CollegeBoard
Advanced Placement Program

AP® Physics B
2010 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2010 and 2011

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 = 4.14×10^{-15} eV•s
	$hc = 1.99 \times 10^{-25}$ J•m = 1.24×10^{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,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 = 1.0×10^{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 FOR 2010 and 2011

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin\theta$

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

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

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

$\Delta U_g = mgh$

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

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

$P = F\upsilon \cos\theta$

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

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

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

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

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

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

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
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

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

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

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

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

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

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

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

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 = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

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

Parallelepiped
$V = \ell w h$

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

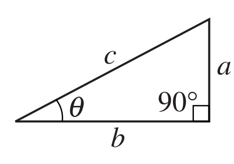
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

Right Triangle
$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

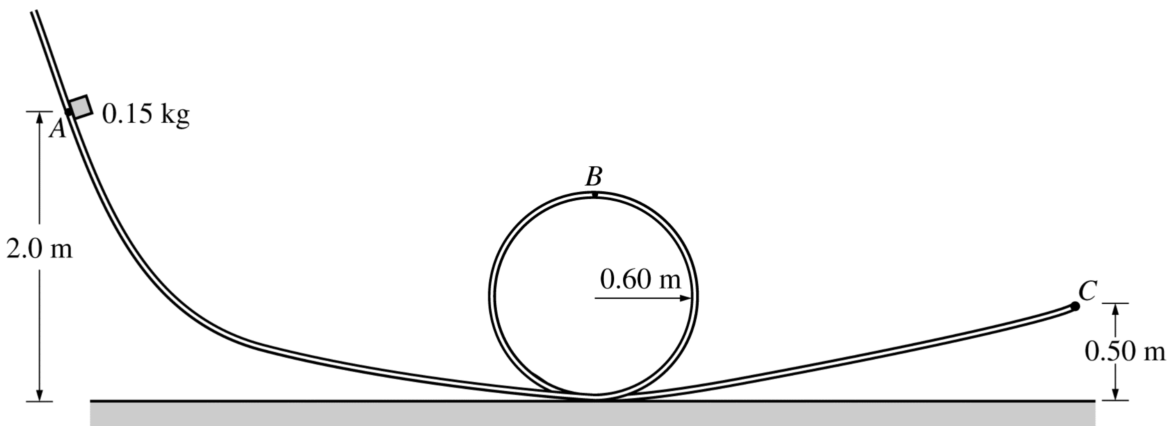
$\tan\theta = \frac{a}{b}$



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 and 4-7 and about 17 minutes for answering each of Questions 2-3. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (10 points)

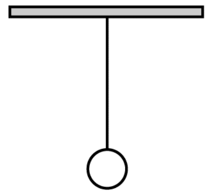
A small block of mass 0.15 kg is placed at point A at a height 2.0 m above the bottom of a track, as shown in the figure above, and is released from rest. It slides with negligible friction down the track, around the inside of the loop of radius 0.60 m, and leaves the track at point C at a height 0.50 m above the bottom of the track.

(a) Calculate the speed of the block when it leaves the track at point C.

(b) On the figure below, draw and label the forces (not components) that act on the block when it is at the top of the loop at point B.

(c) Calculate the minimum speed the block can have at point B without losing contact with the track.

(d) Calculate the minimum height h_{min} above the bottom of the track at which the block can be released and still go around the loop without losing contact with the track.



2. (15 points)

The simple pendulum above consists of a bob hanging from a light string. You wish to experimentally determine the frequency of the swinging pendulum.

(a) By checking the line next to each appropriate item on the list below, select the equipment that you would need to do the experiment.

____ Meterstick ____ Protractor ____ Additional string

____ Stopwatch ____ Photogate ____ Additional masses

(b) Describe the experimental procedure that you would use. In your description, state the measurements you would make, how you would use the equipment to make them, and how you would determine the frequency from those measurements.

(c) You next wish to discover which parameters of a pendulum affect its frequency. State one parameter that could be varied, describe how you would conduct the experiment, and indicate how you would analyze the data to show whether there is a dependence.

(d) After swinging for a long time, the pendulum eventually comes to rest. Assume that the room is perfectly thermally insulated. How will the temperature of the room change while the pendulum comes to rest?

____ It would slightly increase. ____ It would slightly decrease.

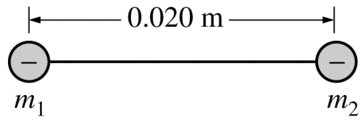
____ No effect. It would remain the same.

Justify your answer.

(e) Another pendulum using a thin, light, metal rod instead of a string is used in a clock to keep time. If the temperature of the room was to increase significantly, what effect, if any, would this have on the period of the pendulum?

____ It would increase. ____ It would decrease. ____ No effect. It would remain the same.

Justify your answer.



3. (15 points)

Two small objects, each with a charge of –4.0 nC, are held together by a 0.020 m length of insulating string as shown in the diagram above. The objects are initially at rest on a horizontal, nonconducting frictionless surface. The effect of gravity on each object due to the other is negligible.

(a) Calculate the tension in the string.

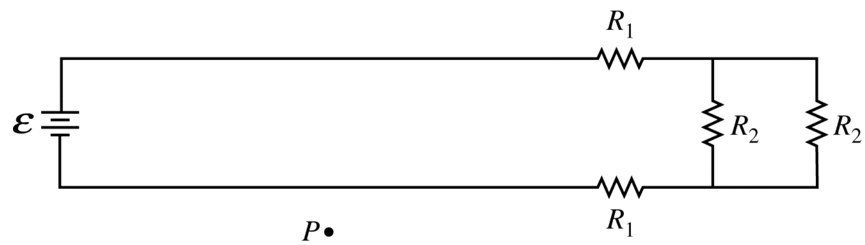
(b) Illustrate the electric field by drawing electric field lines for the two objects on the following diagram.

The masses of the objects are m_1 = 0.030 kg and m_2 = 0.060 kg. The string is now cut.

(c) Calculate the magnitude of the initial acceleration of each object.

(d) On the axes below, qualitatively sketch a graph of the acceleration a of the object of mass m_2 versus the distance d between the objects after the string has been cut.

(e) Describe qualitatively what happens to the speeds of the objects as time increases, assuming that the objects remain on the horizontal, nonconducting frictionless surface.



4. (10 points)

In the circuit above, the battery of emf $\mathcal{E}$ is connected to two long, straight, parallel wires, which in turn are connected to four resistors with resistances given in the figure above. Assume that any other resistances in the circuit are negligible. Express all algebraic answers to the following parts in terms of the given quantities and fundamental constants.

(a) Derive an expression for the total resistance of the circuit.

(b) Derive an expression for the power dissipated in this circuit.

Assume that any magnetic fields result only from the currents in the two long wires.

(c) What is the direction of the magnetic field, if any, at point P, which is in the plane of the page?

____ To the left ____ Toward the top of the page ____ Out of the plane of the page

____ To the right ____ Toward the bottom of the page ____ Into the plane of the page

____ None of the above, because the magnetic field is zero

Explain your reasoning.

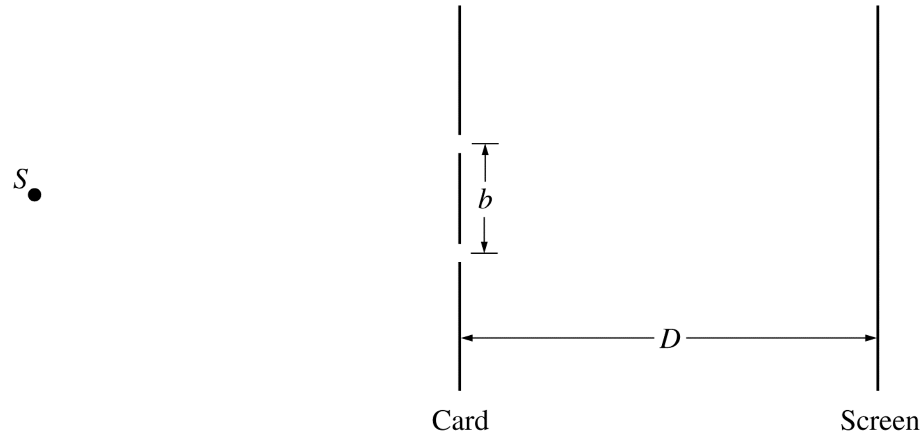
(d) What is the direction of the force, if any, on the bottom wire due to the current in the top wire?

____ To the left ____ Toward the top of the page ____ Out of the plane of the page

____ To the right ____ Toward the bottom of the page ____ Into the plane of the page

____ None of the above, because the force is zero

Explain your reasoning.



Note: Figure not drawn to scale.

5. (10 points)

In a double-slit interference experiment, a parallel beam of monochromatic light is needed to illuminate two narrow parallel slits of width w that are a distance b apart in an opaque card as shown in the figure above. A lens is inserted between the point light source S and the slits in order to produce the parallel beam of light. The interference pattern is formed on a screen a distance D from the slits, where $D >> b$.

(a) On the figure above, draw the lens at the appropriate place to produce the parallel beam of light, and label the location of the source relative to the lens with the appropriate optical parameter of the lens.

(b) Draw two light rays from the source to the slits to show the production of the parallel rays.

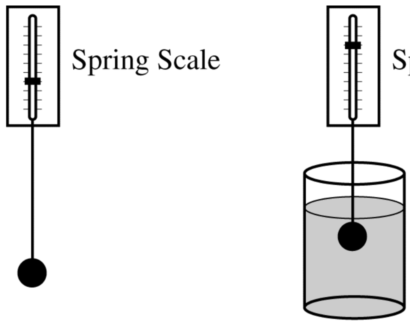
(c) In the interference pattern on the screen, the distance from the central bright fringe to the third bright fringe on one side is measured to be y_3. Derive an expression for the wavelength of the light in terms of the given quantities and fundamental constants.

(d) If the space between the slits and the screen was filled with a material having an index of refraction $n > 1$, would the distance between the bright fringes increase, decrease, or remain the same?

___ Increase   ___ Decrease   ___ Remain the same

Explain your reasoning.

GO ON TO THE NEXT PAGE.



6. (10 points)

An object is suspended from a spring scale first in air, then in water, as shown in the figure above. The spring scale reading in air is 17.8 N, and the spring scale reading when the object is completely submerged in water is 16.2 N. The density of water is 1000 $\mathrm{kg/m^3}$.

(a) Calculate the buoyant force on the object when it is in the water.

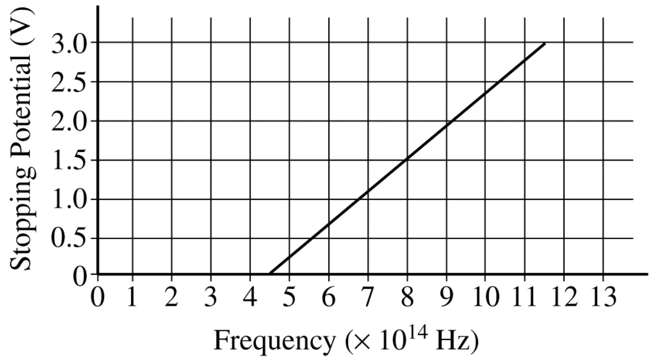
(b) Calculate the volume of the object.

(c) Calculate the density of the object.

(d) How would the absolute pressure at the bottom of the water change if the object was removed?

___ It would increase. ___ It would decrease ___ It would remain the same.

Justify your answer.



7. (10 points)

Your teacher gives you the above graph of stopping potential versus frequency for the photoelectric effect.

(a) Calculate the work function of the metal in eV.

(b) If the stopping potential is 1.5 V, determine the maximum kinetic energy of the emitted photoelectrons in eV.

(c) Calculate the wavelength of light that will eject photoelectrons with the maximum kinetic energy found in part (b).

(d) What would be the wavelength of light that will eject photoelectrons with a lower maximum kinetic energy than that found in part (b) ?

_____ It will be longer than that found in part (c).

_____ It will be the same as that found in part (c).

_____ It will be shorter than that found in part (c).

Explain your reasoning.

END OF EXAM