AP® Physics B
2011 Free-Response Questions

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,	$h = 6.63 \times 10^{-34}$ 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,	$1 \text{ atm} = 1.0 \times 10^{5}$ 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
10^9	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

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

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

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

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

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

$F_B = BI\ell \sin\theta$

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

$\phi_m = BA\cos\theta$

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

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

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

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
$A = \frac{1}{2}bh$

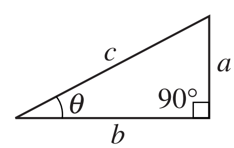
Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell w h$

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

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

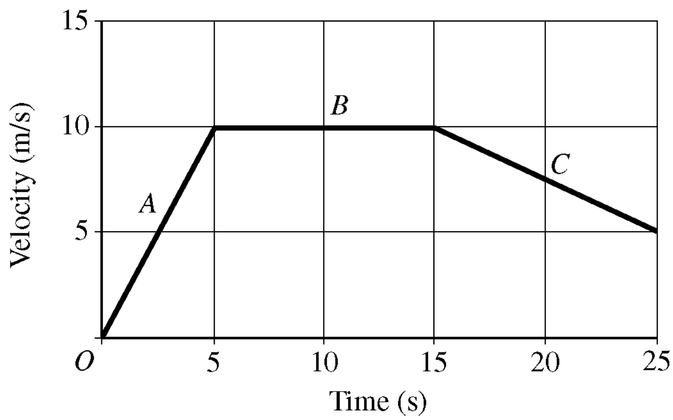
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



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

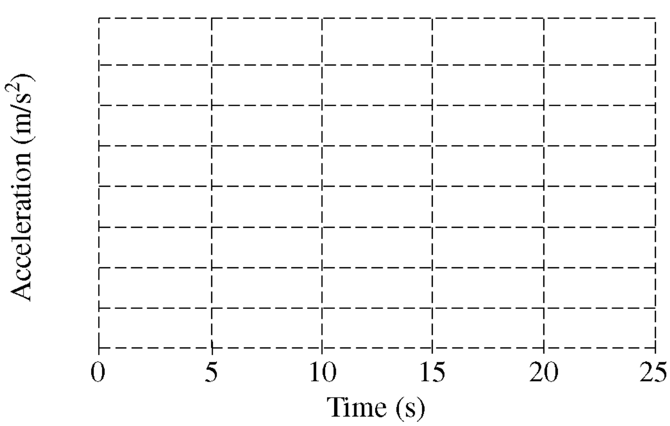
Directions: Answer all six questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-3 and 5 and about 11 minutes for answering each of Questions 4 and 6. The parts within a question may not have equal weight. Show all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



1. (15 points)

A 0.40 kg object moves in a straight line under the action of a net force. The graph above shows the velocity as a function of time for the object during a 25 s interval. At time $t = 0$, the object is at the position $x = 0$.

(a) On the grid below, sketch a graph of the acceleration as a function of time for the object. Label the scale for the acceleration.



(b) Calculate the position of the object at $t = 5.0$ s.

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(c) On which segment of the graph is the net force acting on the object zero?

____ *A* ____ *B* ____ *C*

Justify your answer.

(d) Calculate the net force on the object during the first 3.0 s of the motion.

(e) Calculate the amount of work done on the object by the net force during the first 15 s of the motion.

(f) For the interval $t = 15$ s to $t = 25$ s, is the work done on the object by the net force positive, negative, or zero?

____ Positive ____ Negative ____ Zero

Justify your answer.

2. (15 points)

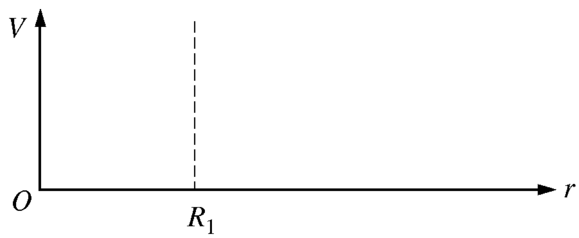
An isolated, solid copper sphere of radius $R_1 = 0.12$ m has a positive charge of 6.4×10^{-9} C.

(a)

i. Calculate the electric potential at a point 0.10 m from the center of the sphere.

ii. Calculate the electric potential at a point 0.24 m from the center of the sphere.

(b) On the axes below, sketch a graph of electric potential V versus radius r from the center of the sphere. Label the value at $r = 0$ on the vertical axis.

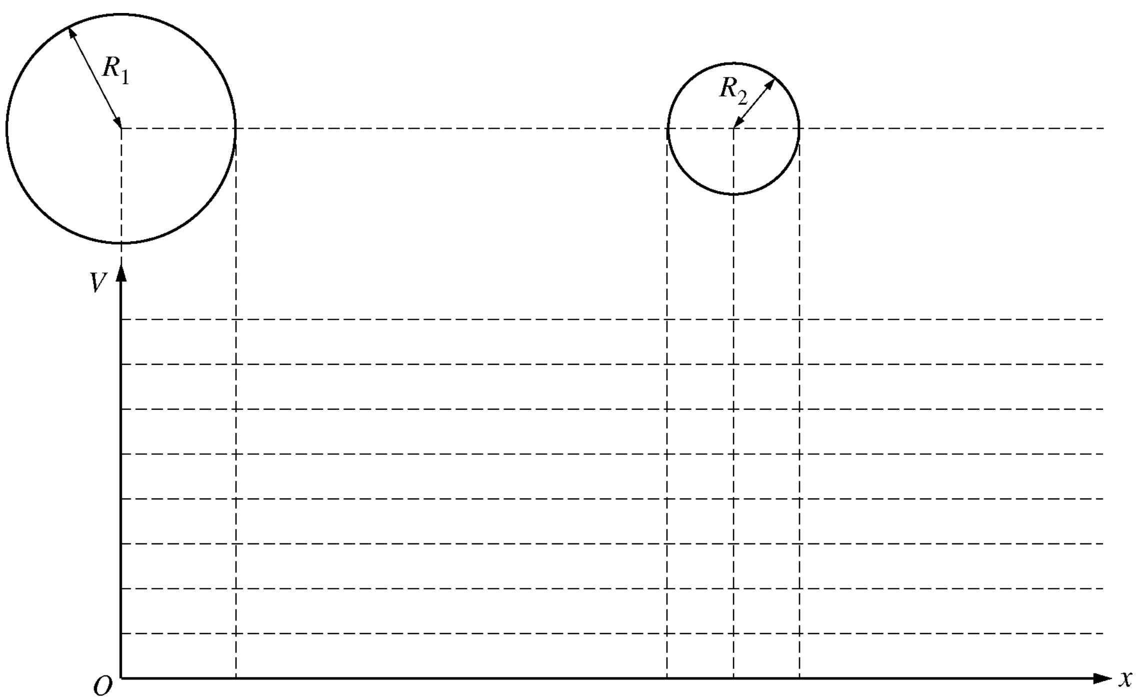


(c)

i. Determine the magnitude of the electric field at a point 0.10 m from the center of the sphere.

ii. Determine the magnitude of the electric field at a point 0.24 m from the center of the sphere.

(d) A second copper sphere of radius R_2 that is uncharged is placed near the first sphere, as represented in the figure below. On the axes below, sketch a graph of electric potential V versus distance along the x-axis shown, where the center of the first sphere is at $x = 0$.



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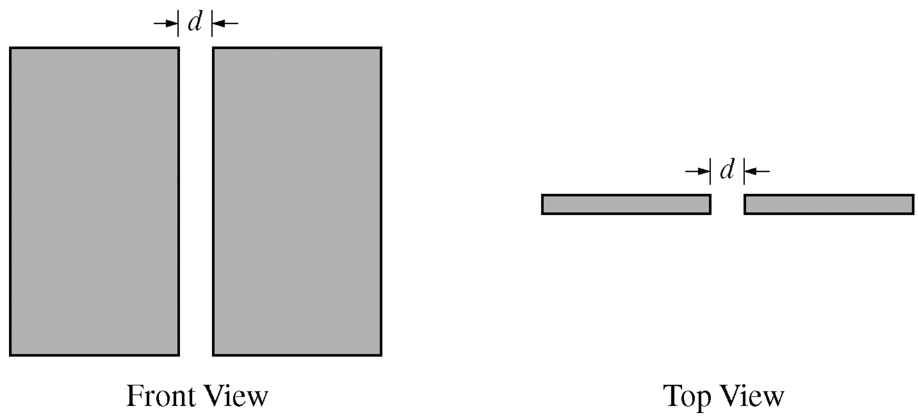


3. (15 points)

Two metal strips are brought together until their edges are separated by a small distance d, forming a narrow slit, as represented above. You are to design a laboratory experiment to determine the width of the slit.

(a) From the following list of available equipment, check those additional items you would use for the purpose of determining the slit width d.

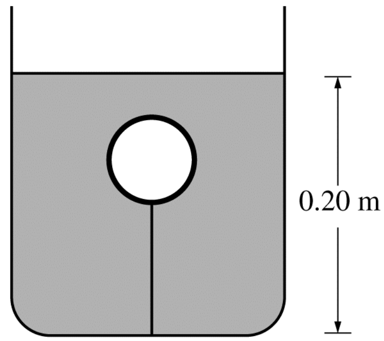
_____ Laser pointer (λ = 635 nm)	______ Meterstick
_____ Mirror	______ Metric ruler
_____ Screen	______ Prism
_____ Filament lamp	______ Stopwatch

(b) Sketch a diagram of your experimental setup and label the pieces of equipment that would be 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) Explain how you would calculate the slit width d by using the measured quantities identified in (c).

(e) Suppose the separation d between the strips was increased, but everything else was kept the same. What changes would you expect to observe? Explain your reasoning.



Note: Figure not drawn to scale.

4. (10 points)

A beaker weighing 2.0 N is filled with $5.0 \times 10^{-3}\ \text{m}^3$ of water. A rubber ball weighing 3.0 N is held entirely underwater by a massless string attached to the bottom of the beaker, as represented in the figure above. The tension in the string is 4.0 N. The water fills the beaker to a depth of 0.20 m. Water has a density of $1000\ \text{kg/m}^3$. The effects of atmospheric pressure may be neglected.

(a) Calculate the weight of the entire apparatus.

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

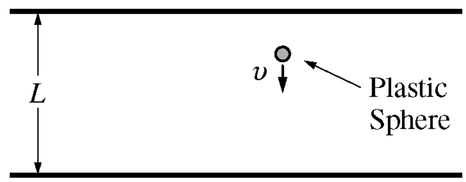
(c) Calculate the buoyant force exerted on the ball by the water. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

(d) Calculate the pressure due to the liquid (the gauge pressure) at the bottom of the beaker.

(e) The string is cut, and the ball rises to the surface and floats. Indicate whether the water level is higher, lower, or the same after equilibrium is reached.

____ Higher ____ Lower ____ The same

Justify your answer.



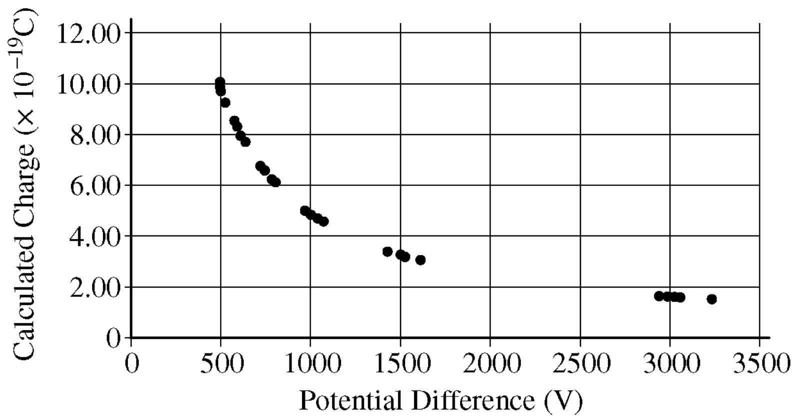
Note: Figure not drawn to scale.

5. (15 points)

In the experimental setup represented above, a very small plastic sphere of mass m with charge q is allowed to fall under the influence of gravity between two parallel metal plates separated by a fixed distance L. A variable potential difference may be applied between the two plates. The experiment is conducted inside a vacuum chamber.

(a) A potential difference of magnitude V is applied between the top and bottom plates such that the sphere falls at constant speed v. Derive an expression for the magnitude of the charge q on the sphere. Express your answer in terms of m, L, V, and fundamental constants, as appropriate.

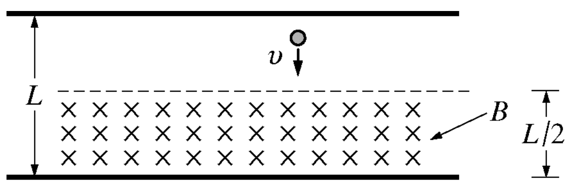
The experiment is performed many times with spheres of identical known mass but different unknown charges, each time adjusting the potential difference V to the value needed so that the sphere falls at constant speed v. The magnitudes of the charges are calculated from the measured values of the potential difference. The data is plotted below as a function of the magnitude of V.



(b) Provide a physical explanation for the gap observed in the data between potential differences of 1700 V and 2800 V.

(c) If the value of L is 0.050 m, calculate the mass m of the spheres.

A uniform magnetic field of magnitude B, directed into the page, is now applied in the bottom half of the region between the plates, as shown in the figure below. The experiment is repeated, with the potential difference adjusted again so that the charged sphere falls with constant speed prior to entering the magnetic field.



Note: Figure not drawn to scale.

(d)

i. Describe the motion of the sphere as it travels through the magnetic field.

ii. Describe how the motion could be used to determine the sign of the charge.

(e) Derive an expression for the minimum value of B needed to prevent the sphere from reaching the bottom plate. Express your answer in terms of m, q, v, L, and fundamental constants, as appropriate.

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6. (10 points)

The allowed energies of a simple hypothetical atom are -6.0 eV, -3.0 eV, and -1.0 eV.

(a) Draw the atom's energy-level diagram. Label each level with the energy and the principal quantum number.

(b) Calculate the wavelengths associated with each possible transition between energy levels for the atom.

(c) The atom is in the ground state when an electron traveling with a speed of 1.3×10^6 m/s collides with it. Can the electron excite the atom to the $n = 2$ state?

____ Yes _____ No _____ It cannot be determined with the information given.

Justify your answer.

(d) Another electron excites the atom from the ground state to the $n = 2$ state. The atom then decays back to the ground state by emitting a photon.

i. Calculate the energy of the emitted photon in joules.

ii. In what region of the electromagnetic spectrum is the radiation?

_____ Radio _____ X-rays _____ Visible light

______ It cannot be determined with the information given.

END OF EXAM