



**AP<sup>®</sup> Physics B**  
**2009 Free-Response Questions**  
**Form B**

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**TABLE OF INFORMATION FOR 2008 and 2009**

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 <sup>-1</sup>	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m <sup>3</sup> /kg·s <sup>2</sup>
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s <sup>2</sup>
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 = $931 \text{ MeV}/c^2$
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 <sup>2</sup> /N·m <sup>2</sup>
Coulomb's law constant, $k = 1/4\pi\epsilon_0 = 9.0 \times 10^9$ N·m <sup>2</sup> /C <sup>2</sup>	
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant, $k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A	
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5$ N/m <sup>2</sup> = $1.0 \times 10^5$ 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							
$\theta$	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 2008 and 2009

## NEWTONIAN MECHANICS

$$v = v_0 + at$$

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

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

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

$$F_{fric} \leq \mu N$$

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

$$\tau = rF \sin \theta$$

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

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

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

$$\Delta U_g = mgh$$

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

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

$$P = Fv \cos \theta$$

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

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

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

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

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

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

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

$a$  = acceleration  
 $F$  = force  
 $f$  = frequency  
 $h$  = height  
 $J$  = impulse  
 $K$  = kinetic energy  
 $k$  = spring constant  
 $\ell$  = 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  
 $\mu$  = coefficient of friction  
 $\theta$  = angle  
 $\tau$  = torque

## ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

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

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

$$V = IR$$

$$P = IV$$

$$C_p = \sum_i C_i$$

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

$$R_s = \sum_i R_i$$

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

$$F_B = qvB \sin \theta$$

$$F_B = BI\ell \sin \theta$$

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

$$\phi_m = BA \cos \theta$$

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

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

$A$  = area  
 $B$  = magnetic field  
 $C$  = capacitance  
 $d$  = distance  
 $E$  = electric field  
 $\mathcal{E}$  = emf  
 $F$  = force  
 $I$  = current  
 $\ell$  = 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  
 $\rho$  = resistivity  
 $\theta$  = angle  
 $\phi_m$  = magnetic flux

# ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

## FLUID MECHANICS AND THERMAL PHYSICS

$$P = P_0 + \rho gh$$

$$F_{\text{buoy}} = \rho Vg$$

$$A_1 v_1 = A_2 v_2$$

$$P + \rho gy + \frac{1}{2} \rho v^2 = \text{const.}$$

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

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

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

$$PV = nRT = Nk_B T$$

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

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

$$W = -P \Delta V$$

$$\Delta U = Q + W$$

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

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

$A$  = area  
 $e$  = efficiency  
 $F$  = force  
 $h$  = depth  
 $H$  = rate of heat transfer  
 $k$  = thermal conductivity  
 $K_{\text{avg}}$  = average molecular kinetic energy  
 $\ell$  = length  
 $L$  = thickness  
 $M$  = 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  
 $v$  = velocity or speed  
 $v_{\text{rms}}$  = root-mean-square velocity  
 $W$  = work done on a system  
 $y$  = height  
 $\alpha$  = coefficient of linear expansion  
 $\mu$  = mass of molecule  
 $\rho$  = density

## ATOMIC AND NUCLEAR PHYSICS

$$E = hf = pc$$

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

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

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

$E$  = energy  
 $f$  = frequency  
 $K$  = kinetic energy  
 $m$  = mass  
 $p$  = momentum  
 $\lambda$  = wavelength  
 $\phi$  = work function

## WAVES AND OPTICS

$$v = f \lambda$$

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

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

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

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

$$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$$

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

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

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

$d$  = 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  
 $v$  = speed  
 $x$  = position  
 $\lambda$  = wavelength  
 $\theta$  = angle

## GEOMETRY AND TRIGONOMETRY

Rectangle  
 $A = bh$   
 Triangle  
 $A = \frac{1}{2} bh$   
 Circle  
 $A = \pi r^2$   
 $C = 2\pi r$   
 Parallelepiped  
 $V = \ell wh$   
 Cylinder  
 $V = \pi r^2 \ell$   
 $S = 2\pi r \ell + 2\pi r^2$

$A$  = area  
 $C$  = circumference  
 $V$  = volume  
 $S$  = surface area  
 $b$  = base  
 $h$  = height  
 $\ell$  = length  
 $w$  = width  
 $r$  = radius

## Sphere

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

$$S = 4\pi r^2$$

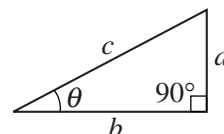
## Right Triangle

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

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

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

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



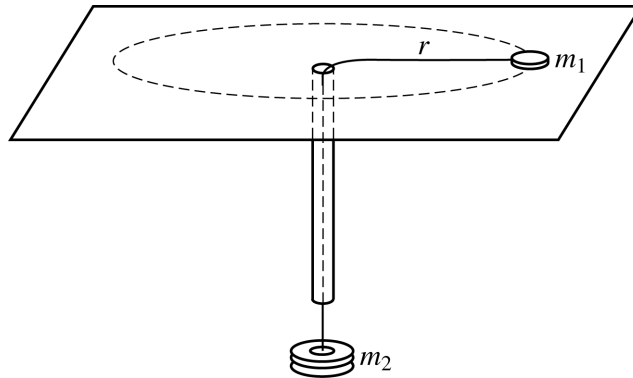
## PHYSICS B

## 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 1-4 and about 11 minutes for answering each of Questions 5-6. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the lavender insert.



1. (15 points)

An experiment is performed using the apparatus above. A small disk of mass  $m_1$  on a frictionless table is attached to one end of a string. The string passes through a hole in the table and an attached narrow, vertical plastic tube. An object of mass  $m_2$  is hung at the other end of the string. A student holding the tube makes the disk rotate in a circle of constant radius  $r$ , while another student measures the period  $P$ .

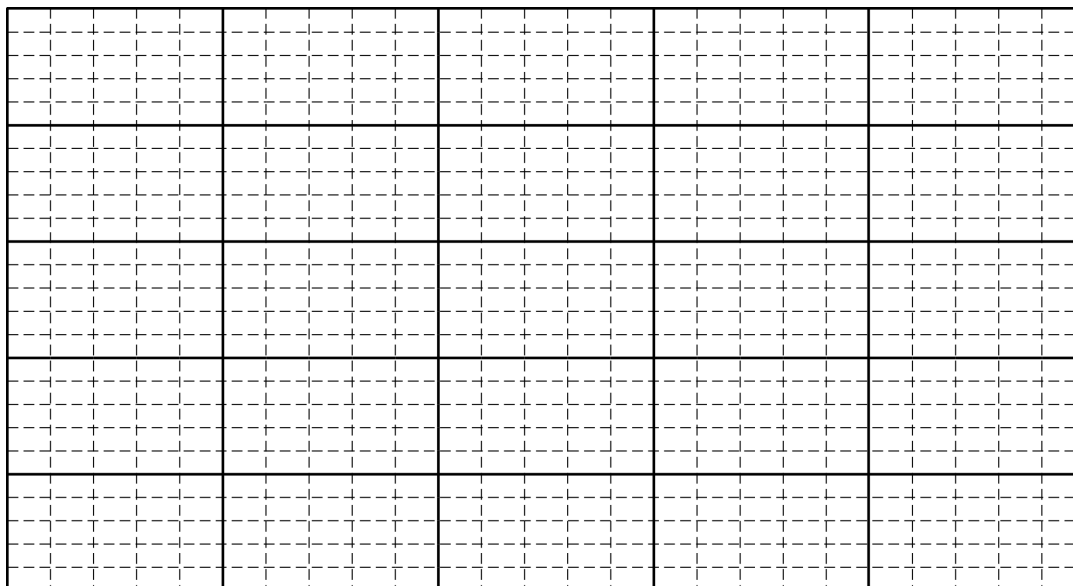
- (a) Derive the equation  $P = 2\pi\sqrt{\frac{m_1 r}{m_2 g}}$  that relates  $P$  and  $m_2$ .

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The procedure is repeated, and the period  $P$  is determined for four different values of  $m_2$ , where  $m_1 = 0.012 \text{ kg}$  and  $r = 0.80 \text{ m}$ . The data, which are presented below, can be used to compute an experimental value for  $g$ .

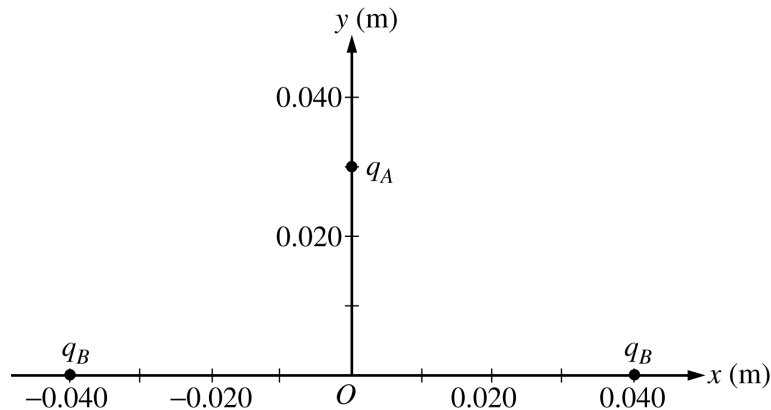
$m_2$ (kg)	0.020	0.040	0.060	0.080
$P$ (s)	1.40	1.05	0.80	0.75

- (b) What quantities should be graphed to yield a straight line with a slope that could be used to determine  $g$  ?
- (c) On the grid below, plot the quantities determined in part (b), label the axes, and draw the best-fit line to the data. You may use the blank rows above to record any values you may need to calculate.



- (d) Use your graph to calculate the experimental value of  $g$ .

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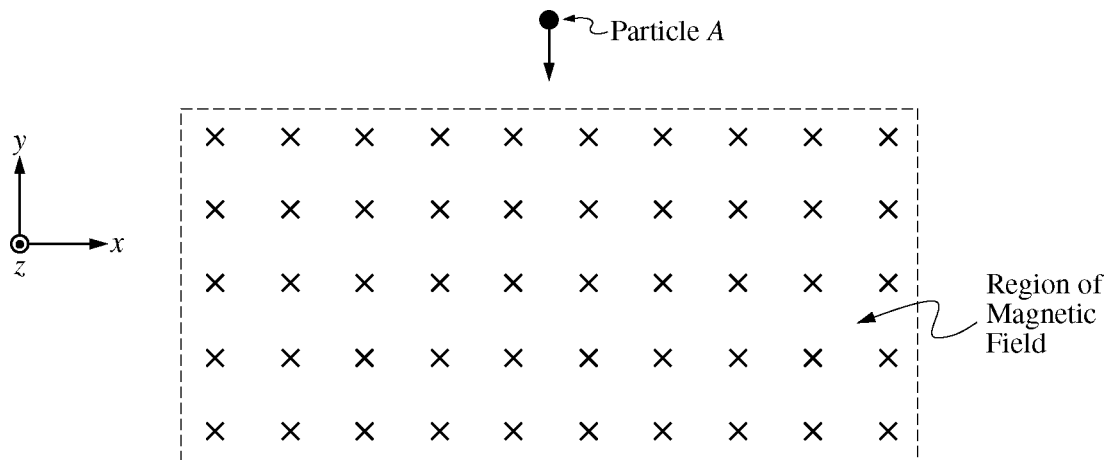


2. (15 points)

Three particles are arranged on coordinate axes as shown above. Particle A has charge  $q_A = -0.20 \text{ nC}$ , and is initially on the  $y$ -axis at  $y = 0.030 \text{ m}$ . The other two particles each have charge  $q_B = +0.30 \text{ nC}$  and are held fixed on the  $x$ -axis at  $x = -0.040 \text{ m}$  and  $x = +0.040 \text{ m}$ , respectively.

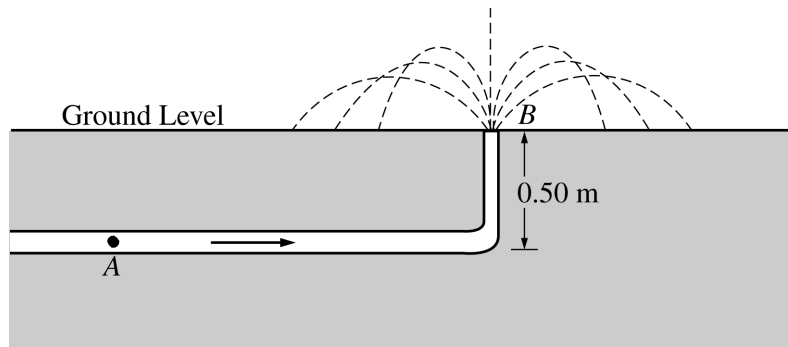
- Calculate the magnitude of the net electric force on particle A when it is at  $y = 0.030 \text{ m}$ , and state its direction.
- Particle A is then released from rest. Qualitatively describe its motion over a long time.

In another experiment, particle A of charge  $q_A = -0.20 \text{ nC}$  is injected into a uniform magnetic field of strength  $0.50 \text{ T}$  directed into the page, as shown below, entering the field with speed  $6000 \text{ m/s}$ .



- On the diagram above, sketch a complete path of particle A as it moves in the magnetic field.
- Calculate the magnitude of the force the magnetic field exerts on particle A as it enters the magnetic field.
- An electric field can be applied to keep particle A moving in a straight line through the magnetic field. Calculate the magnitude of this electric field and state its direction.

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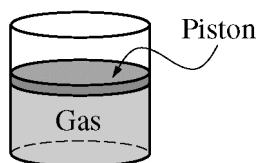
3. (15 points)

An underground pipe carries water of density  $1000 \text{ kg/m}^3$  to a fountain at ground level, as shown above. At point A, 0.50 m below ground level, the pipe has a cross-sectional area of  $1.0 \times 10^{-4} \text{ m}^2$ . At ground level, the pipe has a cross-sectional area of  $0.50 \times 10^{-4} \text{ m}^2$ . The water leaves the pipe at point B at a speed of 8.2 m/s.

- Calculate the speed of the water in the pipe at point A.
- Calculate the absolute water pressure in the pipe at point A.
- Calculate the maximum height above the ground that the water reaches upon leaving the pipe vertically at ground level, assuming air resistance is negligible.
- Calculate the horizontal distance from the pipe that is reached by water exiting the pipe at  $60^\circ$  from the level ground, assuming air resistance is negligible.



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4. (15 points)

The cylinder shown above has an open top, and gas is held inside it by a piston of mass  $m$  and area  $A$ . The gas is insulated from its surroundings and is initially in equilibrium at volume  $V_i$ . Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the absolute pressure  $P_i$  of the gas at equilibrium.

The gas is heated by a circuit that contains three resistors, each of known resistance  $R_0$ , connected in parallel to a power source of emf  $\mathcal{E}$ . The piston is held fixed so that the gas remains at constant volume while being heated for a period of time  $t$ .

(b) Determine the resistance of the circuit.

(c) Calculate the change in internal energy of the gas.

After the time  $t$ , the circuit is disconnected. The piston is then released and the gas is allowed to expand adiabatically until it reaches volume  $V_f$ .

(d) Indicate below whether the temperature increases, decreases, or remains the same during this process.

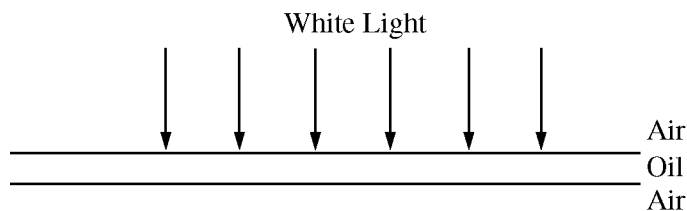
\_\_\_\_\_ Increases    \_\_\_\_\_ Decreases    \_\_\_\_\_ Remains the same

Justify your answer.

(e) The gas is then compressed isothermally to its original pressure and volume. On the axes below, draw a  $PV$  diagram for the complete cycle described in this question, labeling  $V_i$  and  $V_f$  on the volume axis.



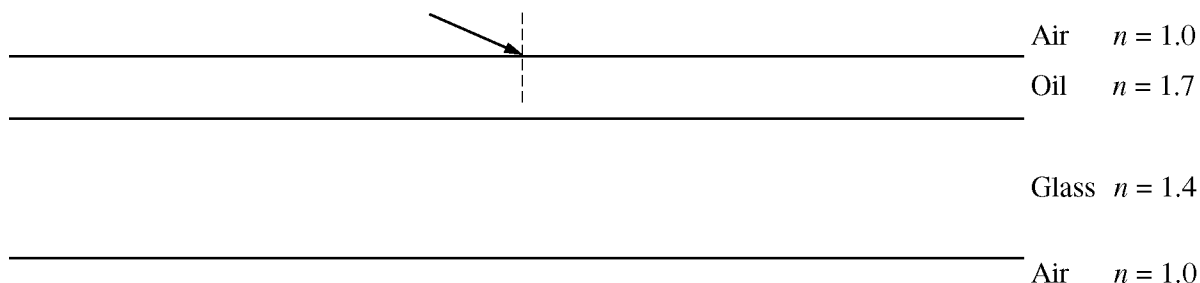
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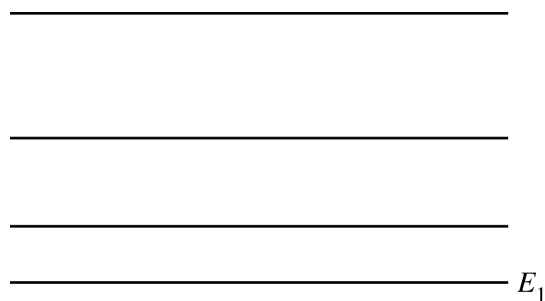
5. (10 points)

A wide beam of white light is incident normal to the surface of a uniform oil film. An observer looking down at the film sees green light that has maximum intensity at a wavelength of  $5.2 \times 10^{-7} \text{ m}$ . The index of refraction of the oil is 1.7.

- Calculate the speed at which the light travels within the film.
- Calculate the wavelength of the green light within the film.
- Calculate the minimum possible thickness of the film.
- The oil film now rests on a thick slab of glass with index of refraction 1.4, as shown in the figure below. A light ray is incident on the film at the angle shown. On the figure, sketch the path of the refracted light ray that passes through the film and the glass slab and exits into the air. Clearly show any bending of the ray at each interface. You are NOT expected to calculate the sizes of any angles.



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Note: Energy levels not drawn to scale.

6. (10 points)

The electron energy levels above are for an electron confined to a certain very small one-dimensional region of space. The energy  $E_n$  of the levels, where  $n = 1, 2, 3, \dots$ , is given by  $E_n = n^2 E_1$ . Express all algebraic answers in terms of  $E_1$  and fundamental constants.

- (a) On the diagram above, label the three excited energy levels with the values for their energies in terms of  $E_1$ , the energy of the ground state.
- (b) Calculate the smallest frequency of light that can be absorbed by an electron in this system when it is in the ground state,  $n = 1$ .
- (c) If an electron is raised into the second excited state, draw on the diagram all the possible transitions that the electron can make in returning to the ground state.
- (d) Calculate the wavelength of the highest energy photon that can be emitted in the transitions in part (c).

**END OF EXAM**