AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice

2017

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 4NBP4-S

84

AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ 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
$A = \pi r^2$
$C = 2\pi r$

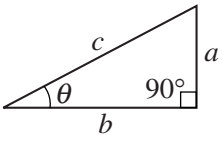
Rectangular solid
$V = \ell wh$

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

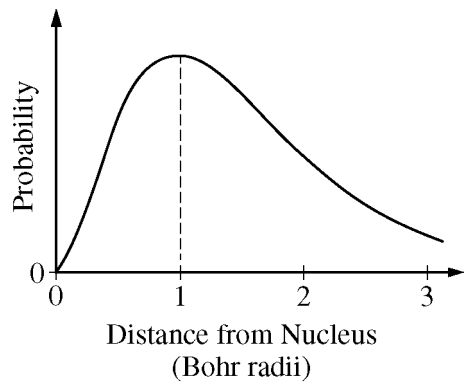
Section I

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. The graph above describes the location of an electron in a hydrogen atom that is in the ground state. What conclusion can be drawn from the graph?

   (A) The distance of the electron from the nucleus is exactly equal to one Bohr radius.
   (B) The electron will probably slide down either the left slope or the right slope, depending on its initial location.
   (C) The electron must always be located within three Bohr radii of the nucleus.
   (D) The greatest probability of locating the electron is at a distance of one Bohr radius from the nucleus.

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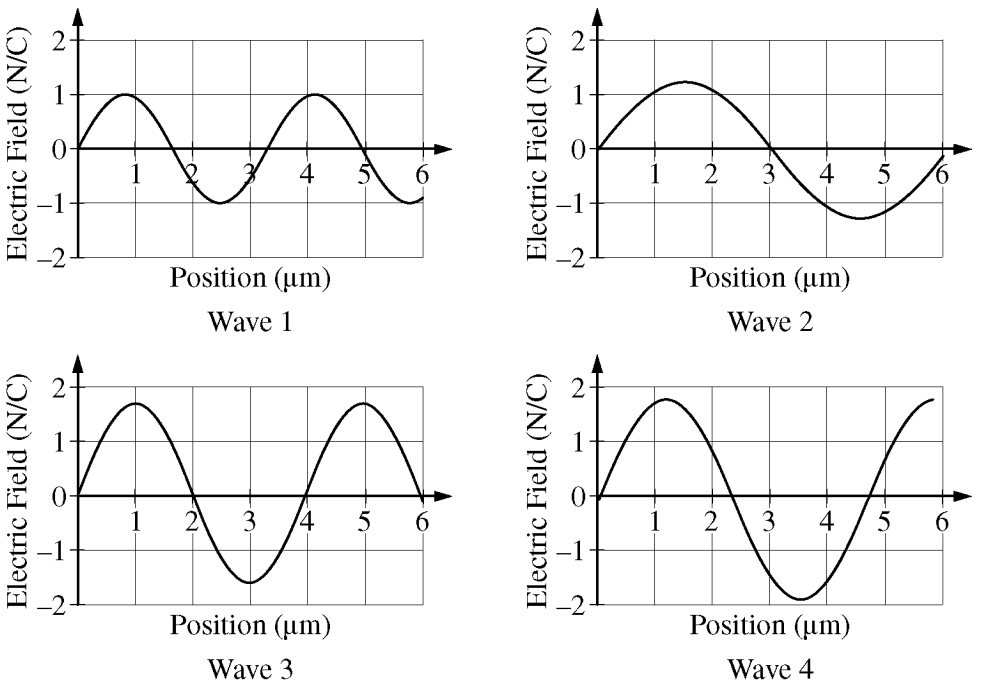

2. The graphs above show the electric field as a function of position at some instant of time for four different electromagnetic plane waves. Which of the following correctly ranks the frequency f of the waves?

   (A) $f_1 > f_2 > f_3 > f_4$

   (B) $f_1 > f_3 > f_4 > f_2$

   (C) $f_2 > f_4 > f_3 > f_1$

   (D) $f_4 > f_3 > f_2 > f_1$

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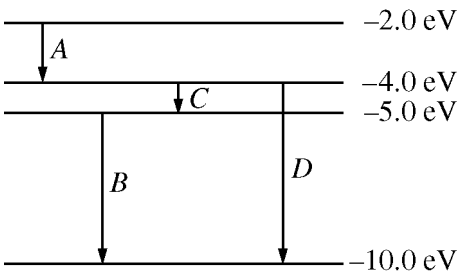
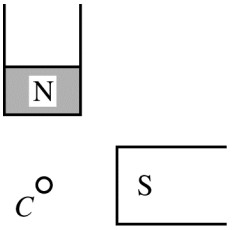
3. When two bowling balls are held with their centers 30 centimeters apart, they exert a gravitational force of magnitude F on each other. For two free protons to exert a net force of magnitude F on each other, the protons must be separated by a distance of approximately 1×10^{-10} m. Under these conditions, will the protons attract or repel each other, and why?

(A) They will attract each other, because they both have positive charge.
(B) They will attract each other, because the gravitational force is always attractive.
(C) They will repel each other, because the repulsive electrical force between the protons is much stronger than the attractive gravitational force.
(D) They will repel each other, because the protons only exert a repulsive electrical force on each other and do not exert an attractive gravitational force.

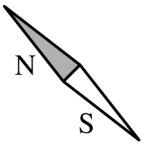


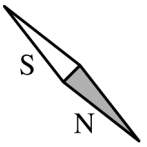
4. The energy level diagram for a hypothetical atom is shown in the figure above. Which of the labeled transitions in the diagram would produce a photon with the shortest wavelength?

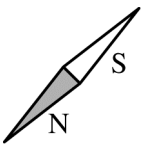
(A) A
(B) B
(C) C
(D) D

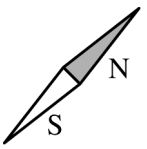


5. The figure above shows a small compass C that is equidistant from the poles of two identical bar magnets. Which of the following best represents the direction that the needle of the compass will point?

(A)


(B)


(C)


(D)


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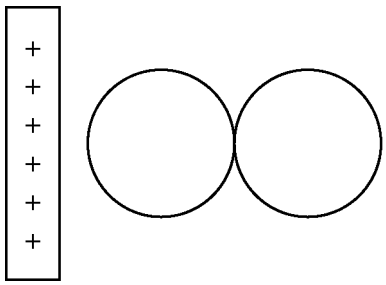
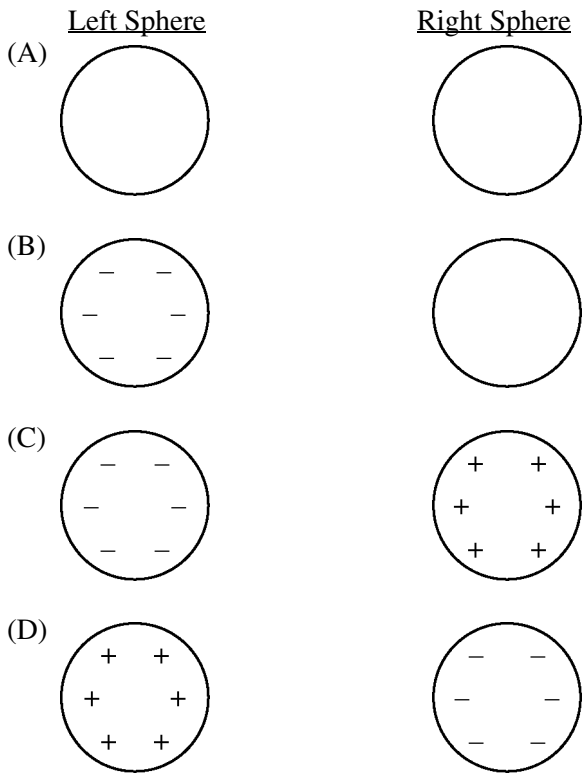
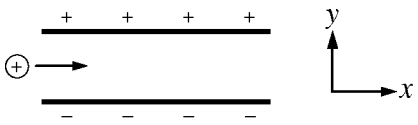
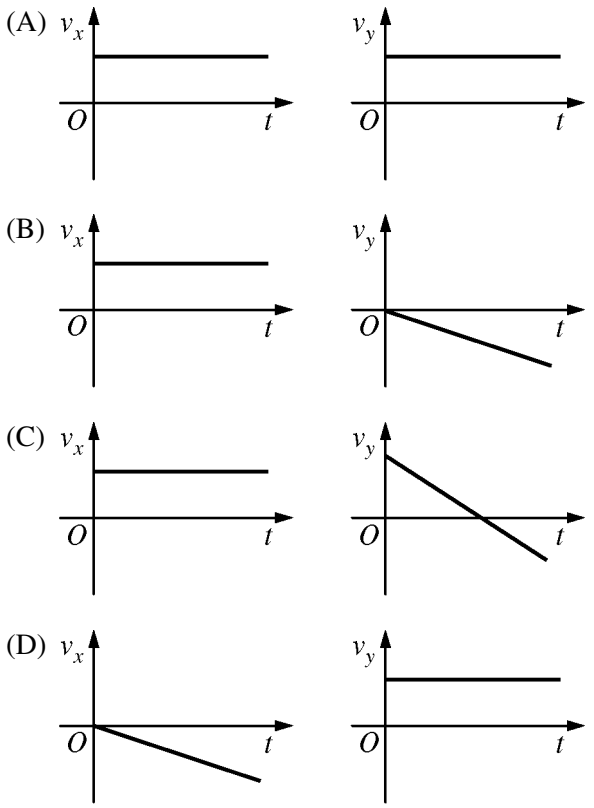


6. Two uncharged conducting spheres on insulating stands are in contact when a positively charged rod is brought near but does not touch them, as shown in the figure above. The right sphere is then moved far to the right, and finally the rod is removed. Which of the following best shows the final distribution of excess charges, if any, on the spheres?





7. 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 correctly shows the x- and y-components of the velocity v as a function of time t ?



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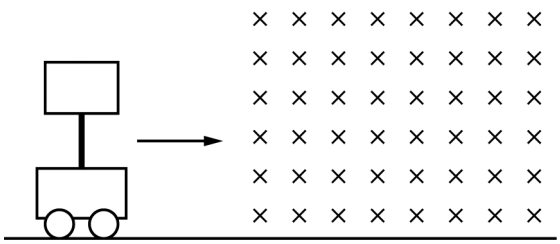
8. A simple circuit has a 24.0 V battery and resistors of resistance 3.0 Ω, 6.0 Ω, and R all connected in parallel. If the current through the battery is 15.0 A, what is the value of R ?

(A) 0.9 Ω
(B) 1.1 Ω
(C) 7.4 Ω
(D) 8.0 Ω



9. A rectangular loop of copper wire is attached to a cart by an insulating rod. The cart is moving at constant speed when it enters a region containing a uniform magnetic field that is perpendicular to the plane of the loop and directed into the page, as shown above. Frictional losses are negligible. Which of the following correctly describes the speed of the cart as it moves into, through, and out of the field?

(A) The speed remains constant.
(B) The speed continually decreases.
(C) The speed decreases as the cart enters the field and increases as it leaves the field but is constant while it is completely inside the field.
(D) The speed decreases as the cart enters and leaves the field but is constant while it is completely inside the field.

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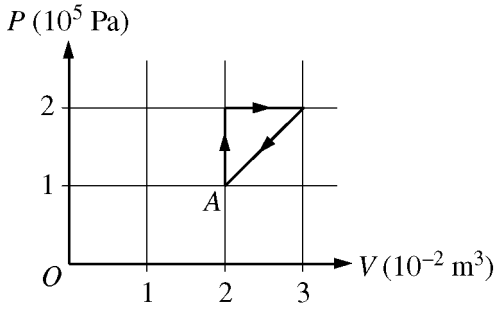

10. A sample of ideal gas that is initially in state *A* shown on the graph above is taken through the cycle shown. What is the net work done on the gas during one cycle?

(A) −500 J
(B) −1000 J
(C) −2000 J
(D) −3500 J

11. A small, well-insulated building is kept cool on a hot day. A person in the building holds a hand close to, but not touching, a solid metal door to the outside and feels warmth coming from the metal door. Which statement best describes how most of the energy is transferred from the outside to the person's hand?

(A) Thermal energy from the outside is convected through the metal door. Thermal energy from the door is conducted by the air and is detected by the person's hand.
(B) Thermal energy from the outside is convected through the metal door. The door radiates energy that is detected by the person's hand.
(C) Thermal energy from the outside is conducted through the metal door. The door radiates energy that is detected by the person's hand.
(D) Thermal energy from the outside is radiated through the metal door. The door radiates energy that is detected by the person's hand.

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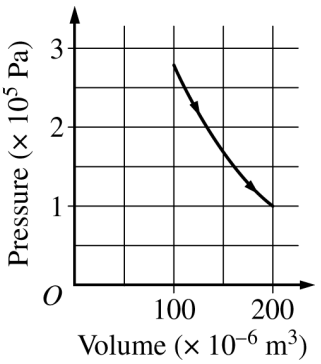
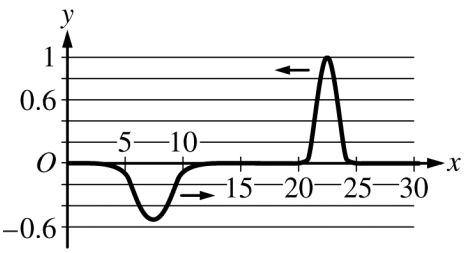
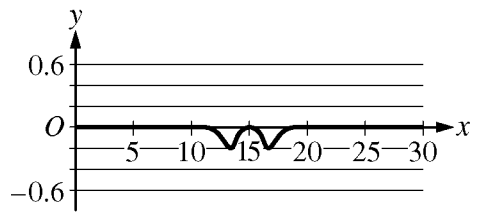


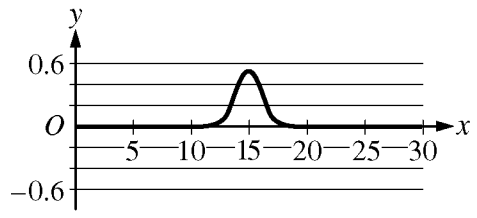
12. The graph above of pressure as a function of volume illustrates a thermodynamic process for an ideal gas in an engine. Which of the following best describes the change in the internal energy of the gas and the work done during the process?

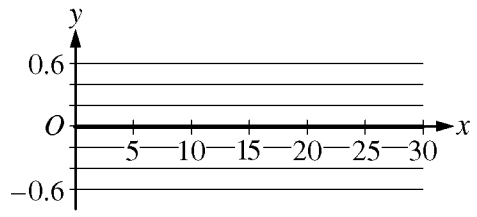
(A) The internal energy increases, and positive work is done by the gas.
(B) The internal energy decreases, and positive work is done on the gas.
(C) The internal energy decreases, and positive work is done by the gas.
(D) The internal energy increases, and positive work is done on the gas.



13. Two wave pulses approach each other, as shown in the figure above. The pulse traveling to the right is half the height and twice the width of the pulse traveling to the left. Which of the following best represents the resulting shape when the peaks of the two pulses are at the same location?

(A)


(B)


(C)


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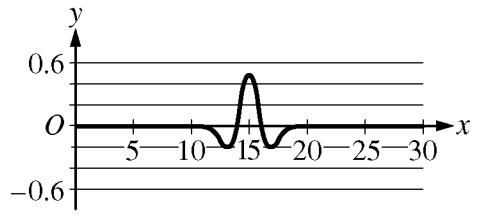

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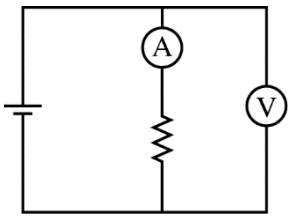
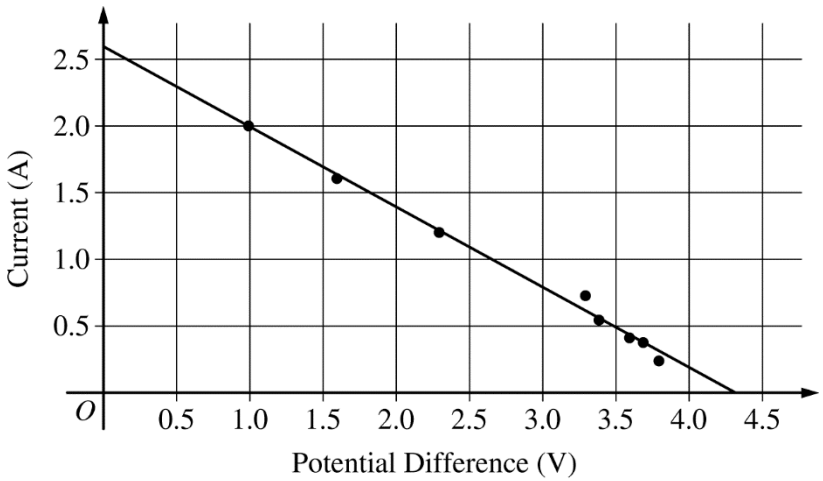
Questions 14-15 refer to the following material.



A student performs an experiment using the circuit shown above, with the goal of determining the characteristics of the battery, which has nonnegligible internal resistance. The student has many resistors with resistances ranging from $0.5\ \Omega$ to $15\ \Omega$. The student puts different resistors in the circuit and records the current and the potential difference measured by the ammeter A and voltmeter V. The student's data table and graph of current as a function of potential difference are shown below.

Resistance (Ω)	0.5	1.0	2.0	4.0	6.0	8.0	10	15
Potential Difference (V)	1.0	1.6	2.3	3.3	3.4	3.6	3.7	3.8
Current (A)	2.0	1.6	1.2	0.72	0.55	0.41	0.35	0.23



14. Which of the following is most nearly the battery's internal resistance?

    (A) 0.4 ohm
    (B) 0.6 ohm
    (C) 1.6 ohm
    (D) 2.6 ohm

15. The student now replaces the battery with a different one that has the same emf but a significantly smaller internal resistance. The student runs the experiment again and graphs the new data. Which of the following correctly describes how the new graph compares to the plot shown above?

    (A) The new graph will be the same as the original graph.
    (B) The vertical intercept will have a greater value, but the slope will be the same.
    (C) The vertical intercept will be the same, but the magnitude of the slope will be greater.
    (D) Both the vertical intercept and the magnitude of the slope will be greater.

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16. A sample of gas has a temperature of 200 K. If the speed of every gas molecule in the sample is doubled, what is the new temperature of the gas?

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

Questions 17-19 refer to the following material.

An atom of polonium (Po-216) is moving slowly enough that it can be considered to be at rest. The Po-216 undergoes alpha decay and becomes lead (Pb-212), via the reaction ${}^{216}_{84}\text{Po} \rightarrow {}^{212}_{82}\text{Pb} + {}^{4}_{2}\alpha$. After the decay, the lead atom is moving to the left with speed v_{Pb}, and the alpha particle is moving to the right with speed v_{α}. The masses of the three isotopes involved in the decay are given below.

$$M_{\text{Po-216}} = 216.001915 \text{ u}$$

$$M_{\alpha} = 4.002603 \text{ u}$$

$$M_{\text{Pb-212}} = 211.991898 \text{ u}$$

17. How do the momentum and kinetic energy of the polonium atom compare with the total momentum and kinetic energy of the decay products?

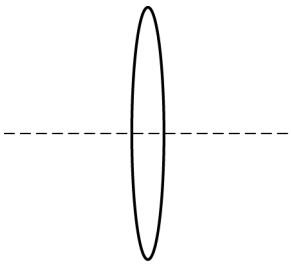
	Polonium Momentum	Polonium Kinetic Energy
(A)	Different	Different
(B)	Different	The same
(C)	The same	Different
(D)	The same	The same

18. How much energy is released in the decay?

(A) None
(B) 0.00741 MeV
(C) 6.90 MeV
(D) 9.31 MeV

19. The half-life of Po-216 is $1/7$ s . What is the probability that any particular Po-216 atom will decay within one second?

(A) 0 %
(B) 7 %
(C) 99 %
(D) 100 %



20. The figure above shows a lens with a focal length of magnitude 30 cm when in air. An object is located 200 cm to the left of the lens. What is the approximate location of the object's image?

(A) 26 cm to the left of the lens
(B) 26 cm to the right of the lens
(C) 35 cm to the left of the lens
(D) 35 cm to the right of the lens

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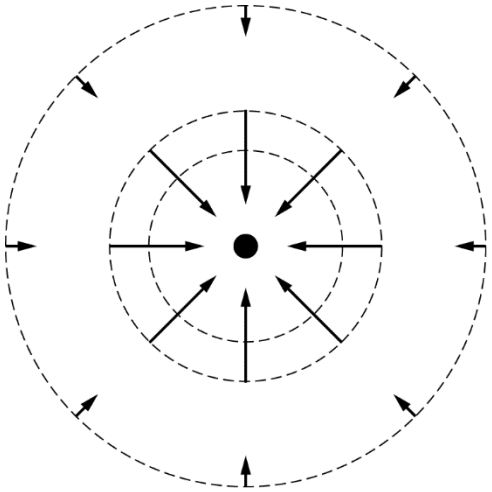
Questions 21-23 refer to the following material.

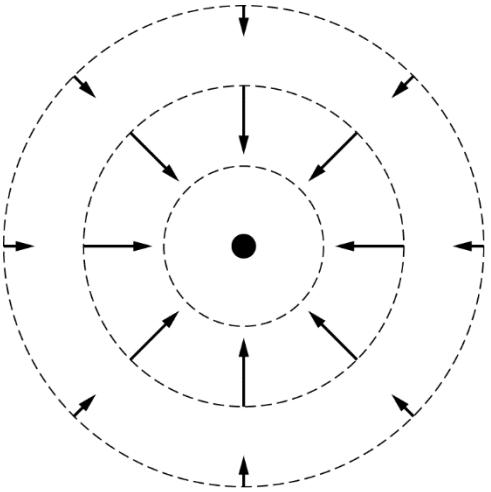
A very small, isolated sphere with charge $+Q$ exists in an empty region of space. A second very small sphere is moved from far away to a short distance from the first sphere.

21. In the figures below, the central dot represents the first sphere. The dashed circles are isolines with the same potential difference between adjacent circles. Which of the figures best represents the isolines and electric field vectors around the first sphere while the second sphere is still far away?

(A)



(B)



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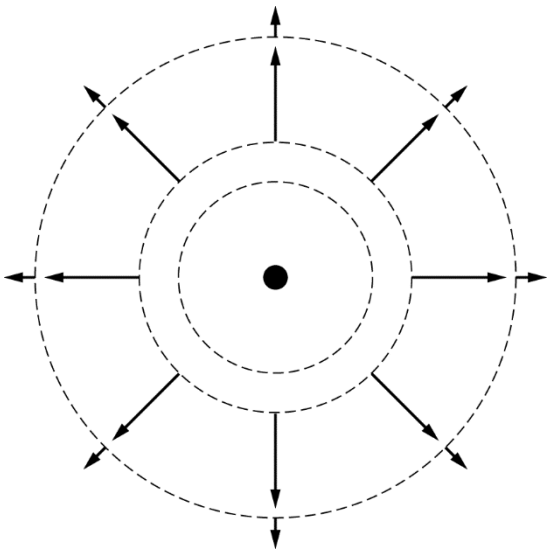

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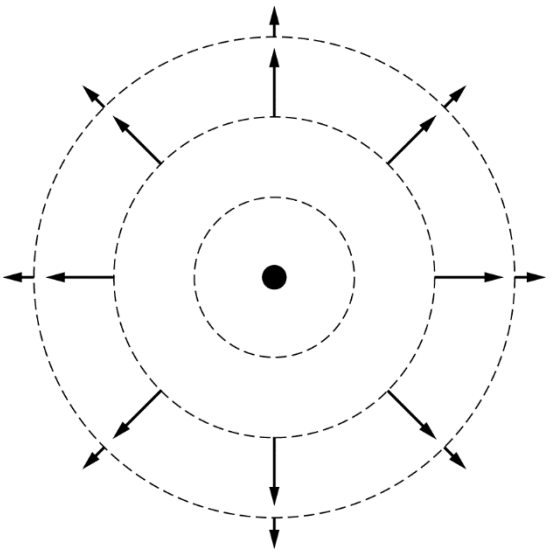

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22. The second sphere has a charge of $+2.0 \times 10^{-9}$ C. As it is moved closer to the first sphere at a constant speed, the second sphere passes through the circular equipotential lines due to the first sphere. Two of these lines are separated by a distance of 0.020 m and have potentials of 100 V and 150 V. What is the magnitude of the average force needed to move the second sphere between the two equipotential lines?

(A) 1.5×10^{-5} N

(B) 5.0×10^{-6} N

(C) 1.0×10^{-7} N

(D) 2.0×10^{-9} N

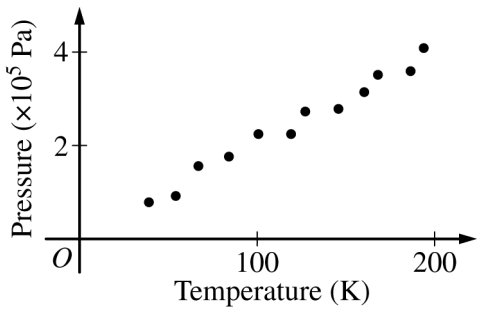
23. As the second sphere is moved at a constant velocity closer to the first sphere, data is taken for the force F exerted on the second sphere by the first sphere as a function of the separation d of the spheres. Which of the following should be graphed to yield a straight line from the data?

(A) F as a function of d

(B) F as a function of d^2

(C) F as a function of $1/d$

(D) F as a function of $1/d^2$



24. A sample of gas is in a sealed container whose volume is held fixed. The pressure of the gas is measured as its absolute temperature is increased. A graph of pressure measurements as a function of temperature is shown above. According to the ideal gas law, which of the following is expected if the sealed container's volume is increased to three times the original value and the experiment is repeated?

(A) The graph will show a linear relationship that still extrapolates to the origin, but with a smaller slope.

(B) The graph will show a linear relationship that still extrapolates to the origin, but with a larger slope.

(C) The graph will show a linear relationship with the same slope, but it will extrapolate to a point on the horizontal axis to the right of the origin.

(D) The graph will show a linear relationship with the same slope, but it will extrapolate to a point on the vertical axis above the origin.

25. Which of the following describes a difference in the behavior of an electrically conducting sphere and that of an insulating sphere?

(A) A conducting sphere can be charged by friction, but an insulating sphere cannot.

(B) An uncharged object can be charged by touching it to a charged conducting sphere, but not by touching it to a charged insulating sphere.

(C) When a conducting sphere is brought near a positively charged object, some of the sphere's electrons move closer to that object. No polarization occurs in the atoms of an insulating sphere.

(D) Excess charge placed on a conducting sphere becomes distributed over the entire surface of the sphere. Excess charge placed on an insulating sphere can remain where it is placed.

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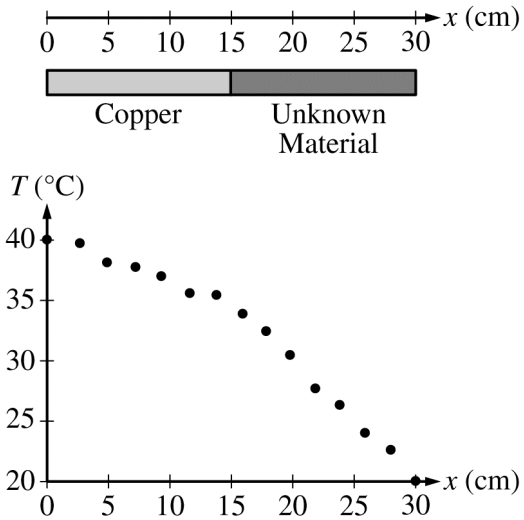

26. A student designs an experiment intended to determine the thermal conductivity of an unknown material. Two 15 cm long bars with the same cross-sectional area are joined together, as shown in the figure above. The bar on the left is made of copper, and the bar on the right is made of the unknown material. The left and right ends of the two-bar combination are maintained at $40°C$ and $20°C$, respectively, and the bars reach equilibrium. The student then measures the temperature T along the bars and produces the data shown in the graph, where $x = 0$ is the left end and 30 cm is the right end. The experimental uncertainty in the data is negligible. Which of the following can the student conclude about k_c, the thermal conductivity of copper, compared with k_u, the thermal conductivity of the unknown material?

(A) $k_c < k_u$
(B) $k_c = k_u$
(C) $k_c > k_u$
(D) The relationship cannot be determined from the data given.

27. A sealed container with a lid of area $0.004\ \text{m}^2$ is filled with an ideal gas. The container and gas are allowed to reach thermal equilibrium with the surrounding air. If a 2000 N block is needed to keep the lid from being pushed off the container, what is the absolute pressure inside the container (the pressure compared to vacuum) ?

(A) 1×10^5 Pa
(B) 2×10^5 Pa
(C) 4×10^5 Pa
(D) 6×10^5 Pa

28. Water initially moving through a small horizontal cylindrical pipe enters a new section of pipe with twice the radius of the initial pipe. What is the ratio of the speed of the water in the new section of pipe to the initial speed of the water?

(A) 2/1
(B) 1/1
(C) 1/2
(D) 1/4

29. A block floating in water is supported by the buoyant force exerted on the block by the water. The buoyant force is created on the atomic scale primarily by which of the following electrostatic forces?

(A) A force of attraction between neutral atoms of the block and neutral atoms of the water
(B) A force of attraction between charged atoms of the block and charged atoms of the water
(C) A force of repulsion between nuclei in the neutral atoms of the block and nuclei in the neutral atoms of the water
(D) A force of repulsion between electrons in the neutral atoms of the block and electrons in the neutral atoms of the water

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30. A supernova explosion occurs at a distance of 2×10^{20} m from Earth. The supernova simultaneously emits radiation at both visible and x-ray wavelengths. Which of the following statements best describes the time it takes for the two types of radiation from the supernova to reach Earth?

(A) The two types of radiation reach Earth at the same time, within a few seconds of the supernova explosion.
(B) The two types of radiation reach Earth at the same time, many years after the supernova explosion.
(C) The two types of radiation reach Earth many years after the supernova explosion, but the visible radiation arrives first due to its shorter wavelength.
(D) The two types of radiation reach Earth many years after the supernova explosion, but the x-ray radiation arrives first due to its shorter wavelength.

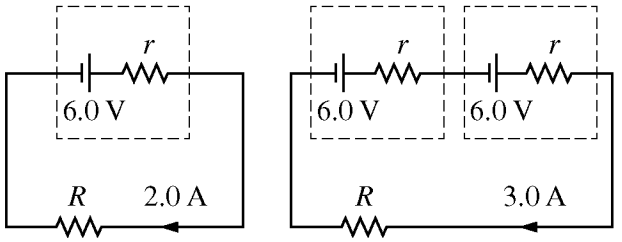
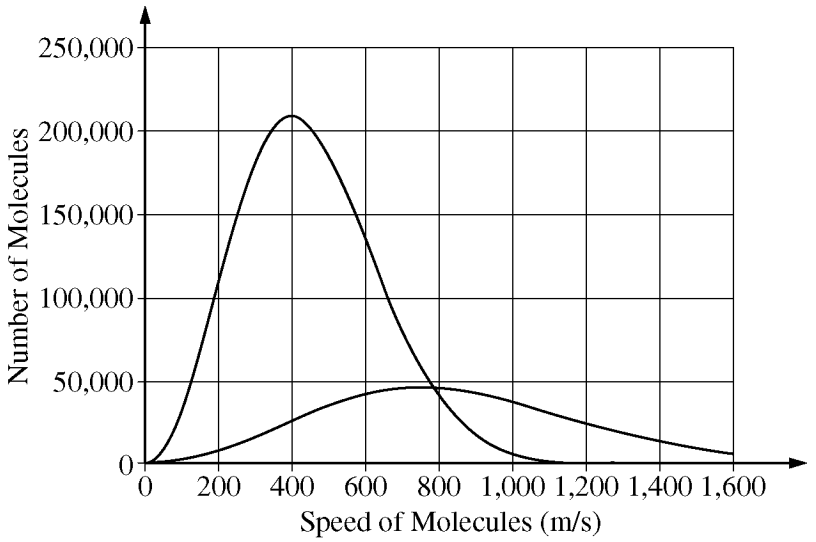


Figure 1 Figure 2

31. A battery with emf 6.0 V and an internal resistance r is connected to a resistor of resistance R, as shown in Figure 1 above. The current in the circuit is 2.0 A. When an identical battery is added to the circuit in series, as shown in Figure 2, the current in the circuit is 3.0 A. Which of the following statements about the resistances in the circuit is true?

(A) r is very small compared to R.
(B) r is very large compared to R.
(C) r is equal to R.
(D) r and R are comparable in magnitude, but they are not equal.



32. Two samples of the same type of gas molecules are placed in different closed containers and are thermally isolated from each other and the environment. The figure above shows the distribution of speeds for the molecules in each of the samples. The two samples are now mixed together and allowed to reach thermal equilibrium. Which of the following is true of the peak of the distribution for the mixed sample?

(A) It is closer to 400 m/s than it is to 800 m/s.
(B) It is closer to 800 m/s than it is to 400 m/s.
(C) It is midway between the peaks of the distributions shown.
(D) There is not just one peak but two, at the same locations as the peaks of the distributions shown.

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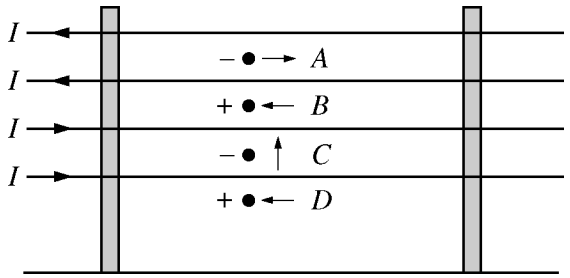

33. Four horizontal wires are arranged on vertical wooden poles, as shown in the figure above. The wires are equally spaced and have equal currents I in the directions indicated in the figure. The dots represent four charged dust particles moving in the plane of the wires. The sign of the charge on each particle and its direction of motion at a particular instant are shown. Which of the dust particles has a magnetic force exerted on it in the downward direction at this instant?

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

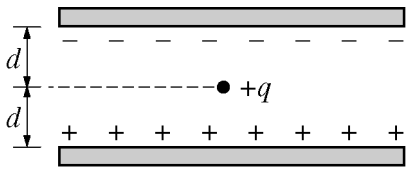

Figure 1

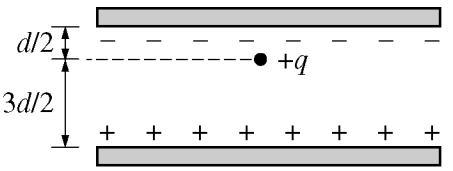

Figure 2

34. A parallel-plate capacitor is charged so that an electric field E is created between the plates. A small oil drop with charge $+q$ is placed halfway between the plates, as shown in Figure 1 above. The force exerted on the oil drop by the electric field is determined to have a magnitude of F. The oil drop is now moved half the distance toward the negatively charged plate, as shown in Figure 2 above. What is the magnitude of the force exerted by the electric field on the oil drop at the position shown in Figure 2 ?

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

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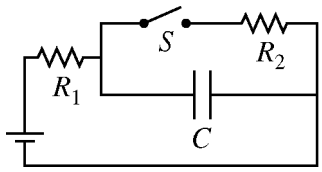

35. In the circuit represented above, resistors R_1 and R_2, capacitor C, and open switch S are connected to a battery. The circuit reaches equilibrium. The switch is then closed, and the circuit is allowed to come to a new equilibrium. Which of the following is a true statement about the charge q_f stored on the capacitor after the switch is closed compared with the charge q_i stored on the capacitor before the switch is closed?

(A) $q_f > q_i$

(B) $q_f = q_i$

(C) $q_f < q_i$

(D) The relationship between the charges cannot be determined unless the resistances of the resistors are known.

36. Louis de Broglie proposed that all forms of matter have both wave properties and particle properties. Which of the following explains why diffraction effects are observable only for small-scale objects?

(A) Wavelengths of large-scale objects are much smaller than any aperture through which the objects could pass.

(B) Wavelengths of large-scale objects are much larger than any aperture through which the objects could pass.

(C) Large-scale objects have too much energy to allow observation of their wave properties.

(D) Large-scale objects move too slowly to allow observation of their wave properties.

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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. A student is given a sample of gas that is at room temperature and is sealed in a container by a movable piston. Which of the following adjustments would allow the student to increase the pressure of the gas? Select two answers.

(A) Put the container in a tank of room-temperature water and pull the piston outward.
(B) Put the container in a tank of room-temperature water and push the piston inward.
(C) Put the container in a tank of hot water and hold the piston in place.
(D) Put the container in a tank of cold water and hold the piston in place.

132. A student is given two different convex spherical mirrors and asked to determine which of the mirrors has the shorter focal length. Answering which of the following questions would allow the student to make this determination? Select two answers.

(A) Which mirror has a larger magnification for a given object distance?
(B) Which mirror has the greater change in magnification when submerged in water?
(C) Which mirror produces an upright image?
(D) Which mirror has a smaller radius of curvature?

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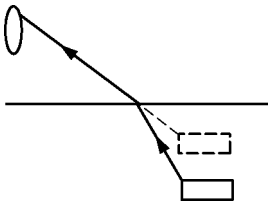
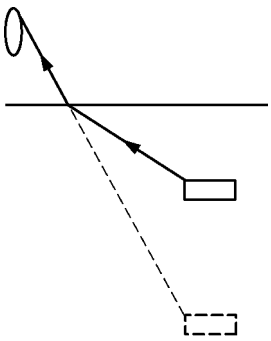
133. On a calm day, student 1 looks down into a pool and sees student 2 swimming underwater. At the same time, student 2 looks up from under the water and sees student 1. In the following diagrams, the oval represents student 1 and the rectangle represents student 2. Diagrams that correctly illustrate the apparent positions seen by student 1 and student 2 include which of the following? Select two answers.

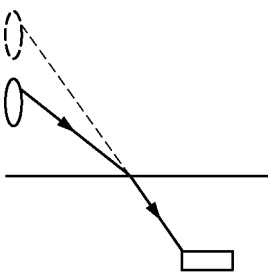
(A)



(B)



(C)



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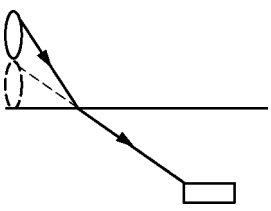

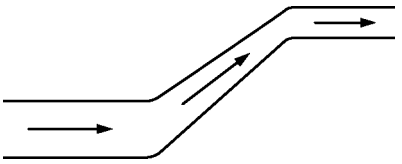

134. An ideal fluid is moving from left to right through a pipe, as shown in the figure above. The diameter of the pipe decreases and the height increases from left to right. True statements about the pressure of the fluid as it moves through the pipe include which of the following? Select two answers.

(A) The pressure tends to decrease due to the increase in the fluid's speed as the pipe gets narrower.
(B) The pressure tends to increase due to the decrease in the fluid's speed as the pipe gets narrower.
(C) The pressure tends to decrease due to the increase in the potential energy of the fluid-Earth system as the pipe gets higher.
(D) The pressure tends to increase due to the increase in the potential energy of the fluid-Earth system as the pipe gets higher.

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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

2017

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 4NBP4-S

84

AP® PHYSICS 2 TABLE OF INFORMATION

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

1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ 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
$A = \pi r^2$
$C = 2\pi r$

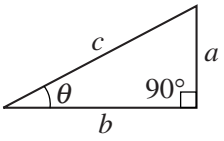
Rectangular solid
$V = \ell w h$

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.

1. (10 points, suggested time 20 minutes)

   A team of engineering students is testing their newly designed 200 kg raft in the pool where the diving team practices. The raft must hold a 730 kg steel cube with edges of length 45.0 cm without sinking. Assume the density of water in the pool is $1000\ \text{kg}/\text{m}^3$.

   (a) The students use a crane to gently place the cube on the raft but accidentally place it off center. The cube remains on the raft for a few moments and then the raft tilts, causing the cube to slide off and sink to the bottom of the pool. The raft remains floating in the pool. In a coherent paragraph-length response, indicate whether the water level in the pool when the cube is on the bottom of the pool is higher than, lower than, or the same as when the cube is on the raft, and explain your reasoning. For both cases, assume that there is no motion of the water.

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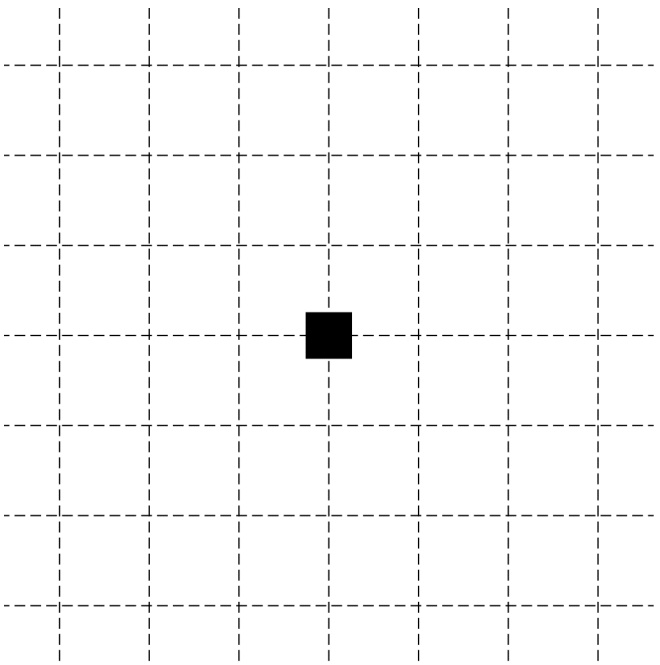
(b) The bottom of the pool is 5 m below the surface of the water. The crane is now used to lift the cube out of the pool. The cube is lifted upward at a slow and constant speed, so all drag forces are negligible.

i. Predict how the force exerted by the crane on the cube when the bottom of the cube is at a depth of 2.0 m compares to the force exerted by the crane on the cube when the bottom of the cube is at a depth of 4.0 m. Explain your reasoning.

ii. On the black square below, which represents the cube, draw and label the forces (not components) that are exerted on the cube while the crane is lifting it and the bottom of the cube is 4 m below the surface of the water. Each force must be represented by a distinct arrow starting on, and pointing away from, the black square. The lengths of the arrows should approximately demonstrate the net force on the cube.



iii. Calculate the force exerted by the crane on the cube when the bottom of the cube is 4 m below the surface of the water.

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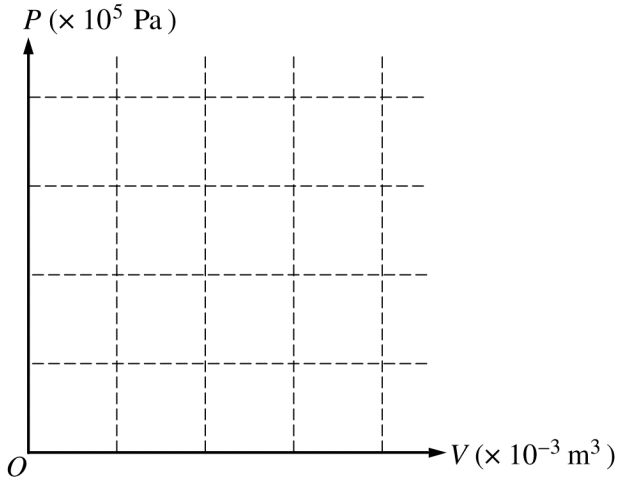
2. (12 points, suggested time 25 minutes)

A student gives the following description of a thermodynamic cycle through which a sample of an ideal monatomic gas is taken.

"Initially, the gas has a volume of 1×10^{-3} m^3 and a pressure of 1×10^5 Pa . The gas is in a closed cylinder that has a movable piston on one end. Call the initial state of the gas state *A*. Process *AB* takes the gas at constant pressure from state *A* to state *B*, where *B* has three times the volume of state *A*. The gas is then compressed isothermally until it is back to its initial volume, reaching state *C*. Finally, a single process *CA* returns the gas to its initial state *A*."

(a)

i. On the axes below, plot states *A*, *B*, and *C*, and sketch a graph of pressure *P* as a function of volume *V* for cycle *ABCA*. Label states *A*, *B*, and *C*, and label the axes with numerical values.



ii. Let the temperature for state *A* be T_0 . In terms of T_0 , determine the temperature for state *B*.

iii. Compare the temperature at state *C* to the temperature at state *A*. Explain how your comparison is consistent with your graph above.

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(b)

i. Briefly describe an experimental procedure that would take the gas from state *C* to state *A*.

ii. Relate the temperature of the gas to the microscopic processes involved in the energy transfer as the gas goes from state *C* to state *A* for the procedure you described in part (b)(i).

(c)

i. Use the student's verbal description or your graph in part (a)(i) to calculate a numerical value for the work done on the gas in process *AB*.

ii. The magnitude of the change in internal energy for process *AB* is $|\Delta U| = 300$ J . Calculate a numerical value for the energy added to or removed from the gas by heating in process *AB*.

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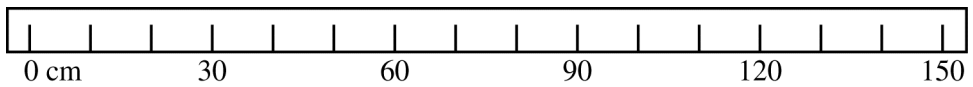
3. (12 points, suggested time 25 minutes)

Students are asked to perform an experiment to determine the focal length of a converging lens. They are given an optical bench that includes a lamp, a converging lens in a holder, and a screen. All three of these can be positioned anywhere along the optical bench. The students decide to form real images by placing the lamp at various specific distances from the lens and moving the screen until a focused image of the lamp filament is formed on the screen. They keep the lens at the 60 cm mark on the optical bench. The table below shows their data for the object and image distances.

Trial	1	2	3	4	5
Object Distance s_o (cm)	55	45	35	30	25
Image Distance s_i (cm)	21.3	23.8	28.5	32.5	43

(a) On the figure below, representing the optical bench, draw and label the screen, lens, and lamp in correct positions for trial 1.



(b) What quantities could be plotted to create a linear graph that could be used to calculate the focal length of the lens? Justify your answer.

Use the empty rows of the table above to record any values you need to calculate.

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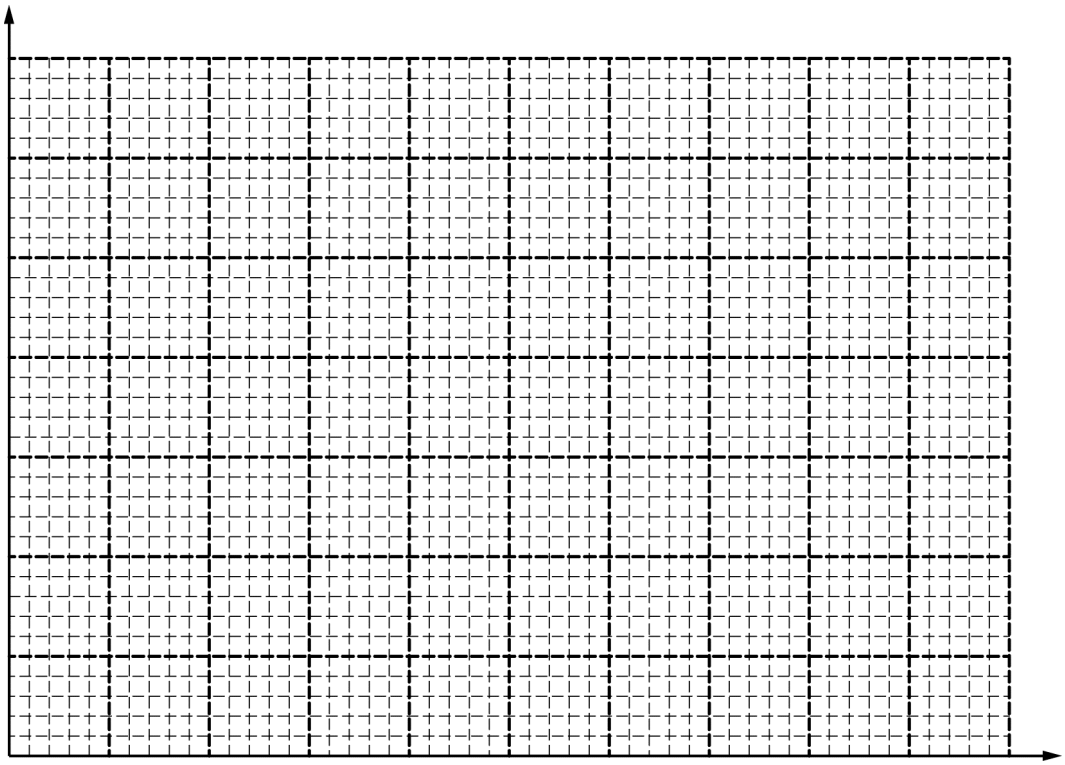
(c)

i. On the axes below, plot data for the quantities you indicated in part (b). Label and scale the axes.



ii. Use your graph to calculate the focal length of the lens. Show your calculations.

Question 3 continues on the next page.

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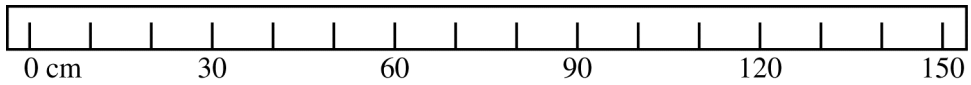
(d) The students are now given a converging mirror of focal length 15 cm to replace the lens and asked to make measurements that would allow them to verify the focal length of the mirror. Describe a procedure that would result in creation of a real image from which the focal length could be determined. On the figure below, representing the optical bench, draw and label the screen, lamp, and mirror in appropriate positions. Indicate what measurements should be made and how they could be used to calculate the focal length.



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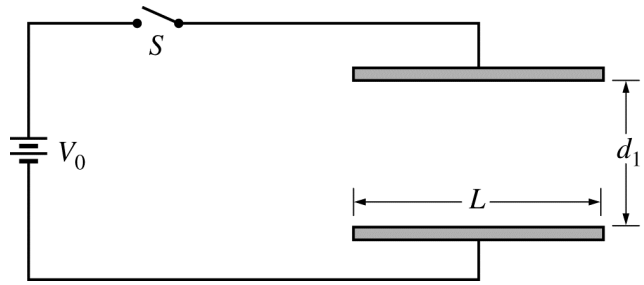
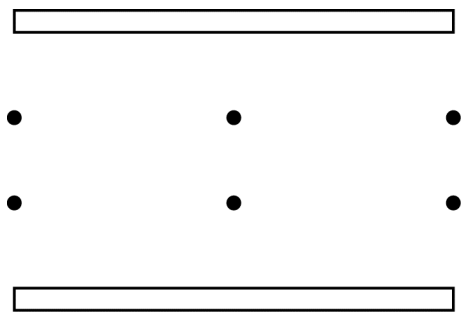


4. (10 points, suggested time 20 minutes)

An uncharged air-filled capacitor has square plates of side L whose separation can be varied. The initial plate separation is d_1, which is comparable to L. The capacitor is connected to a battery with potential difference V_0 and a switch S, as shown above. Assume the dielectric constant of the air is 1.0.

(a) The switch is closed and remains closed for a long time.

i. On the diagram below, draw a vector at each dot to represent the electric field created by the charge on the capacitor plates.



ii. The plates are now moved to a new separation $d_2 << d_1$ and allowed to reach equilibrium. Calculate the magnitude of the charge on each plate of the capacitor in terms of V_0, L, d_2, and physical constants, as appropriate.

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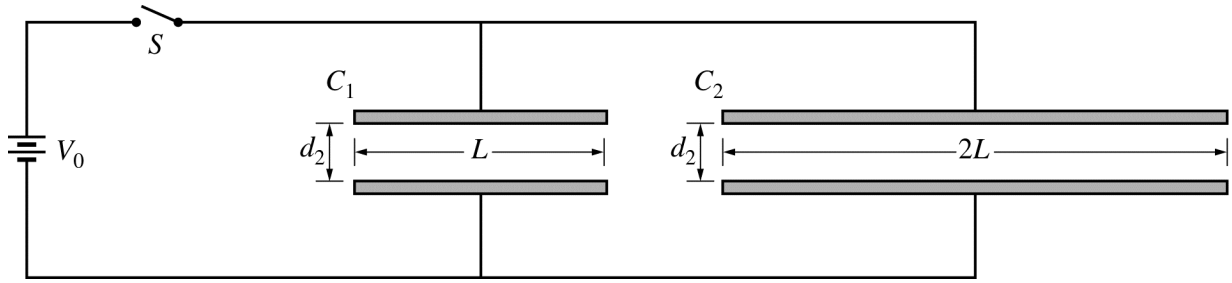
(b) The plates are pulled apart to a separation of $2d_2$, where $2d_2 << d_1$.

i. Suppose the switch remains closed while the plates are pulled apart. Compare the magnitude of the new electric field between the plates when their separation is $2d_2$ to the magnitude of the field for plate separation d_2. Support your comparison using appropriate physics principles.

ii. Suppose the switch is opened before the plates are pulled apart. Compare the magnitude of the new electric field between the plates when their separation is $2d_2$ to the magnitude of the field for plate separation d_2. Support your claim using appropriate physics principles.

(c) The new circuit shown below is now assembled. The plates of the original capacitor, C_1, are at separation d_2. A second capacitor, C_2, with square plates of side 2*L* and plate separation d_2, is connected in parallel with the original capacitor. Both capacitors are initially uncharged. The switch is closed and the circuit reaches equilibrium. Let Q_0 be the magnitude of the charge on each plate of capacitor C_1 in the previous circuit, as determined in part (a)(ii). In terms of Q_0, calculate the magnitude of the charge on each plate of the two capacitors in the new circuit.



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STOP

END OF EXAM

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

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

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