AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice

2016

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

At a Glance

Total Time
1 hour, 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 4MBP4-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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

$K = \frac{1}{2}mv^2$

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

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

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

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

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

$U_s = \frac{1}{2}kx^2$

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

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

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

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

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

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

$U_G = -\frac{Gm_1 m_2}{r}$

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

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

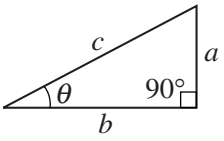
Rectangular solid
$V = \ell wh$

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

40 Questions

Time—90 minutes

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. An insulated container with a divider in the middle contains two separated gases. Gas 1 is initially at a higher temperature than gas 2. The divider is then removed. Which of the following observations might be made over a period of time as the two gases mix together, and why?

   (A) Gas 1 remains at a higher temperature than gas 2 because gas 1 started at a higher temperature.
   (B) Gas 1 remains at a higher temperature than gas 2 because gas 1 started with a higher kinetic energy.
   (C) On average, the molecules of gas 1 lose all of their kinetic energy to the molecules of gas 2 through collisions, resulting in gas 2 eventually having a higher temperature than gas 1.
   (D) On average, the molecules of gas 1 lose some of their kinetic energy to the molecules of gas 2 through collisions, resulting in the two gases eventually having the same temperature.

2. A small amount of charge is placed on both an isolated conducting sphere and an isolated insulating sphere. For both spheres, the charge is added at a small area at the top of the sphere. After a few seconds, where on each of the spheres is the charge that was added?

	Conducting	Insulating
(A)	At the top	At the top
(B)	At the top	Spread over the surface
(C)	Spread over the surface	At the top
(D)	Spread over the surface	Spread over the surface

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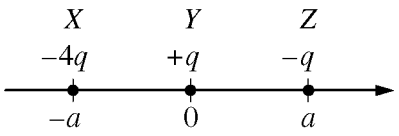
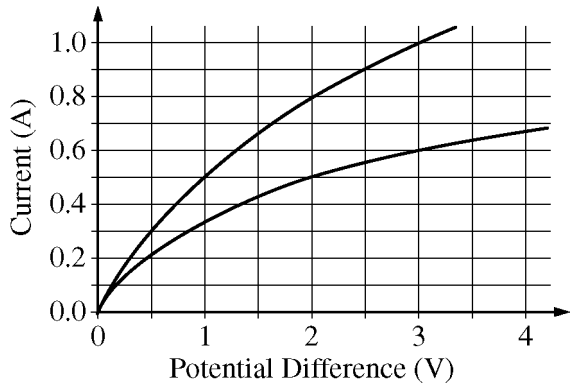
Item 3 was not scored.



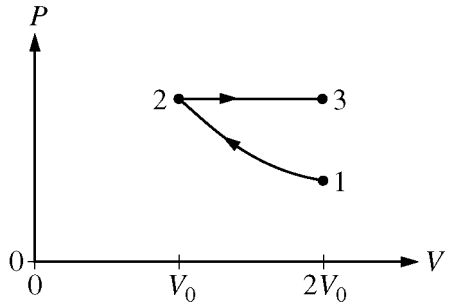
4. The figure above shows three objects (X, Y, and Z) that have charges $-4q$, $+q$, and $-q$, respectively. The objects are held fixed on an axis at the positions shown. The magnitude of the electrostatic force exerted by object Y on object Z is F. What is the magnitude of the net electrostatic force exerted on object Y due to the other two objects?

   (A) Zero
   (B) $2F$
   (C) $3F$
   (D) $5F$



5. The above graph shows current as a function of potential difference for two different filament lamps. If the two lamps are connected in parallel to a 3.0 V battery, what is the total current supplied by the battery?

   (A) 0.5 A
   (B) 0.8 A
   (C) 1.0 A
   (D) 1.6 A



6. An ideal gas is initially in state 1 at a temperature of 200 K. The gas is taken through the two reversible thermodynamic processes shown in the PV diagram above. The process from state 1 to state 2 is isothermal. The process from state 2 to state 3 is isobaric. What is the temperature of the gas when it is in state 3 ?

   (A) 800 K
   (B) 400 K
   (C) 200 K
   (D) 100 K

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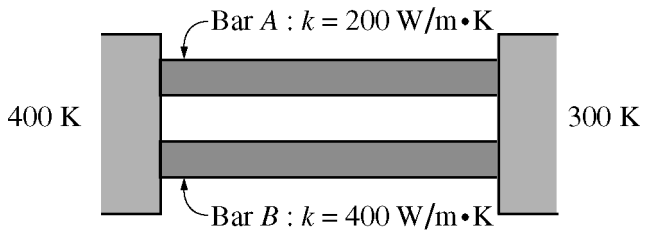

7. Two metal bars with the same length and same cross-sectional area are placed between two tanks with temperatures of 400 K and 300 K, as shown above. The thermal conductivity of the top bar is 200 W/m•K , and that of the bottom bar is 400 W/m•K . If the net energy transferred through the top bar in a given time interval is Q, what is the net energy transferred through the bottom bar during the same time interval?

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

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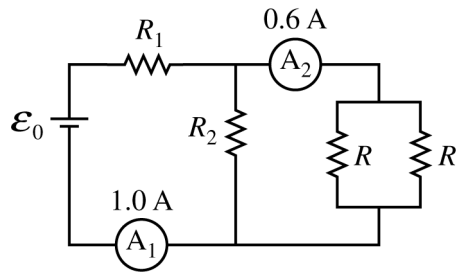
8. A ray of light in air ($n = 1.0$) is incident on glass ($n = 1.5$) at a small angle θ_a to the normal. The angle of the ray to the normal in the glass is θ_g. The speeds of light in air and the glass are v_a and v_g, respectively. How do the values of the speed of light and the angle of the ray of light to the normal in air compare to those in the glass?

	Speed of Light	Angle to Normal
(A)	$v_a > v_g$	$\theta_a > \theta_g$
(B)	$v_a > v_g$	$\theta_a < \theta_g$
(C)	$v_a < v_g$	$\theta_a > \theta_g$
(D)	$v_a < v_g$	$\theta_a < \theta_g$



9. The figure above shows a circuit containing four resistors, a battery, and two ammeters. The current in ammeter A_1 is 1.0 A, and the current in ammeter A_2 is 0.6 A. The two resistors labeled R are identical. What are the currents in R_2 and in each of the two resistors labeled R?

	R_2	Each R
(A)	1.6 A	0.3 A
(B)	1.6 A	0.6 A
(C)	0.4 A	0.3 A
(D)	0.4 A	0.6 A

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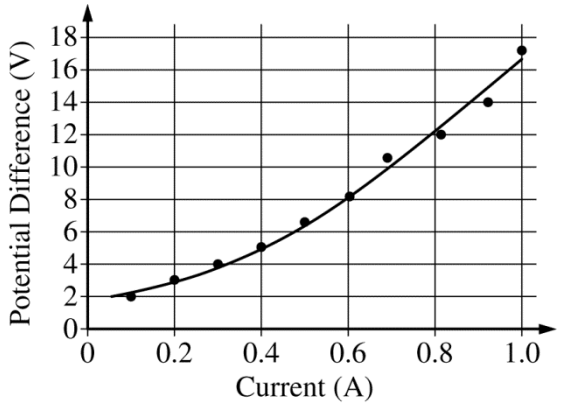
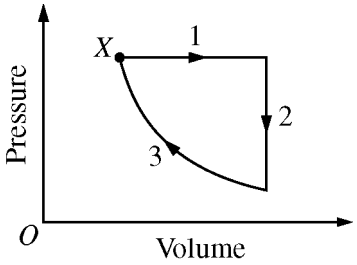


10. The graph above shows experimental data for the potential difference across a lightbulb as a function of the current through the lightbulb. The power dissipated by the lightbulb when the potential difference across the bulb is 12 V is most nearly

(A) 0.067 W
(B) 7.7 W
(C) 9.6 W
(D) 15 W



11. The graph above shows pressure as a function of volume for a sample of an ideal gas. The gas has an internal energy of 1000 J at state *X* and is taken through the cycle shown. Process 3 is isothermal. The work that the gas does on the environment is 400 J during process 1 and 250 J during one complete cycle. What is the net thermal energy transferred into the gas during one complete cycle?

(A) 0 J
(B) 250 J
(C) 400 J
(D) 650 J

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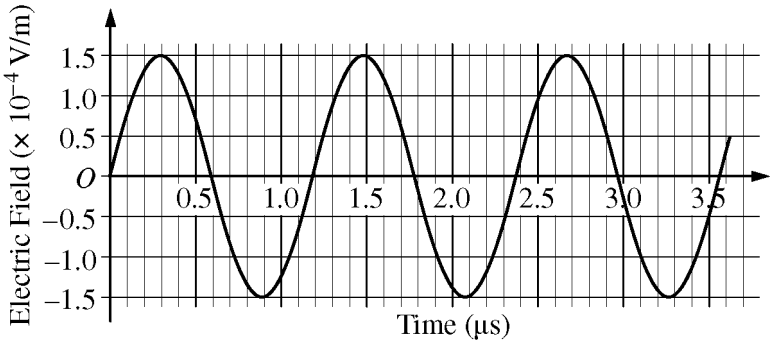
Questions 12-13 refer to the following material.

You and a friend are traveling in a car. You tune the car radio to a station of frequency 850 kHz. The graph below represents the electric field strength of the radio wave at a given position as a function of time.



12. Both the sound and radio waves are present inside the car. Which of the following is true about these waves?

(A) Both waves are longitudinal.
(B) Both waves can be polarized.
(C) Both waves travel at the speed of light.
(D) Sound waves require a medium in which to propagate and radio waves do not.

13. Which of the following best represents the electric field strength E measured in V/m as a function of time t measured in μs?

(A) $E = \left(3.0 \times 10^{-4}\right)\sin(10.6t)$

(B) $E = \left(3.0 \times 10^{-4}\right)\sin(5.32t)$

(C) $E = \left(1.5 \times 10^{-4}\right)\sin(10.6t)$

(D) $E = \left(1.5 \times 10^{-4}\right)\sin(5.32t)$

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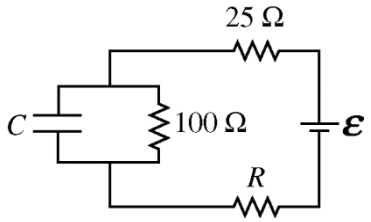
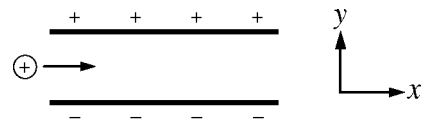
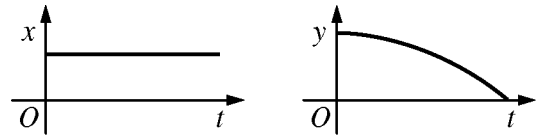


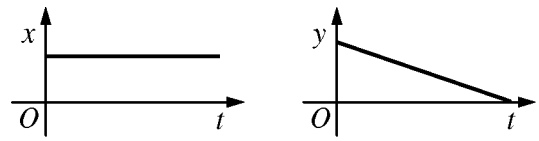
14. A 25 Ω resistor and a 100 Ω resistor are connected in a circuit with a third resistor of unknown resistance R, a capacitor of unknown capacitance C, and a battery of unknown emf $\mathcal{E}$, as shown above. After a long time, the potential difference across the 25 Ω resistor is measured to be 4 V. What is the emf of the battery?

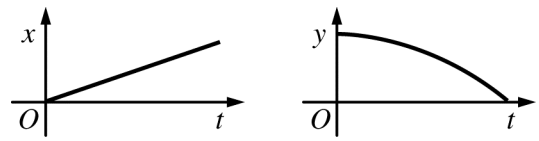
(A) 20 V
(B) 16 V
(C) 4 V
(D) The emf of the battery cannot be determined without knowing the value of R.

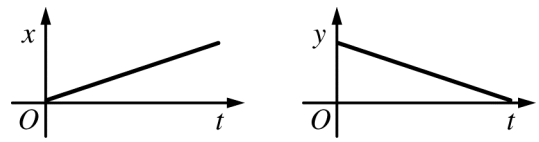


15. A positively charged particle is moving horizontally when it enters the uniform electric field between two parallel charged plates, as shown in the figure above. Which of the following could show the x and y positions of the particle as a function of time t?

(A)


(B)


(C)


(D)


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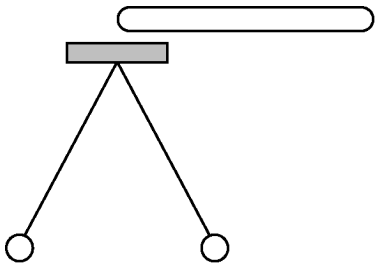
16. A typical iron nucleus contains 30 neutrons and 26 protons. Which of the following explains why the nucleus stays together despite the electric repulsion between the protons?

(A) The neutrons become polarized and exert a net attractive electric force on each proton that is stronger than the net repulsive force.
(B) The net gravitational force exerted on each proton due to all the nucleons is stronger than the net repulsive force.
(C) The net magnetic force exerted on each proton due to all the nucleons is stronger than the net repulsive force.
(D) The net strong force on each proton due to all the nucleons is stronger than the net repulsive force.



17. An initially uncharged electroscope consists of two thin, 50 cm long conducting wires attached to a cap, with a 25 g conducting sphere attached to the other end of each wire. When a charged rod is brought close to but not touching the cap, as shown above, the spheres separate a distance of 30 cm. What can be determined about the induced charge on each sphere from this information?

(A) The magnitude but not the sign
(B) The sign but not the magnitude
(C) Both the magnitude and the sign
(D) Nothing can be determined about the induced charges.

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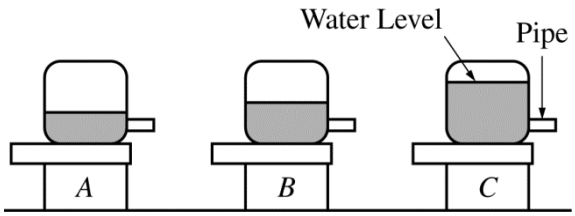
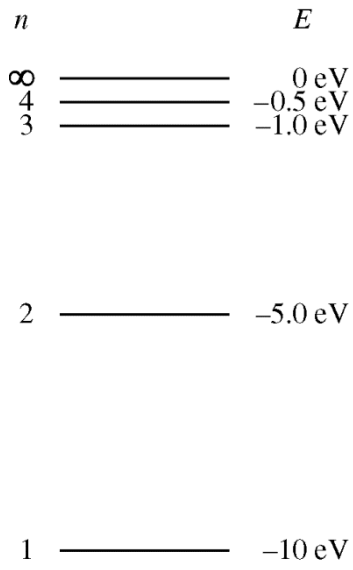


18. Three identical reservoirs, A, B, and C, are represented above, each with a small pipe where water exits horizontally. The pipes are set at the same height above a pool of water. The water in the reservoirs is kept at the levels shown. Which of the following correctly ranks the horizontal distances d that the streams of water travel before hitting the surface of the pool?

(A) $d_A > d_B > d_C$
(B) $d_A = d_B = d_C$
(C) $(d_A = d_B) > d_C$
(D) $d_C > d_B > d_A$



19. A hypothetical hydrogen-like atom has energy states as represented in the energy-level diagram above. The atom is in the ground state when it absorbs a photon with frequency 2.18×10^{15} Hz. What energy state will the atom be in after it absorbs the photon?

(A) $n = \infty$
(B) $n = 4$
(C) $n = 3$
(D) $n = 2$

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20. In each of the nuclear reactions given below, a product is indicated by the letter X. In which of the reactions does the letter X represent a positron? (A positron is a positively charged particle with the same mass and magnitude of charge as an electron.)

(A) ${}^{14}_{7}\mathrm{N} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{15}_{8}\mathrm{O} + \mathrm{X}$

(B) ${}^{15}_{8}\mathrm{O} \rightarrow {}^{15}_{7}\mathrm{N} + \mathrm{X} + \nu$

(C) ${}^{15}_{7}\mathrm{N} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{12}_{6}\mathrm{C} + \mathrm{X}$

(D) ${}^{12}_{6}\mathrm{C} + \mathrm{X} \rightarrow {}^{13}_{7}\mathrm{N} + \gamma$

---

21. Which of the following correctly describes the motion of particles when a single transverse mechanical wave passes through a medium?

(A) The particles vibrate back and forth along the same direction as the wave propagates.
(B) The particles vibrate back and forth along a single direction that is perpendicular to the direction of propagation of the wave.
(C) Each particle vibrates back and forth along a single direction that is perpendicular to the direction of propagation of the wave, but each particle's direction is different.
(D) The particles vibrate back and forth without any energy being carried along with the wave as it propagates.

22. A student is given a loudspeaker with a square opening and asked to make a change in the dimensions of the opening so that the sound wave is more spread out vertically and narrowed horizontally. Which of the following is the correct use of the principle of diffraction to accomplish the desired result?

(A) The task is impossible since diffraction affects only electromagnetic radiation and very short wavelengths.
(B) Make the opening into a rectangle with a longer vertical dimension and a shorter horizontal dimension.
(C) Make the opening into a rectangle with a longer horizontal dimension and a shorter vertical dimension.
(D) Keep the opening in the shape of a square, but reduce both the horizontal and vertical dimensions.

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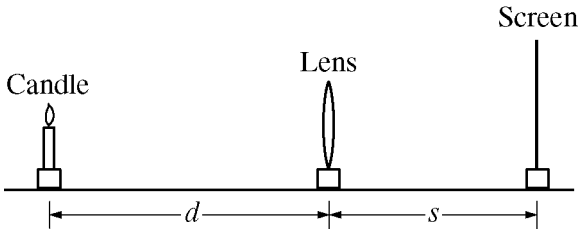

23. In the experimental setup shown in the figure above, a thin lens stands between a candle and a screen. A student moves the candle to several positions relative to the lens and then adjusts the position of the screen until an image is formed. Each time, the student records the distance d from the candle to the lens and the distance s from the lens to the screen. Which of the following procedures will allow the student to determine the focal length of the lens?

(A) Graph s as a function of d. The focal length will be the vertical intercept.
(B) Graph s as a function of d. The focal length will be the slope of the line.
(C) Graph $1/s$ as a function of $1/d$. The focal length will be the inverse of the vertical intercept.
(D) Graph $1/s$ as a function of $1/d$. The focal length will be the inverse of the slope of the line.

24. A student in an electronics lab is studying the electrical properties of pieces of graphite. The student applies a potential difference of 24 V across the length of a cylindrical piece of graphite with a radius of 0.5 mm. The student has another piece of graphite of the same length but with a radius of 0.7 mm. The student wants the same current in both pieces of graphite. What potential difference should the student apply across the 0.7 mm piece?

(A) 6 V
(B) 12 V
(C) 17 V
(D) 24 V

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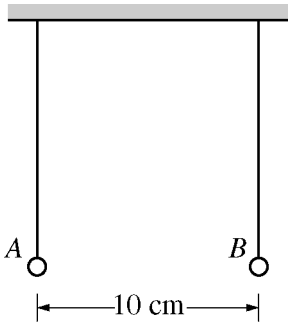
Questions 25-28 refer to the following material.



Two identical, uncharged, nonconducting spheres hang vertically from insulating strings and are a distance of 10 cm apart, as shown in the figure above. The spheres are then each given a net charge; sphere A gets $-10\ \mu C$ and sphere B gets $-20\ \mu C$. The spheres are allowed to come to rest in a new equilibrium configuration.

25. Let $y = 0$ be the vertical position of the uncharged spheres, with positive y toward the top of the page. Which of the following correctly ranks the new vertical positions y_A and y_B of spheres A and B, respectively, in the new equilibrium configuration?

(A) $(y_A = y_B) > 0$

(B) $y_A > y_B > 0$

(C) $y_A > (y_B = 0)$

(D) $y_B > y_A > 0$

26. Let E_A be the magnitude of the electric field produced by sphere A near the location of sphere B, and let E_B be the magnitude of the electric field produced by sphere B near the location of sphere A. Which of the following correctly ranks E_A and E_B and provides a correct justification for the ranking?

(A) $E_A < E_B$, because at the same distance away from a point charge, a larger-magnitude charge will produce a larger-magnitude electric field, and sphere B has twice as much charge on it.

(B) $E_A = E_B$, because Newton's third law indicates that the electric field produced by one charge must be equal in magnitude and opposite in direction to the electric field produced by another charge.

(C) $E_A = E_B$, because in the expression for electrostatic force, $\frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$, the product of $10\ \mu C$ and $20\ \mu C$ is the same regardless of which charge is labeled Q_1 or Q_2.

(D) $E_A > E_B$, because at the same distance away from a point charge, a larger charge will produce a larger electric field, and sphere A has more charge on it because $-10\ \mu C$ is greater (less negative) than $-20\ \mu C$.

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27. Consider a system defined as only spheres A and B. In the new equilibrium configuration, how (if at all) has the potential energy of the system changed compared to when the spheres were initially uncharged, and why?

(A) The potential energy of the system has remained the same, because the spheres are still at the same height as each other, so no energy is stored.
(B) The potential energy of the system has increased, because the two spheres repel each other, storing energy in an electric field.
(C) The potential energy of the system has increased, because the charged spheres are at a higher vertical position, storing energy in a gravitational field.
(D) The potential energy of the system has decreased, because the charged spheres will repel each other rather than attract, reducing the energy stored in the electric field.

28. Consider a position P located halfway between the charged spheres in their new equilibrium configuration. Which of the following correctly indicates whether the electric potential at this position is positive, negative, or zero and explains why?

(A) Zero, because without a charge at position P no electric potential can exist there.
(B) Zero, because both spheres are located the same distance from position P, so the contributions from each charge cancel each other out.
(C) Positive, because both negatively charged spheres contribute a negative electric potential, and these negatives multiplied together produce a net positive electric potential.
(D) Negative, because both negatively charged spheres contribute a negative electric potential to the total.

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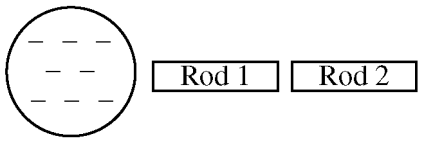
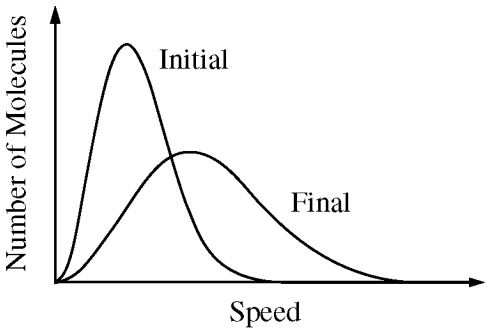


29. Two electrically neutral conducting rods are near a negatively charged sphere, as shown in the figure above. Rod 1 is touched to rod 2 for several seconds, and then the rods are separated. The rods are then both removed from the vicinity of the charged sphere. Which of the following best describes the resulting net charge on each rod?

(A) Rod 1 is positively charged, and rod 2 is negatively charged.
(B) Rod 2 is positively charged, and rod 1 is negatively charged.
(C) Rods 1 and 2 are both negatively charged.
(D) Rods 1 and 2 are both uncharged.

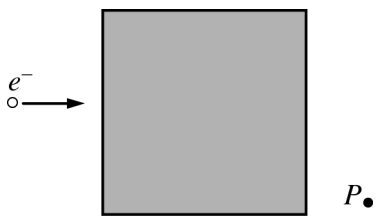
30. The Sun's energy production is due to the fusion of $^{1}\mathrm{H}$ into $^{4}\mathrm{He}$. How does the mass of four $^{1}\mathrm{H}$ nuclei $(4m_{\mathrm{H}})$ compare with the mass of one $^{4}\mathrm{He}$ nucleus (m_{He})?

(A) $4m_{\mathrm{H}} = m_{\mathrm{He}}$
(B) $4m_{\mathrm{H}} < m_{\mathrm{He}}$
(C) $4m_{\mathrm{H}} > m_{\mathrm{He}}$
(D) It cannot be determined without knowing the amount of energy released.



31. The graph above shows the initial and final molecular speed distributions of a gas as a result of a thermodynamic process. Which of the following processes could produce this change?

(A) Expansion of the gas at constant temperature
(B) Compression of the gas with no transfer of energy by heating
(C) Cooling of the gas at constant volume
(D) Cooling of the gas at constant pressure



32. An electron is moving to the right, as shown in the figure above. It passes through the shaded region, which contains a magnetic field. The electron travels along a path that takes it through point P. The gravitational force on the electron is negligible. What is the direction of the magnetic field?

(A) Into the page
(B) Out of the page
(C) Toward the top of the page
(D) Toward the bottom of the page

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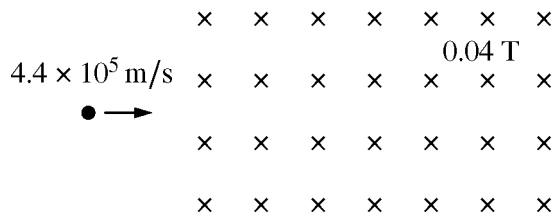
33. Water flowing in a horizontal pipe speeds up as it goes from a section with a large diameter to a section with a small diameter. Which of the following can explain why the speed of the water increases?

(A) The gravitational potential energy of the water-Earth system increases.
(B) The gravitational potential energy of the water-Earth system decreases.
(C) Work is done because the water in the larger pipe has a higher pressure.
(D) Work is done because the water in the larger pipe has a lower pressure.

34. An ideal gas with molecules of mass m is contained in a cube with sides of area A. The pressure exerted by the gas on the top of the cube is P, and N molecules hit the top of the cube in a time Δt. What is the average vertical component of the velocity of the gas molecules?

(A) $PA\Delta t/m$
(B) $PA\Delta t/2m$
(C) $PA\Delta t/Nm$
(D) $PA\Delta t/2Nm$



35. A proton is moving at 4.4×10^5 m/s in the plane of the page when it enters a magnetic field of magnitude 0.04 T perpendicular to the page, as shown in the figure above. The radius of curvature of the path of the proton as it moves through the magnetic field is approximately which of the following?

(A) 1×10^4 m
(B) 1×10^1 m
(C) 1×10^{-4} m
(D) 1×10^{-1} m

36. An object is placed in front of a thin lens. An upright image is formed that is one-third the height of the object. If the image is 6.0 cm from the lens, what is the focal length of the lens?

(A) –27 cm
(B) –9 cm
(C) 9 cm
(D) 27 cm

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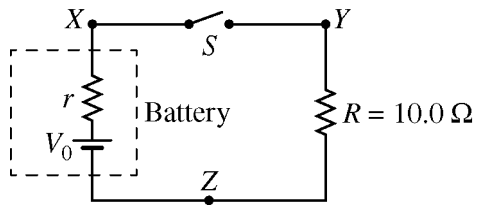
Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in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

131. Which of the following phenomena involving light can be explained with a particle model? Select two answers.

(A) The photoelectric effect
(B) Diffraction
(C) Atomic emission
(D) Thin-film interference



132. A battery of unknown emf V_0 and unknown internal resistance r is placed in a circuit with a switch S and a resistor of known resistance $R = 10\ \Omega$, as shown in the figure above. The internal resistance r can be determined by taking measurements with the switch open and with the switch closed. Which of the following pairs of measurements with the switch open and closed can be used to determine the value of r? Select two answers.

	With Switch Open	With Switch Closed
(A)	Potential difference between X and Z	Current at Y
(B)	Potential difference between X and Z	Potential difference between Y and Z
(C)	Potential difference between Y and Z	Current at X
(D)	Potential difference between Y and Z	Potential difference between X and Z

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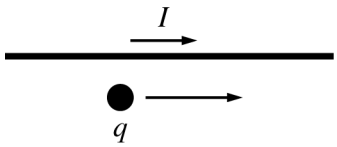

133. An object with charge q is initially moving at a constant speed v parallel to a wire carrying current I, as shown in the figure above. The object is at a distance d from the wire, and the magnetic force exerted on the object by the wire is F. Which of the following changes, when made individually, will result in a magnetic force of $2F$? Select two answers.

(A) Increasing the charge to $\sqrt{2}q$
(B) Increasing the current to $2I$
(C) Decreasing the speed to $v/\sqrt{2}$
(D) Decreasing the distance to $0.5d$

134. A simple generator contains a conducting loop that rotates between the poles of a magnet. Which of the following helps explain why this rotation generates a potential difference? Select two answers.

(A) The magnitude of the magnetic field produced by the magnet changes.
(B) The component of the magnetic field perpendicular to the loop changes.
(C) The area of the loop changes.
(D) The angle between the plane of the loop and the magnetic field changes.

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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

2016

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

At a Glance

Total Time
1 hour, 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.
   No, I do not grant the College Board these rights. ☐

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 4MBP4-S

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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

$K = \frac{1}{2}mv^2$

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

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

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

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

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

$U_s = \frac{1}{2}kx^2$

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

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

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

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

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

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

$U_G = -\frac{Gm_1 m_2}{r}$

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

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

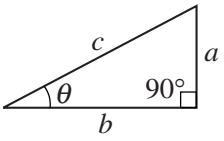
Rectangular solid
$V = \ell w h$

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

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

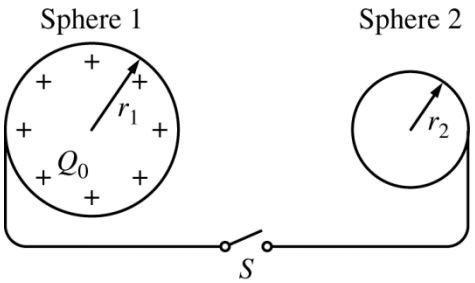
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

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
4 Questions
Time—90 minutes

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.



Note: Figure not drawn to scale.

1. (10 points, suggested time 20 minutes)

   The figure above shows two metal spheres that are far apart compared to their size and that are held in place. The spheres are connected by wires to either side of switch *S*. Initially, the switch is open. Sphere 1 has mass m_1, radius r_1, and a net positive charge $+Q_0$. Sphere 2 has mass m_2 and radius $r_2 < r_1$ and is initially uncharged. The switch is then closed. Afterward, sphere 1 has a charge Q_1 and is at potential V_1, and the electric field strength just outside its surface is E_1. The corresponding values for sphere 2 are Q_2, V_2, and E_2. Neglect air resistance and gravitational interactions.

   (a)

   i. Indicate whether V_1 is larger than, smaller than, or equal to V_2. Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

   ii. Indicate whether Q_1 is larger than, smaller than, or equal to Q_2. Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

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GO ON TO THE NEXT PAGE.

iii. Indicate whether E_1 is larger than, smaller than, or equal to E_2. Show how you arrived at your answer using appropriate physics principles and/or mathematical models.

(b) The distance between the centers of sphere 1 and sphere 2 is D. The switch is now opened, the wires are disconnected from the spheres, and the spheres are released, all without changing the charges on the spheres. Write but do NOT solve equations that could be used to determine the velocities v_1 and v_2 of the spheres a long time after they are released, in terms of m_1, m_2, Q_1, Q_2, D, and physical constants, as appropriate.

(c) The spheres are now returned to their original locations. Sphere 1 once again has initial net charge $+Q_0$, and sphere 2 is initially uncharged. The switch is again closed and then reopened. Sphere 3, an uncharged metal sphere of radius $r_3 > r_1 > r_2$ on an insulating handle, is now brought into contact with sphere 2. Sphere 3 is then moved away.

i. Indicate the sign of the final charge on each sphere.

ii. Rank the absolute value of the final charge on each of the three spheres. Explain how you arrived at this answer.

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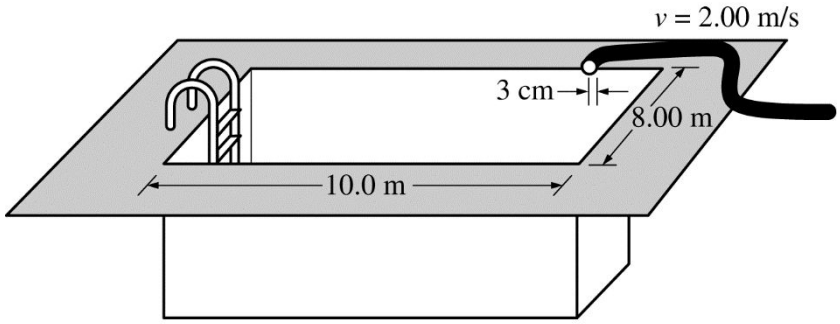

Note: Figure not drawn to scale.

2. (12 points, suggested time 25 minutes)

Water flows at a speed v of $2.00\ \text{m/s}$ through a hose of radius 3 cm and into a large empty rectangular pool. The pool has a level bottom and measures 10.0 m long by 8.00 m wide. The density of water is $1.00 \times 10^3\ \text{kg/m}^3$ and atmospheric pressure is 1.01×10^5 Pa . Express all numerical answers to the following parts to at least three significant figures.

(a) Calculate the total pressure exerted downward on the bottom of the pool after the water has been running for 3 hours.

(b) A small ball is floating in the water as the pool fills. Indicate whether the buoyant force on the floating ball increases, decreases, or stays the same as the amount of water in the pool increases. Briefly explain your reasoning.

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GO ON TO THE NEXT PAGE.

(c) A person gets impatient because it is taking too long to fill the pool. The person attaches a nozzle to the end of the hose that reduces the radius of the opening to 1.5 cm. Assume the speed of the water in the hose (before it reaches the nozzle) remains at $2.00\ \text{m/s}$. The person claims that the water now comes out of the nozzle faster than it did from the hose without the nozzle and therefore the pool will fill faster.

i. Do you agree that the pool will fill faster? Explain your reasoning in terms of conservation principles.

ii. Calculate the speed of the water as it leaves the nozzle. Explain how your calculation is consistent with the conservation principles used in part (c)(i).

(d) When the water in the pool is 1.50 m deep, the hose is turned off. A person who is 1.80 m tall then floats in the pool.

i. Is the net downward force exerted on the bottom of the pool now greater than, less than, or the same as it was before the person got into the pool? Explain your reasoning in terms of the forces exerted on the person.

ii. Would your answer to part (d)(i) be different if the person was standing on the bottom of the pool? Explain your reasoning.

(e) Consider the total pressure exerted by the water on the sides of the pool near the bottom of the pool. When the person floats in the pool, is this pressure greater than, less than, or the same as it was before the person got into the pool? Explain your reasoning.

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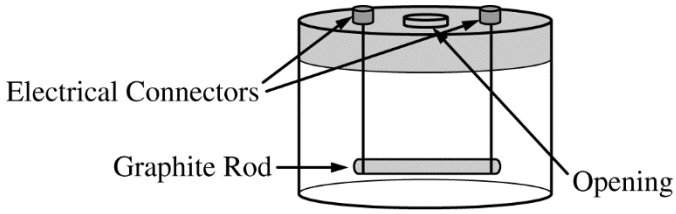

3. (12 points, suggested time 25 minutes)

Students observe that a graphite rod gets hot when there is an electric potential difference ΔV applied across it that causes an electric current I in it. The graphite rod is placed in an apparatus that consists of a clear plastic container with a lid, as shown above. The lid is equipped with electrical connectors and an opening that can be sealed around an inserted sensor. The graphite rod is connected to the electrical connectors by wires and sealed inside the container so that all the energy emitted by the rod goes into heating the air in the container. The teacher tells the students that in this situation the change in the internal energy of the air is equal to $(5/2)Nk_B\Delta T$, where N is the number of molecules and T is the temperature, and the air can be treated as an ideal gas.

(a) Derive an expression for the temperature change of the air as a function of time t as a result of the electrical energy dissipated by the rod and delivered to the air in the container. Express your answer in terms of I, ΔV, N, and physical constants, as appropriate. Assume that the temperature of the graphite rod remains constant while the air is being heated.

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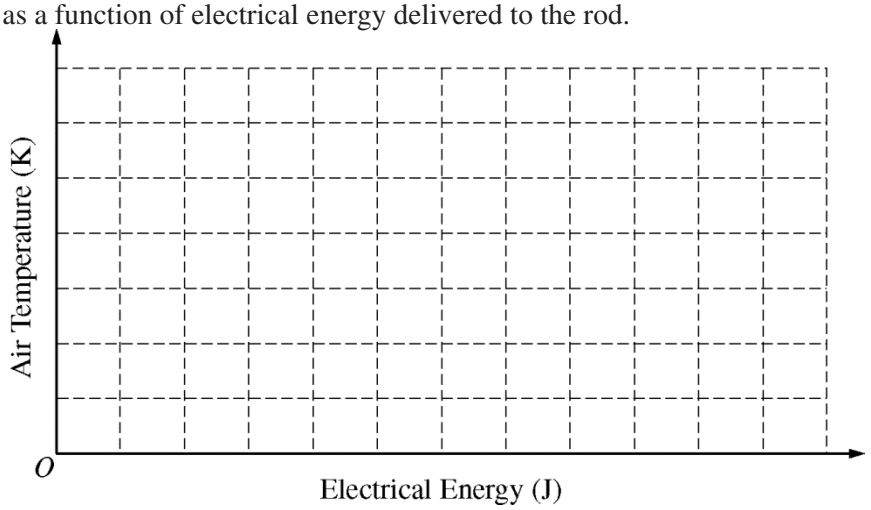
GO ON TO THE NEXT PAGE.

The students are asked to design an experiment using the apparatus shown to investigate this heating. The students have an ammeter, a voltmeter, a fixed DC power supply, a stopwatch, an electronic temperature sensor, and a pressure sensor. Assume that the electrical connectors and connecting wires have negligible resistance.

(b) Outline an experimental procedure that can be used to gather data to determine how the air temperature in the container depends on the electrical energy delivered to the rod. Indicate the measurements to be taken and how the measurements will be used to obtain the data needed. On the diagram on the previous page, show how the container will be connected to instruments to take the necessary measurements.

(c) On the axes below, sketch the line or curve you predict will represent a plot of the temperature of the air in the container as a function of electrical energy delivered to the rod.



Question 3 continues on the next 2 pages.

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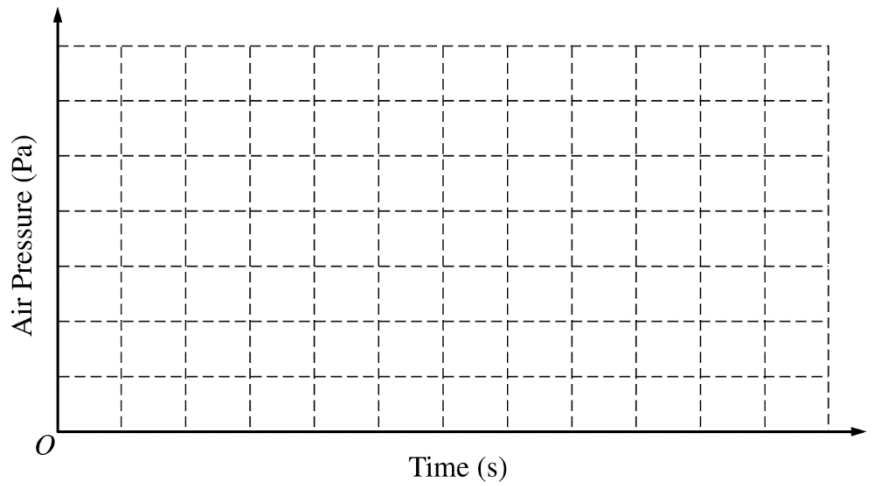
(d)

i. On the axes below, sketch a line or curve you predict will represent a plot of the pressure of the air in the container as a function of time. Clearly label the sketch as R_1.



Explain why your graph has this shape.

ii. The rod is now replaced by a second graphite rod that has twice the length but the same radius. The potential difference across the new rod is the same as that across the original rod. On the axes in part (d)(i), sketch a line or curve you predict will represent a plot of the pressure of the air in the container as a function of time for the second rod. Clearly label the sketch as R_2. Compare this graph to the graph from part (d)(i) and explain why it is the same or different.

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(e) Another group of students performing this experiment notices a gap in the seal of the container opening and thinks that some gas has leaked out of the container. If this is true, how would this group's graph of air temperature as a function of electrical energy compare to the graph you drew in part (c) ?

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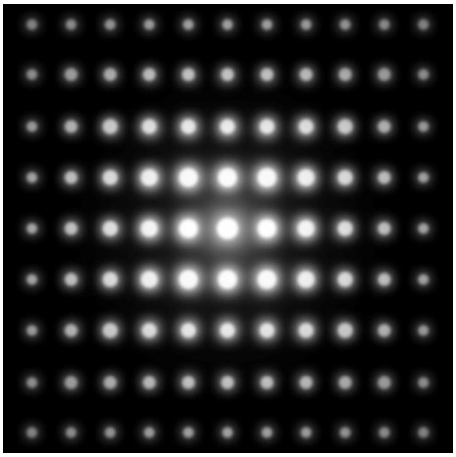

4. (10 points, suggested time 20 minutes)

The picture above appears in a magazine with a caption indicating that the picture represents electron diffraction by atoms in a crystal. The picture was created by directing a beam of electrons through a thin slice of crystal. The article states that a diffraction pattern like the one shown in the picture can be used to determine the distance between atoms in the crystal used in the experiment.

(a) In a coherent paragraph-length response, explain how electrons can be used to form a diffraction pattern and how the pattern can be used to determine the spacing of atoms in a crystal. Your answer may include a diagram that supports your explanation of the pattern formation.

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(b) The article states that x-ray diffraction can also be used to determine crystal spacing. It describes one experiment in which a beam of x-rays with wavelength 8.30 nm was used and another experiment in which a beam of 100 eV electrons was used.

i. Calculate the energy of a photon in the x-ray beam.

ii. Calculate the de Broglie wavelength of an electron in the electron beam.

iii. Will directing the x-ray beam at a crystal with atoms spaced 0.6 nm apart result in the formation of a diffraction pattern? Will directing the electron beam at the same crystal result in the formation of a diffraction pattern? Explain your reasoning in terms of appropriate physics principles.

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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.**

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.**