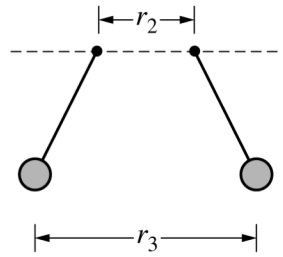

Figure 3

Note: Figure 1 not drawn to scale.

3. (12 points, suggested time 25 minutes)

Two insulating spheres with mass *m* and charge $+Q_0$ are near Earth's surface, suspended vertically from identical light, stiff rods with pivots at the top, as shown in Figure 1. The spheres are initially far apart. The pivots are locked so the rods remain vertical while the spheres are moved together by external forces until the spheres are a distance r_2 from each other, as shown in Figure 2. Finally, the pivots are held a distance r_2 apart and unlocked, and the rods are allowed to swing out until the spheres momentarily come to rest a distance r_3 apart, as shown in Figure 3. The pivots are always at the same height.

(a) Consider the system that includes only the two spheres, with Earth external to the system.

i. Write an expression for the work done moving the spheres horizontally from far apart to a separation of r_2. Express your answer in terms of Q_0, r_2, and physical constants, as appropriate.

ii. The total energy of the two-sphere system (with Earth still external to the system) changes as the system goes from the configuration in Figure 2 to the configuration in Figure 3. Explain how the energy changes in terms of the forces exerted on the system.

(b) Now consider the system that contains both Earth and the two spheres. What is the work done on this new system for the changes in sphere position described in parts (a)(i) and (ii) ? Explain your reasoning.

Part (a)(i) Part (a)(ii)

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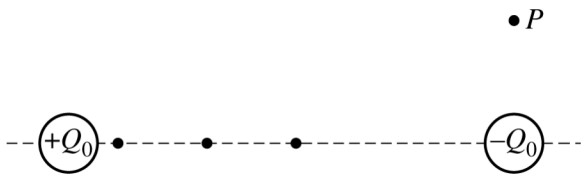
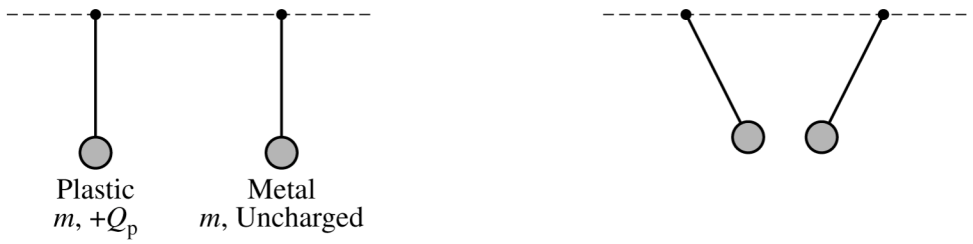
(c) The rods are now held fixed at the positions shown in Figure 3, and negative charge is added to the right sphere so its net charge is -lo. The circles in the figure below represent the spheres. On the figure, do the following.

- Draw a single vector originating on point *P* that represents the net electric field at that point.
- For each of the dots on the horizontal dashed line, draw an isoline of electric potential that goes through the dot.



(d) In a new situation, the two spheres still have the same mass *m*, but the left sphere is made of plastic and has charge $+Q_p$ and the right sphere is made of metal and is uncharged. The spheres are brought near but do not touch, as shown below on the left. When the rods are allowed to pivot, the spheres move toward each other, as shown on the right. In terms of charge distributions, explain why the force between the spheres is attractive.



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4. (10 points, suggested time 20 minutes)

A uranium-231 nucleus can decay into an alpha particle and a thorium-227 nucleus.

(a) Nuclei in a 500 g sample of uranium-231 undergo this decay. The amount of uranium-231 remaining is measured at the same time every day for a period of eight days. The table below shows the data obtained.

Amount of uranium-231 (g)	500	424	359	305	258	219	186	157	134
Time (days)	0	1	2	3	4	5	6	7	8

According to the data, what is the approximate half-life of uranium-231 ?

(b) One uranium-231 nucleus decays. The uranium nucleus has a mass of 3.835609×10^{-25} kg and is moving in the $-x$-direction with a kinetic energy of 2.5×10^{-13} J before the decay. The thorium nucleus has a mass of 3.769064×10^{-25} kg , and the alpha particle has a mass of 0.066447×10^{-25} kg .

i. Calculate the velocity of the center of mass of the two decay products immediately after the decay. Be sure to specify the direction of the velocity.

ii. Calculate the amount of energy released in the decay of the uranium-231 nucleus.

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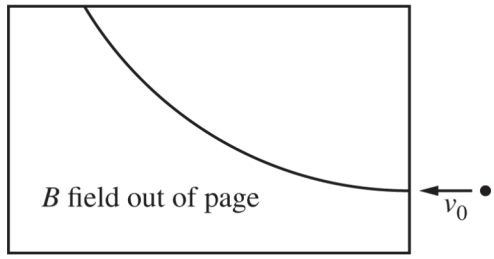

(c) An alpha particle is moving to the left with speed v_0 when it enters a region containing a uniform magnetic field of known magnitude B directed out of the page. The figure above shows the path of the alpha particle through the region. In a coherent paragraph-length response, explain how the charge-to-mass ratio and sign of the charge of the alpha particle can be verified by using the effect of the magnetic field on the path of the particle. Equations or diagrams that support your written description may be included.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

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

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- **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.**