AP

AP® Physics B
2013 Free-Response Questions

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

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^3$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^5$ N/m$^2 = 1.0 \times 10^5$ Pa

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

PREFIXES		
Factor	Prefix	Symbol
10^9	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.   Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
  II. The direction of any electric current is the direction of flow of positive charge (conventional current).
  III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
  IV. For mechanics and thermodynamics equations, W represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \dfrac{1}{2}at^2$

$v^2 = v_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

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

$\tau = rF \sin \theta$

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

$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$

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

$\Delta U_g = mgh$

$W = F\Delta r \cos \theta$

$P_{avg} = \dfrac{W}{\Delta t}$

$P = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

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

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

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

$T = \dfrac{1}{f}$

$F_G = -\dfrac{Gm_1 m_2}{r^2}$

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

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on
      a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \dfrac{kq_1 q_2}{r^2}$

$\mathbf{E} = \dfrac{\mathbf{F}}{q}$

$U_E = qV = \dfrac{kq_1 q_2}{r}$

$E_{avg} = -\dfrac{V}{d}$

$V = k\left(\dfrac{q_1}{r_1} + \dfrac{q_2}{r_2} + \dfrac{q_3}{r_3} + ... \right)$

$C = \dfrac{Q}{V}$

$C = \dfrac{\epsilon_0 A}{d}$

$U_c = \dfrac{1}{2}QV = \dfrac{1}{2}CV^2$

$I_{avg} = \dfrac{\Delta Q}{\Delta t}$

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

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + ...$

$\dfrac{1}{C_s} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} + ...$

$R_s = R_1 + R_2 + R_3 + ...$

$\dfrac{1}{R_p} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + ...$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

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

$\phi_m = BA \cos \theta$

$\varepsilon_{avg} = -\dfrac{\Delta \phi_m}{\Delta t}$

$\varepsilon = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored)
      energy
V = electric potential or
      potential difference
v = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

FLUID MECHANICS AND THERMAL PHYSICS

$$\rho = m/V$$

$$P = P_0 + \rho g h$$

$$F_{buoy} = \rho V g$$

$$A_1 \upsilon_1 = A_2 \upsilon_2$$

$$P + \rho g y + \frac{1}{2}\rho \upsilon^2 = \text{const.}$$

$$\Delta \ell = \alpha \ell_0 \Delta T$$

$$H = \frac{kA\,\Delta T}{L}$$

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

$$PV = nRT = Nk_B T$$

$$K_{avg} = \frac{3}{2}k_B T$$

$$\upsilon_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$$

$$W = -P\Delta V$$

$$\Delta U = Q + W$$

$$e = \left|\frac{W}{Q_H}\right|$$

$$e_c = \frac{T_H - T_C}{T_H}$$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
υ = velocity or speed
υ_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$$E = hf = pc$$

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

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

$$\Delta E = (\Delta m)c^2$$

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

WAVES AND OPTICS

$$\upsilon = f\lambda$$

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

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

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$$

$$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$$

$$f = \frac{R}{2}$$

$$d\sin\theta = m\lambda$$

$$x_m \approx \frac{m\lambda L}{d}$$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
υ = speed
x = position
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
$$V = \frac{4}{3}\pi r^3$$
$$S = 4\pi r^2$$

Right Triangle
$$a^2 + b^2 = c^2$$
$$\sin\theta = \frac{a}{c}$$
$$\cos\theta = \frac{b}{c}$$
$$\tan\theta = \frac{a}{b}$$
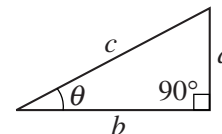
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering each of Questions 1, 3-5 and 7 and about 17 minutes for answering each of Questions 2 and 6. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.
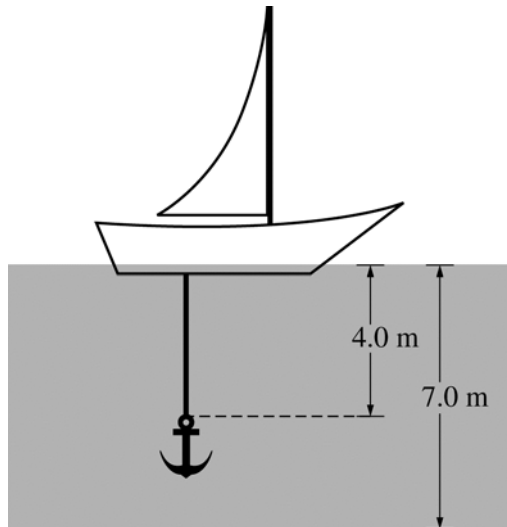
1. (10 points)

   A sailboat at rest on a calm lake has its anchor dropped a distance of 4.0 m below the surface of the water. The anchor is suspended by a rope of negligible mass and volume. The mass of the anchor is 50 kg, and its volume is 6.25×10^{-3} m^3. The density of water is 1000 kg$/$m^3.

   (a) On the dot below that represents the anchor, draw and label the forces (not components) that act on the anchor.

   ●

(b) Calculate the magnitude of the buoyant force acting on the anchor. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. DO NOT add anything to the figure in part (a).

(c) Calculate the tension in the rope. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. DO NOT add anything to the figure in part (a).

(d) The bottom of the boat is at a depth d below the surface of the water. Suppose the anchor is lifted back into the boat so that the bottom of the boat is at a new depth d' below the surface of the water. How does d' compare to d ?

_____ $d' < d$ _____ $d' = d$ _____ $d' > d$

Justify your answer.

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2. (15 points)

A 20 kg box on a horizontal frictionless surface is moving to the right at a speed of 4.0 m/s . The box hits and remains attached to one end of a spring of negligible mass whose other end is attached to a wall. As a result, the spring compresses a maximum distance of 0.50 m, and the box then oscillates back and forth.

(a)
    i. The spring does work on the box from the moment the box first hits the spring to the moment the spring first reaches its maximum compression. Indicate whether the work done by the spring is positive, negative, or zero.

         ____ Positive   ____ Negative   ____ Zero
         Justify your answer.

   ii. Calculate the magnitude of the work described in part i.

(b) Calculate the spring constant of the spring.

(c) Calculate the magnitude of the maximum acceleration of the box.

(d) Calculate the frequency of the oscillation of the box.

GO ON TO THE NEXT PAGE.

(e) Let $x = 0$ be the point where the box makes contact with the spring, with positive x directed toward the right.

    i. On the axes below, sketch the kinetic energy K of the oscillating box as a function of <u>position</u> x for the range $x = -0.50$ m to $x = +0.50$ m.
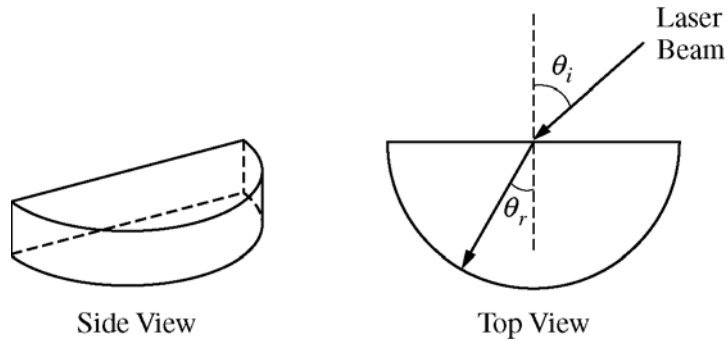
K

          −0.50 O 0.50 x (m)
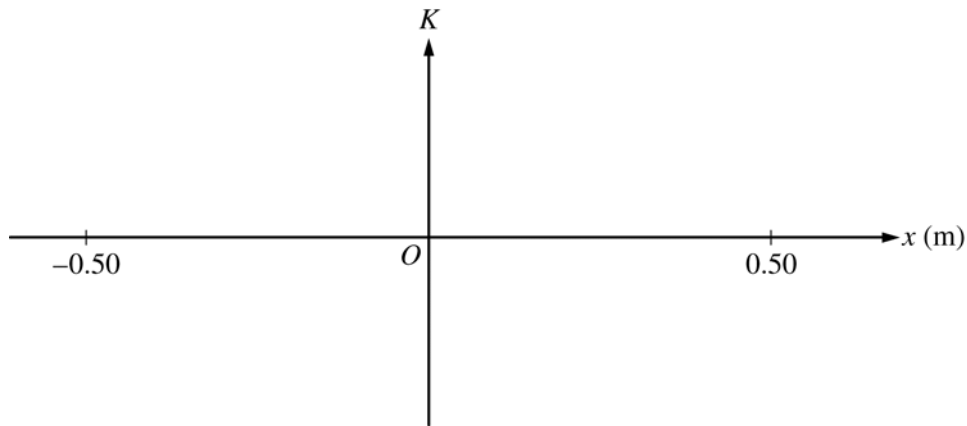
    ii. On the axes below, sketch the acceleration a of the oscillating box as a function of <u>position</u> x for the range $x = -0.50$ m to $x = +0.50$ m.

a

          −0.50 O 0.50 x (m)

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Side View   Top View
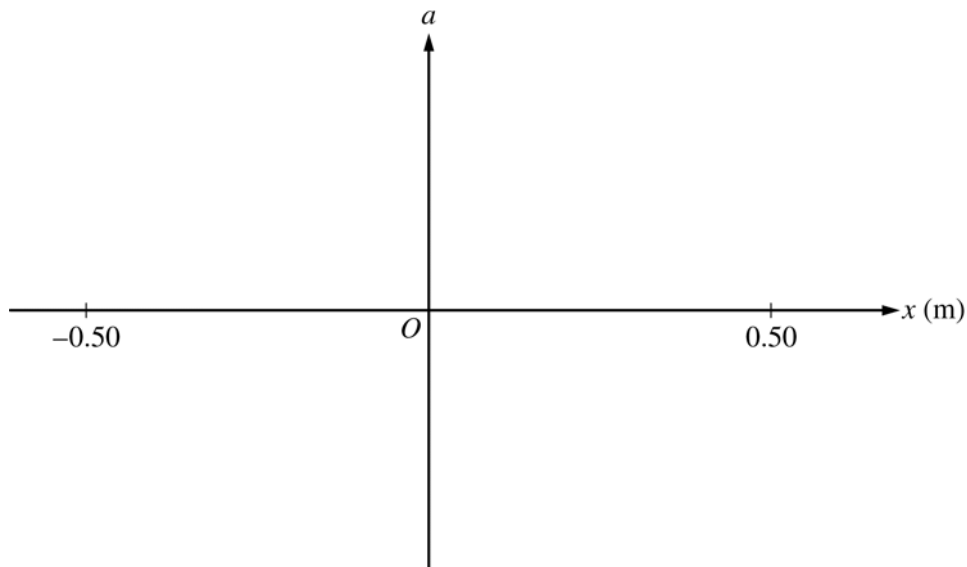
3. (10 points)

A student is asked to experimentally determine the index of refraction of the semicircular block of transparent plastic shown in the figure above. The student aims a red laser beam of wavelength $\lambda = 632$ nm at the center of the flat side of the block, as shown. The ray is refracted from air into the plastic and strikes the semicircular side of the block perpendicularly. The student uses a protractor to aim the laser at several different angles of incidence θ_i between $0°$ and $90°$ and to measure the angles of refraction θ_r. The student's data are given in the table below.

| θ_i	$0°$	$15°$	$30°$	$45°$	$60°$	$75°$
θ_r	$0°$	$10°$	$21°$	$30°$	$37°$	$44°$
$\sin\theta_i$	0	0.26	0.50	0.71	0.87	0.97
$\sin\theta_r$	0	0.17	0.36	0.50	0.60	0.70

(a) On the grid below, plot data that will allow the index of refraction of the plastic to be calculated from a straight line that represents the data. Clearly label the axes, including the scales.

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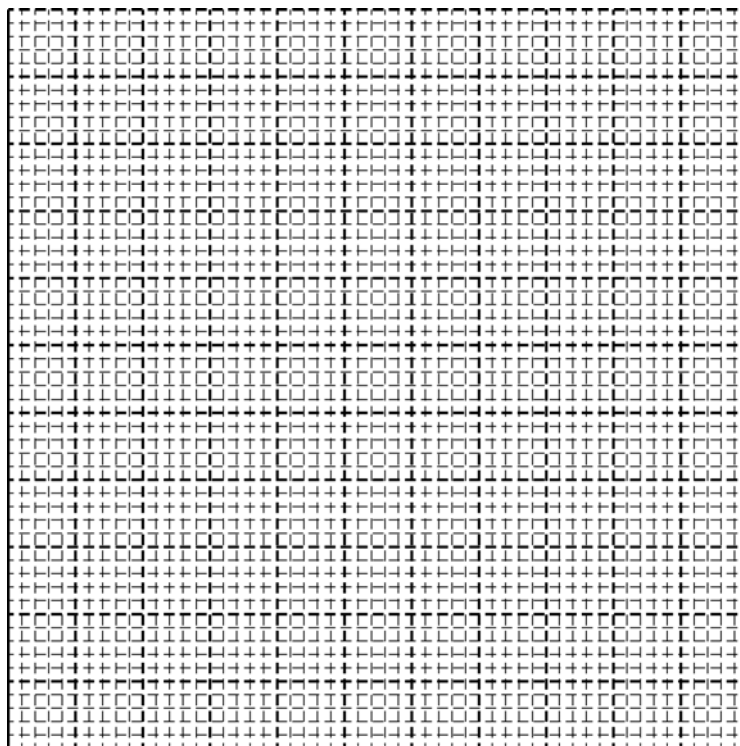
(b) On your graph, draw a straight line that best represents the data. Use the slope of the line to determine the index of refraction of the plastic.

(c) The student now wants to confirm the result obtained in part (b) by using the critical angle for the plastic. Describe one experimental method the student can use to measure the critical angle. Indicate how the index of refraction can be determined from this measurement.
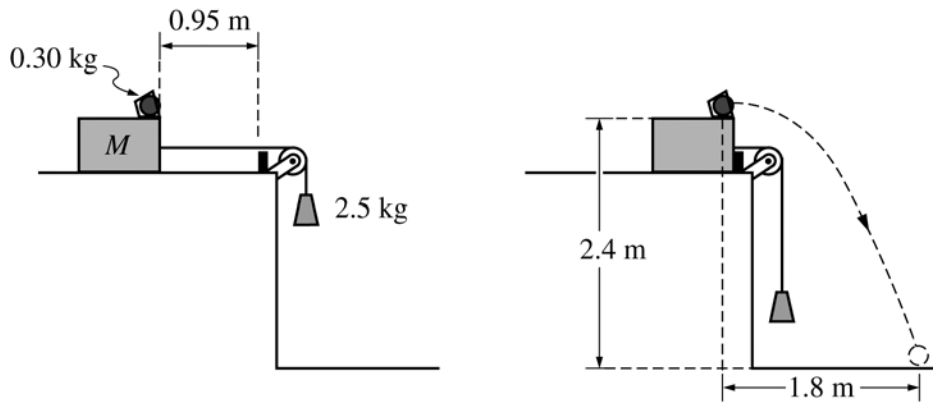
4. (10 points)

A 0.30 kg ball is in a cup of negligible mass attached to a block of mass *M* that is on a table. A string passing over a light pulley connects the block to a 2.5 kg object, as shown above. The system is released from rest, the block accelerates to the right, and after moving 0.95 m the block collides with a bumper near the end of the table. The ball continues to move and lands on the floor at a position 2.4 m below and 1.8 m horizontally from where it leaves the cup. Assume all friction is negligible.

(a) Calculate the speed of the ball just after the block hits the bumper and the ball leaves the cup.

(b) Calculate the magnitude of the acceleration of the block as it moves across the table.

(c) Calculate the mass *M* of the block.

(d) If the mass of the ball is increased, the horizontal distance it travels before hitting the floor will decrease. Explain why this will happen.

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5. (10 points)

   In a certain process, 3200 J of energy is added to an ideal gas by heating. During the same process, 2100 J of work is done <u>on</u> the gas.

   (a) Determine the change in the internal energy of the gas.

   (b) Indicate whether each of the following properties of the gas increases, decreases, or remains the same during the process.

      i. Volume

         ____ Increases   ____ Decreases   ____ Remains the same
         Justify your answer.

      ii. Temperature

         ____ Increases   ____ Decreases   ____ Remains the same
         Justify your answer.

      iii. Pressure

         ____ Increases   ____ Decreases   ____ Remains the same
         Justify your answer.

   Suppose that in a different process 1800 joules of work is done <u>on</u> the ideal gas at a constant temperature.
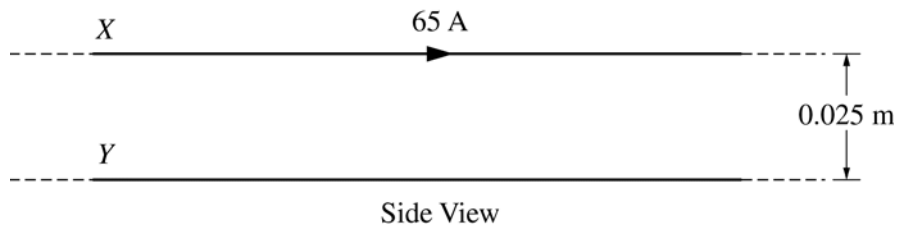
   (c) Determine the change in internal energy of the gas during the process.

   (d) Which of the following correctly describes the energy transfer by heating, if any, between the gas and its surroundings?

         ____ Energy is transferred into the gas.   ____ Energy is transferred out of the gas.

         ____ There is no energy transfer by heating.
      Justify your answer.
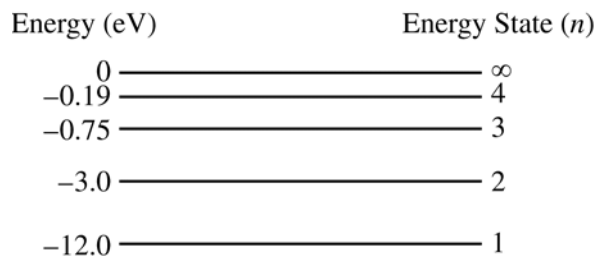
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Side View

6. (15 points)

Two long, straight horizontal wires are near each other and parallel, with one directly above the other as shown in the figure. Wire *X* is fixed in place and connected to a battery (not shown) so that it carries a current of 65 A. Wire *Y*, which is part of a second circuit, is free to move vertically and is suspended at rest by the magnetic force between the wires. The mass per length of wire *Y* is 5.6×10^{-3} kg/m . Neglect effects from the parts of the circuits that are not shown.

(a) Calculate the magnitude of the magnetic field produced by wire *X* at the position of wire *Y*.

(b)
     i. Calculate the magnitude of the current in wire *Y*.
    ii. Indicate the direction of the current in wire *Y*.

        ____ To the left   ____ To the right   ____ Neither left nor right, since there is no current

(c) Now wire *Y* is moved to a new position that is closer to wire *X*, but wire *Y* is still below wire *X* and is still carrying the same current as determined in part (b). Wire *Y* is released from rest. Describe the initial motion of wire *Y*. Justify your answer.

(d) Suppose wire *Y* is moved to a position 0.025 m above wire *X*. What changes in current, if any, must occur to maintain equilibrium?

(e) With wire *Y* still above wire *X*, the circuit connected to wire *Y* is removed. Wire *Y*, which is 1.2 m long, is then moved vertically up and away from wire *X* at a constant speed of 3.0 m/s.

     i. Calculate the magnitude of the induced emf in wire *Y* when the wires are 0.050 m apart.

    ii. Indicate which end of wire *Y* is at a higher electric potential.

        ____ The left end   ____ The right end
        ____ Neither end, since they are at the same electric potential
    Justify your answer.

GO ON TO THE NEXT PAGE.

Energy (eV)   Energy State (n)

$$0 \text{————————} \infty$$
$$-0.19 \text{————————} 4$$
$$-0.75 \text{————————} 3$$
$$-3.0 \text{————————} 2$$
$$-12.0 \text{————————} 1$$

Note: Figure not drawn to scale.

7. (10 points)

The energy-level diagram for an isolated hypothetical atom is shown above.

(a) A collection of such atoms with electrons in the $n = 3$ state undergo transitions in which the atoms only emit photons, and the electrons eventually end in the $n = 1$ state. On the diagram above, draw arrows to indicate all possible transitions, given the starting and ending states for the electrons.

(b) Calculate the longest wavelength of photons that the atom can emit during the transitions identified in part (a).

(c) What is the ionization energy of an atom in the ground state?

(d) Photons of energy 11.0 eV are incident on the atom. What effect can this have on an electron in the $n = 1$ state? Justify your answer.

(e) Photons of energy 14.0 eV are incident on the atom. What effect can this have on an electron in the $n = 1$ state? Justify your answer.

STOP

END OF EXAM