CollegeBoard
Advanced Placement Program

AP® Physics B
2011 Free-Response Questions
Form B

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

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

$\upsilon = \upsilon_0 + at$

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

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

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

$F_{fric} \leq \mu N$

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

$\tau = rF \sin\theta$

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

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

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

$\Delta U_g = mgh$

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

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

$P = F\upsilon \cos\theta$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

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

$F_B = BI\ell \sin\theta$

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

$\phi_m = BA\cos\theta$

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

$\varepsilon = B\ell\upsilon$

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
υ = 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
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell w h$

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

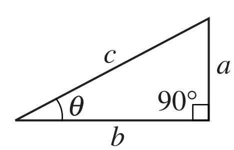
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

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

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

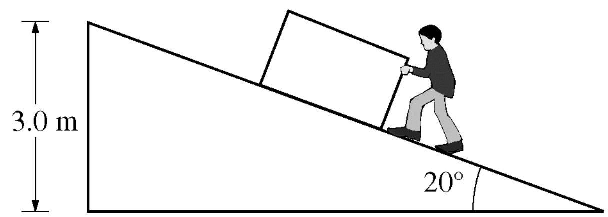
$\tan\theta = \frac{a}{b}$



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
6 Questions

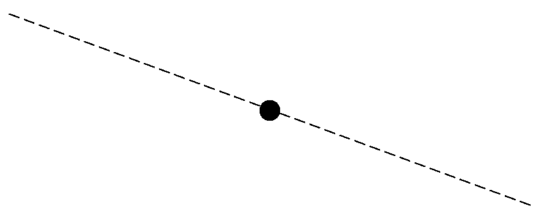
Directions: Answer all six questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-3 and 5, and about 11 minutes for answering each of Questions 4 and 6. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

A box is being pushed at constant speed up an inclined plane to a vertical height of 3.0 m above the ground, as shown in the figure above. The person exerts a force parallel to the plane. The mass m of the box is 50 kg, and the coefficient of kinetic friction μ_k between the box and the plane is 0.30.

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



(b) Calculate the normal force of the plane on the box. 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 component of the force of gravity acting on the box that is parallel to the plane.

(d) Calculate the friction force between the plane and the box.

(e) Calculate the force applied by the person on the box.

(f) Calculate the work done by the person pushing the box, assuming the box is raised to the vertical height of 3.0 m.

2. (15 points)

You are to determine the magnitude and direction of the electric field at a point between two large parallel conducting plates. The two plates have equal but opposite charges, but it is not known which is positive and which is negative. The plates are mounted vertically on insulating stands.

(a) A small ball of known mass m, with a small charge $+q$ of known magnitude, is provided. The ball is attached to an insulating string. The additional laboratory equipment available includes only those items listed below, plus stands and clamps as needed. Choose the equipment you would use to make measurements needed to determine the magnitude and direction of the electric field between the two plates.

____ Wooden meterstick	____ Protractor	____ Screen
____ Spring scale	____ Stopwatch	____ Bright light
____ Metal rod	____ Camera (still or video)	____ Binoculars

(b) Sketch a diagram of the experimental setup and label the pieces of equipment used.

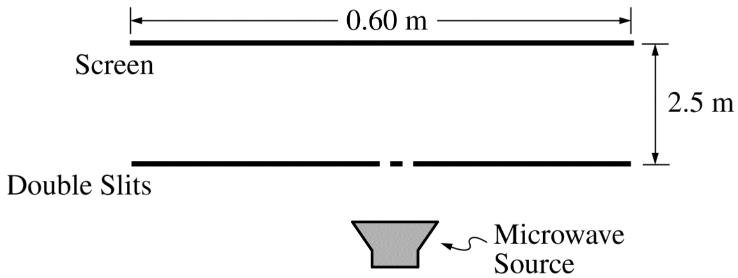
(c) Outline the experimental procedure you would use, including a list of quantities you would measure. For each quantity, identify the equipment you would use to make the measurement.

(d)

i. Explain how you would calculate the magnitude of the electric field.

ii. Explain how you would determine the direction of the electric field.

iii. Explain how you would determine which plate is positive.



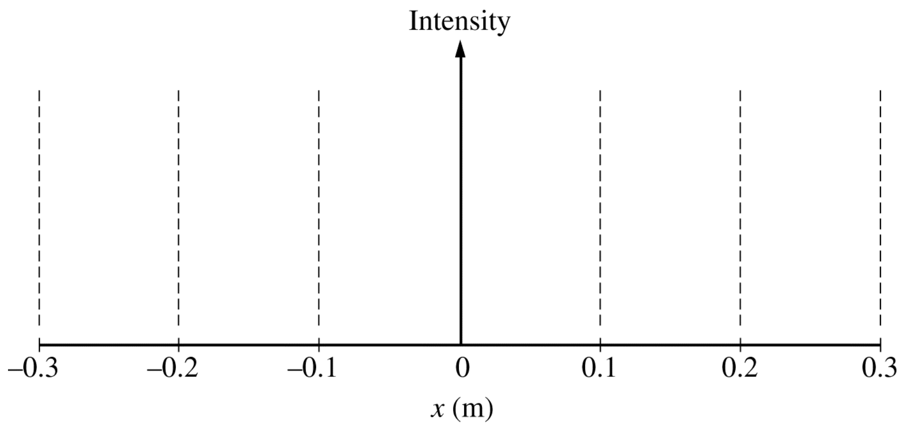
Note: Figure not drawn to scale.

3. (15 points)

A microwave source is placed behind two identical slits, as represented in the diagram above. The slit centers are separated by a distance of 0.20 m, and the slit widths are small compared to the slit separation but not negligible. The microwave wavelength is 2.4×10^{-2} m. The resulting interference pattern is centered on a screen 0.60 m wide, located 2.5 m from the slits.

(a) Calculate the frequency of the microwave radiation.

(b) On the graph below, where the x-axis represents the distance along the screen and $x = 0$ represents the center of the pattern, sketch the intensity of the interference pattern expected for that arrangement.



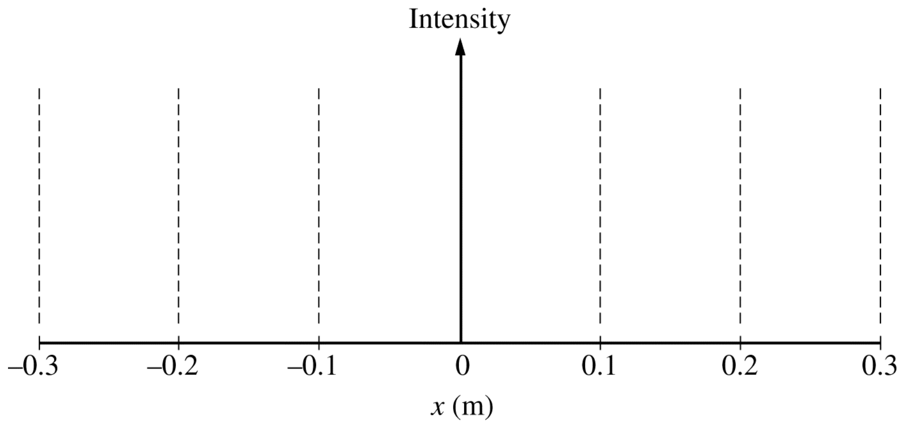
(c) Consider points on the screen located at $x = 0.00$ m, $x = 0.15$ m, and $x = 0.30$ m. Rank the intensity at those points from highest to lowest, with number 1 corresponding to the highest intensity. If two points have equal intensity, give them the same ranking.

____ $x = 0.00$ m ____ $x = 0.15$ m ____ $x = 0.30$ m

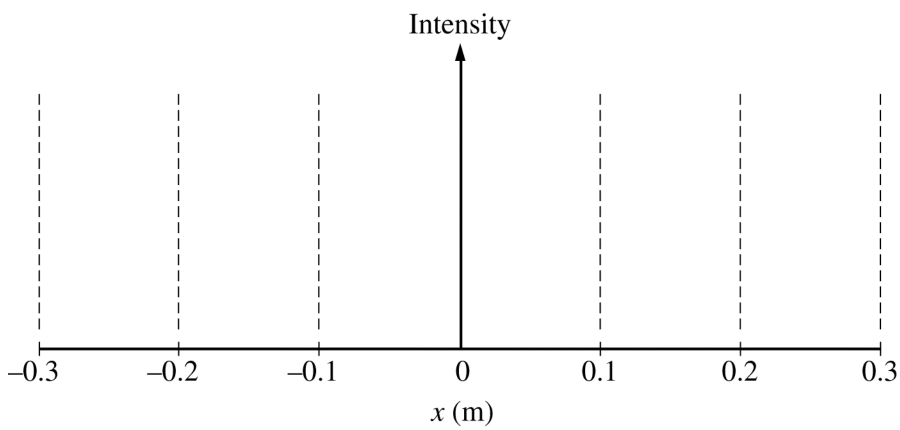
Justify your ranking.

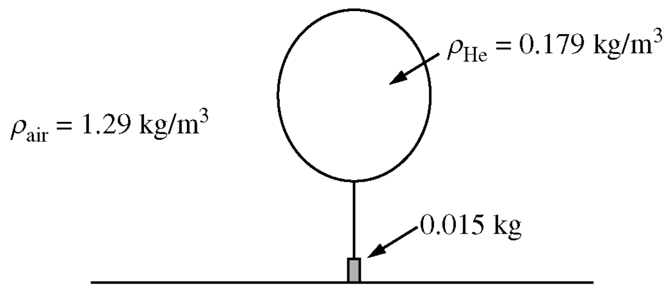
GO ON TO THE NEXT PAGE.

(d) Suppose the microwave wavelength is decreased by a factor of three, to 0.80×10^{-2} m . Sketch the resulting interference pattern below.



(e) Suppose the material separating the two slits is removed so that there is now one slit approximately 0.20 m in width. The wavelength is held at 0.80×10^{-2} m . Sketch the resulting diffraction pattern below.





4. (10 points)

A helium-filled balloon is attached by a string of negligible mass to a small 0.015 kg object that is just heavy enough to keep the balloon from rising. The total mass of the balloon, including the helium, is 0.0050 kg. The density of air is $\rho_{air} = 1.29\text{ kg/m}^3$, and the density of helium is $\rho_{He} = 0.179\text{ kg/m}^3$. The buoyant force on the 0.015 kg object is small enough to be negligible.

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

(b) Calculate the buoyant force on the balloon. 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 volume of the balloon.

(d) A child holds the string midway between the balloon and the 0.015 kg object. The child gets into a car, brings the balloon and the 0.015 kg object into the car, and holds the string so that neither the balloon nor the 0.015 kg object touches any surface. The car then begins to move forward, accelerating in a straight line. What behavior does the 0.015 kg object exhibit when the car accelerates?

____ It swings toward the front of the car.

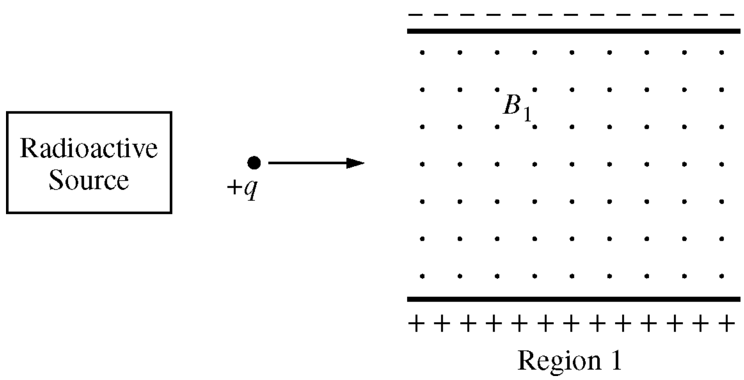
____ It swings toward the back of the car.

____ It swings toward the right side of the car.

____ It swings toward the left side of the car.

____ It remains vertical below the child's hand.

Explain your reasoning.



5. (15 points)

The diagram above illustrates a velocity selector, labeled region 1. It consists of two parallel conducting plates, with charges on the plates as indicated creating an electric field of magnitude E directed toward the top of the page. A uniform magnetic field of magnitude B_1 directed out of the page exists between the plates. The magnitude of the magnetic field can be adjusted so that only particles of a particular speed pass through the selector in a straight line. A radioactive source to the left of the selector emits charged particles, each having the same charge $+q$ and moving to the right in the plane of the page. The effect of gravity can be neglected throughout the problem.

(a)

i. Derive the equation $v = E/B_1$ for the speed v of particles that move in a straight line through region 1.

ii. Some particles are emitted from the source with speeds greater than E/B_1. Which of the following describes the initial path of one of these particles immediately after entering region 1 ?

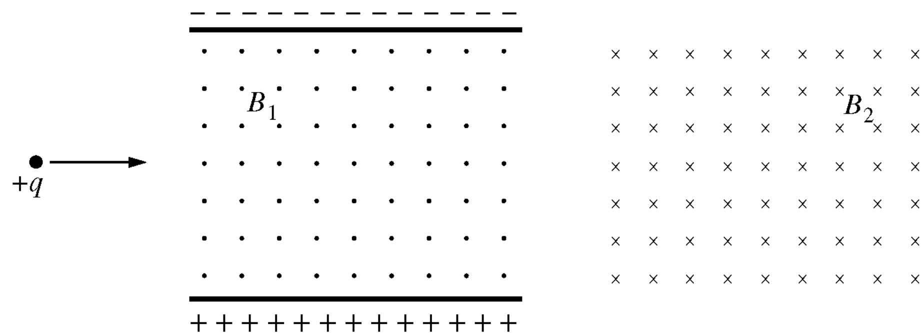
____ It curves toward the top of the page. ____ It curves toward the bottom of the page.

____ It curves into the page. ____ It curves out of the page.

____ It moves in a straight line.

Explain your reasoning.

A constant magnetic field of magnitude B_2 directed into the page is now added in region 2 to the right of region 1, as represented in the figure below. Suppose a particle leaves the radioactive source, travels through region 1 in a straight line, and enters region 2. For each of the following, express algebraic answers in terms of E, B_1, B_2, q, and fundamental constants, as appropriate.

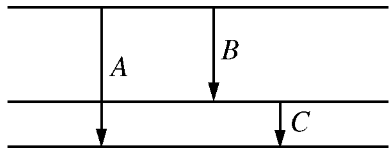


(b) Determine an expression for the initial magnetic force on the particle in region 2 and state its direction.

(c) Describe the changes, if any, in the magnitude and direction of the magnetic force as the particle moves in region 2.

(d) Describe the path of the particle in region 2.

(e) Derive an expression for the charge-to-mass ratio q/m of the particle. Specifically note any quantities not previously defined that are included in your answer.



6. (10 points)

The figure above shows the energy-level diagram for a hypothetical simple atom. The wavelength of the radiation emitted when an electron undergoes transition *B* is 400 nm, and for transition *C* it is 700 nm.

(a) Calculate the wavelength of the radiation emitted when an electron makes transition *A*.

The photon emitted during transition *B* is then incident on a metal surface of work function 2.46 eV.

(b) Calculate the maximum kinetic energy of the electron ejected from the metal by the photon.

(c) Calculate the de Broglie wavelength of the ejected electron.

(d) Photons emitted during which of transitions *A* and *C*, when incident on the metal surface, will also result in electrons being ejected from the metal?

____ *A* only ____ *C* only ____ Both *A* and *C* ____ Neither *A* nor *C*

Justify your answer.

END OF EXAM