AP

AP® Physics B
2014 Free-Response Questions

CollegeBoard

TABLE OF INFORMATION, EFFECTIVE 2012

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.

NEWTONIAN MECHANICS

$v = v_0 + at$

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

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

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin \theta$

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

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

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

$\Delta U_g = mgh$

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

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

$P = Fv\cos\theta$

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

$F = \frac{kq_1q_2}{r^2}$

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

$U_E = qV = \frac{kq_1q_2}{r}$

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + \ldots$

$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$

$R_s = R_1 + R_2 + R_3 + \ldots$

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

$F_B = qvB\sin\theta$

$F_B = BI\ell\sin\theta$

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

$\phi_m = BA\cos\theta$

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

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

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

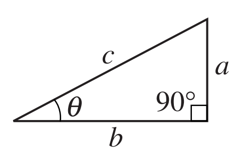
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

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

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

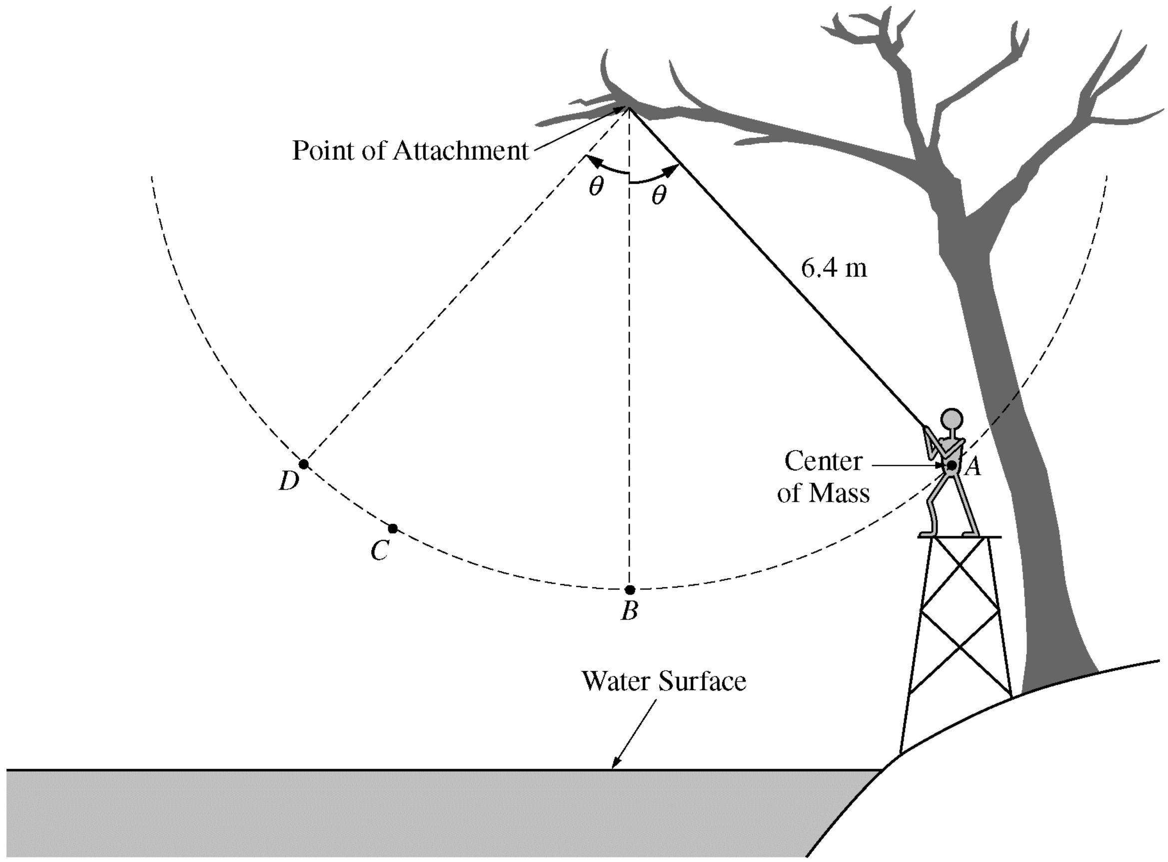
$\tan\theta = \frac{a}{b}$



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 17 minutes for answering each of Questions 1 and 5, and about 11 minutes for answering each of Questions 2-4 and 6-7. 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. (15 points)

Starting from rest at point *A*, a 50 kg person swings along a circular arc from a rope attached to a tree branch over a lake, as shown in the figure above. Point *D* is at the same height as point *A*. The distance from the point of attachment to the center of mass of the person is 6.4 m. Ignore air resistance and the mass and elasticity of the rope.

(a) The person swings two times, each time letting go of the rope at a different point.

i. On the first swing, the person lets go of the rope when first arriving at point *C*. Draw a solid line to represent the trajectory of the center of mass after the person releases the rope.

ii. A second time, the person lets go of the rope at point *D*. Draw a dashed line to represent the trajectory of the center of mass after the person releases the rope.

(b) The center of mass of the person standing on the platform is at point *A*, 4.1 m above the surface of the water. Calculate the gravitational potential energy when the person is at point *A* relative to when the person is at the surface of the water.

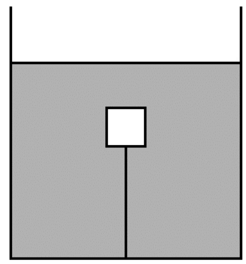
(c) The center of mass of the person at point *B*, the lowest point along the arc, is 2.4 m above the surface of the water. Calculate the person's speed at point *B*.

(d) Suppose that the person swings from the rope a third time, letting go of the rope at point *B*. Calculate *R*, the horizontal distance moved from where the person releases the rope at point *B* to where the person hits the water.

(e) If the person does not let go of the rope, how does the magnitude of the person's momentum p_C at point *C* compare with the magnitude of the person's momentum p_B at point *B* ?

____ $p_C > p_B$ ____ $p_C < p_B$ ____ $p_C = p_B$

Provide a physical explanation to justify your answer.



2. (10 points)

A cube of mass m and side length L is completely submerged in a tank of water and is attached to the bottom of the tank by a string, as shown in the figure above. The tension in the string is 0.25 times the weight of the cube. The density of water is 1000 kg/m^3.

(a) On the dot below that represents the cube, draw and label the forces (not components) that act on the cube while it is attached to the string. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

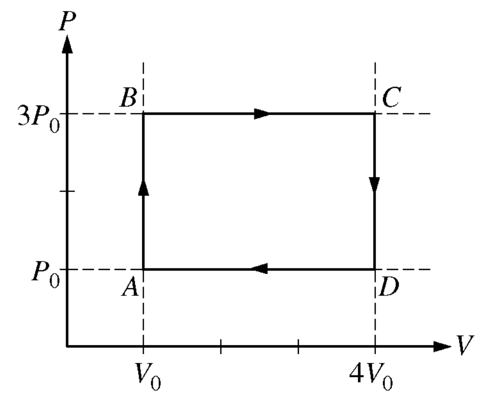
(b) Calculate the density of the cube.

(c) The string is now cut. Calculate the magnitude of the acceleration of the cube immediately after the string is cut. 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) Indicate whether the magnitude of the buoyant force on the cube increases, decreases, or remains the same while the cube is rising, but before it reaches the surface.

____ Increases ____ Decreases ____ Remains the same

Justify your answer.



3. (10 points)

A sample containing three moles of an ideal gas is taken through a series of equilibrium states, as represented by the closed path *ABCDA* in the diagram above.

(a)

i. Rank the temperatures at the 4 labeled points from least to greatest, using 1 for the lowest temperature. If two or more points have the same temperature, give them the same ranking.

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

ii. Determine the temperature T_D at point *D* in terms of P_0, V_0, and fundamental constants, as appropriate.

(b) Indicate all segments of the path *ABCDA*, if any, for which the work done by the gas is positive. If the work done by the gas is not positive for any of the segments, then check "None".

____ *AB* ____ *BC* ____ *CD* ____ *DA* ____ None

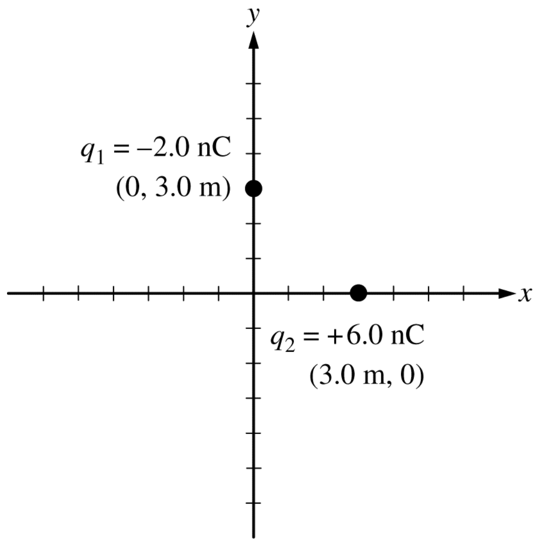
Justify your answer.

(c) In process *AB*, is the energy transferred to the gas by heating positive, negative, or zero?

____ Positive ____ Negative ____ Zero

Justify your answer.

(d) Derive an expression for the net work done on the gas during the entire process *ABCDA*. Express your answer in terms of P_0, V_0, and fundamental constants, as appropriate.

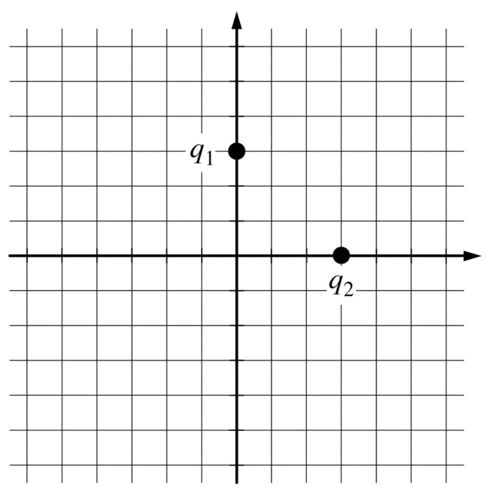


4. (10 points)

Two point charges are fixed at the coordinates shown in the diagram above. The charges are $q_1 = -2.0\text{ nC}$ and $q_2 = +6.0\text{ nC}$.

(a) Calculate the magnitudes of the x and y components of the net electric field at the origin (0, 0).

(b) On the diagram below, draw a single vector (not components) originating at the origin (0,0) to represent the direction of the net electric field at that point.



(c) Calculate the electric potential at the origin (0, 0).

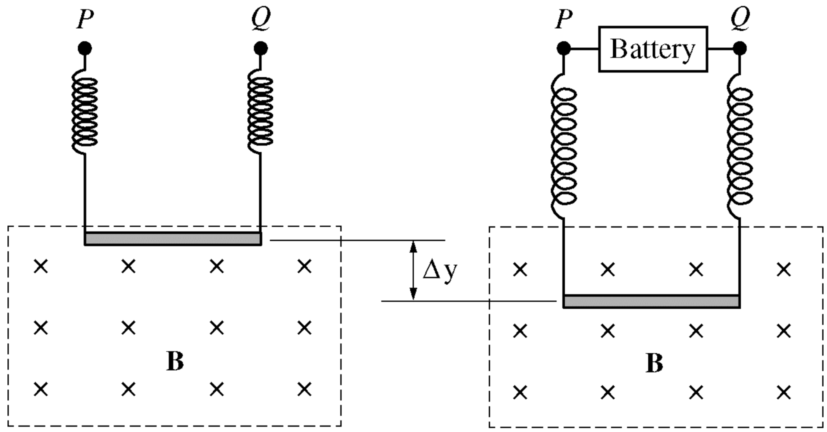
A third charge, $q_3 = +3.0 \text{ nC}$, is moved by an external force from very far away to the origin. The third charge has the same speed at the start and end of the motion.

(d) Indicate whether the total work done by the external force is positive, negative, or zero.

____ Positive ____ Negative ____ Zero

Justify your answer.

(e) Calculate the magnitude of the net force on q_3 due to the other two charges when q_3 is at the origin.



5. (15 points)

A conducting rod of mass m and length L hangs at rest from two identical conducting springs, each with spring constant k, as shown in the figure at left above. The upper ends of the springs are fixed at points P and Q, and the rod is in a uniform magnetic field $\mathbf{B}$ directed into the page. A battery is then connected between points P and Q, as shown in the figure at right above, resulting in a current I in the rod. The rod is displaced downward, eventually reaching a new equilibrium position with the springs stretched an additional distance Δy.

(a) Which point, P or Q, is connected to the positive terminal of the battery?

____ P ____ Q

Justify your answer.

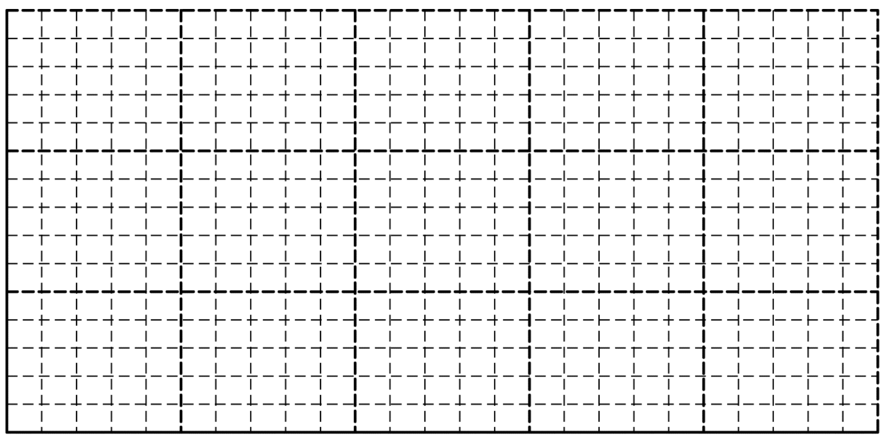
(b) On the dot below that represents the rod, draw and label the forces (not components) that act on the rod in its new equilibrium position. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

(c) Derive an expression for Δy in terms of k, m, L, I, the magnetic field strength B, and fundamental constants, as appropriate.

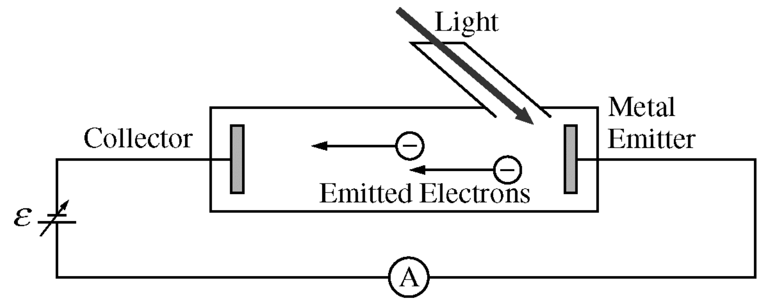
An experiment is conducted with batteries of different emf connected between points *P* and *Q*. The current *I* in the rod and the stretch of the springs Δy are measured and recorded in the table below.

I (amperes)	Δy (meters)
1.0	0.0028
2.0	0.0050
3.0	0.0084
4.0	0.0119
5.0	0.0140

(d) On the grid below, plot the data points for Δy as a function of *I*. Be sure to label your axes with variables, units, and scale. Draw a straight line that best represents the data.



(e) Using the straight line you drew in part (d), calculate the value *B* for the magnetic field if *m* is 0.019 kg, *L* is 0.35 m, and *k* is 25 N/m.



6. (10 points)

The apparatus shown above is used in determining the work function of a particular metal using the photoelectric effect. The experiment is set up with an ammeter A and a variable power supply. A light source that emits photons of frequency 7.5×10^{14} Hz is used. The emf $\mathcal{E}$ provided by the power supply is slowly increased from zero until the ammeter shows that the current between the collector and metal emitter is zero. The magnitude of the emf is 0.65 V when the current becomes zero.

(a) Determine the wavelength of the incident photons.

(b) Calculate the work function of the metal.

(c) Calculate the minimum frequency of light at which electrons would be emitted.

(d) If the power per unit area (intensity) of the incident light is increased and the wavelength stays the same, does the magnitude of the emf needed to stop the current increase, decrease, or remain the same?

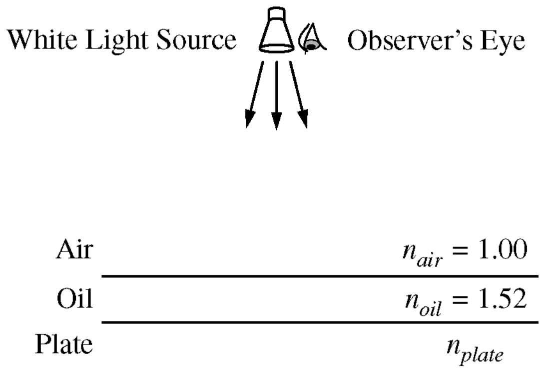
____ Increases ____ Decreases ____ Remains the same

Justify your answer.

(e) If the wavelength of light is decreased while the power per unit area (intensity) of the incident light stays the same, does the number of electrons emitted from the metal surface per unit time increase, decrease, or remain the same? (Assume that the light is initially above the threshold frequency.)

____ Increases ____ Decreases ____ Remains the same

Justify your answer.



Note: Figure not drawn to scale.

7. (10 points)

A thin layer of transparent oil is placed on top of a transparent plate. The oil film is then illuminated by white light shining onto the oil's surface, as shown in the figure above. To an observer standing right next to the light source and looking straight down on the oil film, the oil film appears green, corresponding to a wavelength of 520 nm in air. The oil has an index of refraction of 1.52.

(a) Determine the frequency of the green light in the air.

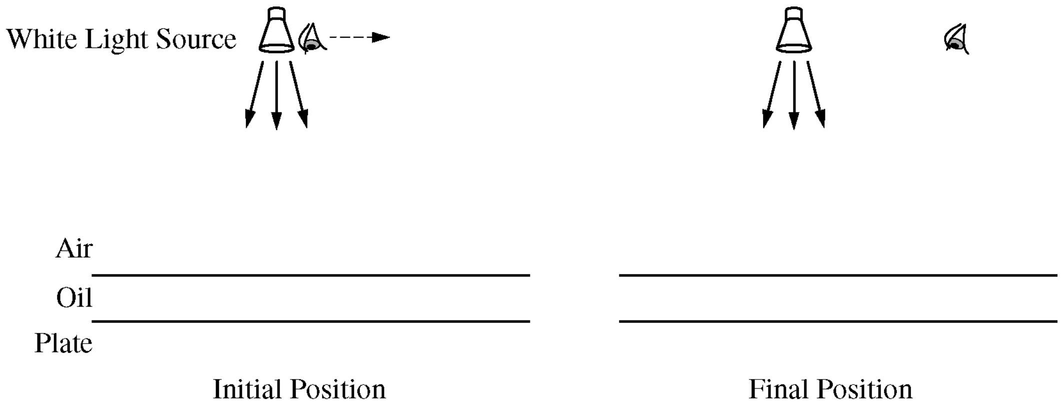
(b) Determine the frequency of the green light in the oil film.

(c) Calculate the wavelength of the green light in the oil film.

(d) The oil film thickness is half of the wavelength you found in part (c). Is the index of refraction of the plate greater than, less than, or equal to that of the oil?

____ Greater than ____ Less than ____ Equal to

Justify your answer.



Note: Figure not drawn to scale.

(e) As the observer starts moving to the right away from the light source, as shown in the figures above, the film appears to change color. Describe the color change and give an explanation for this phenomenon.

STOP

END OF EXAM