



## **AP<sup>®</sup> Physics B 2007 Free-Response Questions**

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TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS		UNITS		PREFIXES			
		Name	Symbol	Factor	Prefix	Symbol	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ $= 931 \text{ MeV}/c^2$	meter	m	$10^9$	giga	G	
Proton mass,	$m_p = 1.67 \times 10^{-27} \text{ kg}$	kilogram	kg	$10^6$	mega	M	
Neutron mass,	$m_n = 1.67 \times 10^{-27} \text{ kg}$	second	s	$10^3$	kilo	k	
Electron mass,	$m_e = 9.11 \times 10^{-31} \text{ kg}$	ampere	A	$10^{-2}$	centi	c	
Electron charge magnitude,	$e = 1.60 \times 10^{-19} \text{ C}$	kelvin	K	$10^{-3}$	milli	m	
Avogadro's number,	$N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	mole	mol	$10^{-6}$	micro	$\mu$	
Universal gas constant,	$R = 8.31 \text{ J}/(\text{mol}\cdot\text{K})$	hertz	Hz	$10^{-9}$	nano	n	
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23} \text{ J}/\text{K}$	newton	N	$10^{-12}$	pico	p	
Speed of light,	$c = 3.00 \times 10^8 \text{ m}/\text{s}$	pascal	Pa	VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES			
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$ $= 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$ $hc = 1.99 \times 10^{-25} \text{ J}\cdot\text{m}$ $= 1.24 \times 10^3 \text{ eV}\cdot\text{nm}$	joule	J				
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$	watt	W	$0^\circ$	0	1	0
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$	coulomb	C	$30^\circ$	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T}\cdot\text{m})/\text{A}$	volt	V	$37^\circ$	3/5	4/5	3/4
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7} (\text{T}\cdot\text{m})/\text{A}$	ohm	$\Omega$	$45^\circ$	$\sqrt{2}/2$	$\sqrt{2}/2$	1
Universal gravitational constant,	$G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg}\cdot\text{s}^2$	henry	H	$53^\circ$	4/5	3/5	4/3
Acceleration due to gravity at Earth's surface,	$g = 9.8 \text{ m}/\text{s}^2$	farad	F	$60^\circ$	$\sqrt{3}/2$	1/2	$\sqrt{3}$
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N}/\text{m}^2$ $= 1.0 \times 10^5 \text{ Pa}$	tesla	T	$90^\circ$	1	0	$\infty$
1 electron volt,	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	degree Celsius	$^\circ\text{C}$				
		electron-volt	eV				

The following conventions are used in this examination.

- 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 2006 and 2007**

NEWTONIAN MECHANICS		ELECTRICITY AND MAGNETISM	
$v = v_0 + at$	$a =$ acceleration	$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$	$A =$ area
$x = x_0 + v_0t + \frac{1}{2}at^2$	$F =$ force	$\mathbf{E} = \frac{\mathbf{F}}{q}$	$B =$ magnetic field
$v^2 = v_0^2 + 2a(x - x_0)$	$f =$ frequency	$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$	$C =$ capacitance
$\Sigma \mathbf{F} = \mathbf{F}_{net} = ma$	$h =$ height	$E_{avg} = -\frac{V}{d}$	$d =$ distance
$F_{fric} \leq \mu N$	$J =$ impulse	$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$	$E =$ electric field
$a_c = \frac{v^2}{r}$	$K =$ kinetic energy	$C = \frac{Q}{V}$	$\mathcal{E} =$ emf
$\tau = rF \sin \theta$	$k =$ spring constant	$C = \frac{\epsilon_0 A}{d}$	$F =$ force
$\mathbf{p} = m\mathbf{v}$	$\ell =$ length	$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$	$I =$ current
$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$	$m =$ mass	$I_{avg} = \frac{\Delta Q}{\Delta t}$	$\ell =$ length
$K = \frac{1}{2}mv^2$	$N =$ normal force	$R = \frac{\rho \ell}{A}$	$P =$ power
$\Delta U_g = mgh$	$P =$ power	$V = IR$	$Q =$ charge
$W = F\Delta r \cos \theta$	$p =$ momentum	$P = IV$	$q =$ point charge
$P_{avg} = \frac{W}{\Delta t}$	$r =$ radius or distance	$C_p = \sum_i C_i$	$R =$ resistance
$P = Fv \cos \theta$	$T =$ period	$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$	$r =$ distance
$\mathbf{F}_s = -k\mathbf{x}$	$t =$ time	$R_s = \sum_i R_i$	$t =$ time
$U_s = \frac{1}{2}kx^2$	$U =$ potential energy	$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$	$U =$ potential (stored) energy
$T_s = 2\pi\sqrt{\frac{m}{k}}$	$v =$ velocity or speed	$F_B = qvB \sin \theta$	$V =$ electric potential or potential difference
$T_p = 2\pi\sqrt{\frac{\ell}{g}}$	$W =$ work done on a system	$F_B = BI\ell \sin \theta$	$v =$ velocity or speed
$T = \frac{1}{f}$	$x =$ position	$B = \frac{\mu_0 I}{2\pi r}$	$\rho =$ resistivity
$F_G = -\frac{Gm_1m_2}{r^2}$	$\mu =$ coefficient of friction	$\phi_m = BA \cos \theta$	$\theta =$ angle
$U_G = -\frac{Gm_1m_2}{r}$	$\theta =$ angle	$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$	$\phi_m =$ magnetic flux
	$\tau =$ torque	$\mathcal{E} = B\ell v$	

**ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007**

**FLUID MECHANICS AND THERMAL PHYSICS**

$P = P_0 + \rho gh$	$A = \text{area}$
$F_{\text{buoy}} = \rho Vg$	$e = \text{efficiency}$
$A_1 v_1 = A_2 v_2$	$F = \text{force}$
$P + \rho gy + \frac{1}{2} \rho v^2 = \text{const.}$	$h = \text{depth}$
$\Delta \ell = \alpha \ell_0 \Delta T$	$H = \text{rate of heat transfer}$
$H = \frac{kA \Delta T}{L}$	$k = \text{thermal conductivity}$
$P = \frac{F}{A}$	$K_{\text{avg}} = \text{average molecular kinetic energy}$
$PV = nRT = Nk_B T$	$\ell = \text{length}$
$K_{\text{avg}} = \frac{3}{2} k_B T$	$L = \text{thickness}$
$v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$	$M = \text{molar mass}$
$W = -P \Delta V$	$n = \text{number of moles}$
$\Delta U = Q + W$	$N = \text{number of molecules}$
$e = \left  \frac{W}{Q_H} \right $	$P = \text{pressure}$
$e_c = \frac{T_H - T_C}{T_H}$	$Q = \text{heat transferred to a system}$
	$T = \text{temperature}$
	$U = \text{internal energy}$
	$V = \text{volume}$
	$v = \text{velocity or speed}$
	$v_{\text{rms}} = \text{root-mean-square velocity}$
	$W = \text{work done on a system}$
	$y = \text{height}$
	$\alpha = \text{coefficient of linear expansion}$
	$\mu = \text{mass of molecule}$
	$\rho = \text{density}$

**ATOMIC AND NUCLEAR PHYSICS**

$E = hf = pc$	$E = \text{energy}$
$K_{\text{max}} = hf - \phi$	$f = \text{frequency}$
$\lambda = \frac{h}{p}$	$K = \text{kinetic energy}$
$\Delta E = (\Delta m)c^2$	$m = \text{mass}$
	$p = \text{momentum}$
	$\lambda = \text{wavelength}$
	$\phi = \text{work function}$

**WAVES AND OPTICS**

$v = f\lambda$	$d = \text{separation}$
$n = \frac{c}{v}$	$f = \text{frequency or focal length}$
$n_1 \sin \theta_1 = n_2 \sin \theta_2$	$h = \text{height}$
$\sin \theta_c = \frac{n_2}{n_1}$	$L = \text{distance}$
$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$	$M = \text{magnification}$
$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$	$m = \text{an integer}$
$f = \frac{R}{2}$	$n = \text{index of refraction}$
$d \sin \theta = m\lambda$	$R = \text{radius of curvature}$
$x_m \sim \frac{m\lambda L}{d}$	$s = \text{distance}$
	$v = \text{speed}$
	$x = \text{position}$
	$\lambda = \text{wavelength}$
	$\theta = \text{angle}$

**GEOMETRY AND TRIGONOMETRY**

Rectangle	$A = \text{area}$
$A = bh$	$C = \text{circumference}$
Triangle	$V = \text{volume}$
$A = \frac{1}{2}bh$	$S = \text{surface area}$
Circle	$b = \text{base}$
$A = \pi r^2$	$h = \text{height}$
$C = 2\pi r$	$\ell = \text{length}$
Parallelepiped	$w = \text{width}$
$V = \ell wh$	$r = \text{radius}$
Cylinder	
$V = \pi r^2 \ell$	
$S = 2\pi r \ell + 2\pi r^2$	

Sphere

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

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

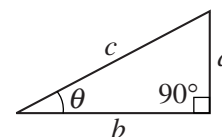
Right Triangle

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

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

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

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



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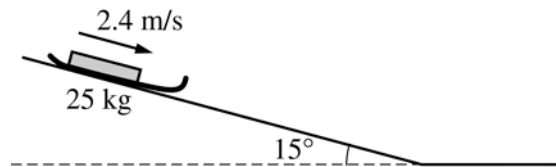
**PHYSICS B**

**SECTION II**

**Time—90 minutes**

**7 Questions**

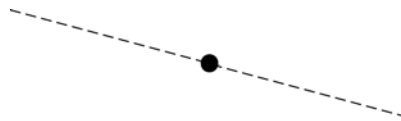
**Directions:** Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1 and 3 and about 11 minutes for answering each of Questions 2 and 4-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (15 points)

An empty sled of mass 25 kg slides down a muddy hill with a constant speed of 2.4 m/s. The slope of the hill is inclined at an angle of  $15^\circ$  with the horizontal as shown in the figure above.

- (a) Calculate the time it takes the sled to go 21 m down the slope.
- (b) On the dot below that represents the sled, draw and label a free-body diagram for the sled as it slides down the slope.



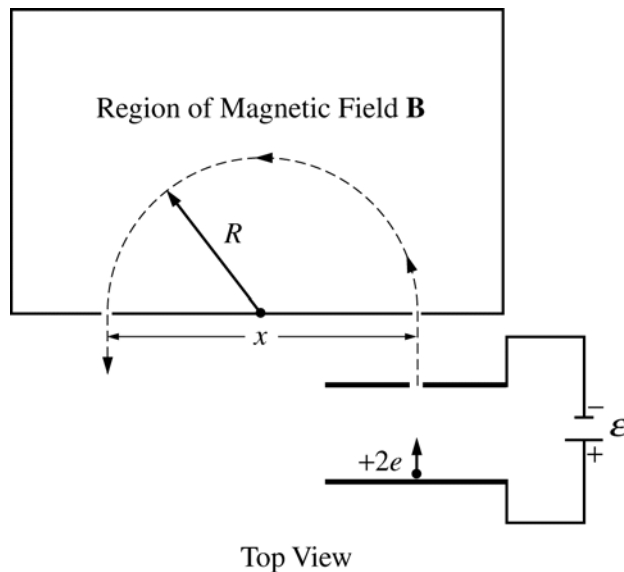
- (c) Calculate the frictional force on the sled as it slides down the slope.
- (d) Calculate the coefficient of friction between the sled and the muddy surface of the slope.
- (e) The sled reaches the bottom of the slope and continues on the horizontal ground. Assume the same coefficient of friction.
  - i. In terms of velocity and acceleration, describe the motion of the sled as it travels on the horizontal ground.

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- ii. On the axes below, sketch a graph of speed  $v$  versus time  $t$  for the sled. Include both the sled's travel down the slope and across the horizontal ground. Clearly indicate with the symbol  $t_\ell$  the time at which the sled leaves the slope.



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2. (10 points)

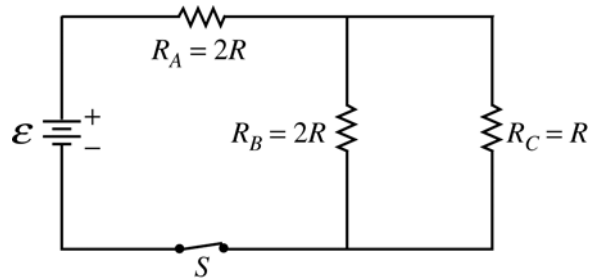
Your research director has assigned you to set up the laboratory's mass spectrometer so that it will separate strontium ions having a net charge of  $+2e$  from a beam of mixed ions. The spectrometer above accelerates a beam of ions from rest through a potential difference  $\mathcal{E}$ , after which the beam enters a region containing a uniform magnetic field  $\mathbf{B}$  of constant magnitude and perpendicular to the plane of the path of the ions. The ions leave the spectrometer at a distance  $x$  from the entrance point. You can manually change  $\mathcal{E}$ .

Numerical values for this experiment:

Strontium atomic number:	38
Strontium ion mass:	$1.45 \times 10^{-25}$ kg
Magnitude of $B$ field:	0.090 T
Desired exit distance $x$ :	1.75 m

- In what direction must  $\mathbf{B}$  point to produce the trajectory of the ions shown?
- The ions travel at constant speed around the semicircular path. Explain why the speed remains constant.
- Calculate the speed of the ions with charge  $+2e$  that exit at distance  $x$ .
- Calculate the accelerating voltage  $\mathcal{E}$  needed for the ions with charge  $+2e$  to attain the speed you calculated in part (c).

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3. (15 points)

The circuit above contains a battery with negligible internal resistance, a closed switch  $S$ , and three resistors, each with a resistance of  $R$  or  $2R$ .

(a)

- i. Rank the currents in the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same current, give them the same ranking.

\_\_\_\_\_  $I_A$       \_\_\_\_\_  $I_B$       \_\_\_\_\_  $I_C$

- ii. Justify your answers.

(b)

- i. Rank the voltages across the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same voltage across them, give them the same ranking.

\_\_\_\_\_  $V_A$       \_\_\_\_\_  $V_B$       \_\_\_\_\_  $V_C$

- ii. Justify your answers.

For parts (c) through (e), use  $\mathcal{E} = 12 \text{ V}$  and  $R = 200 \ \Omega$ .

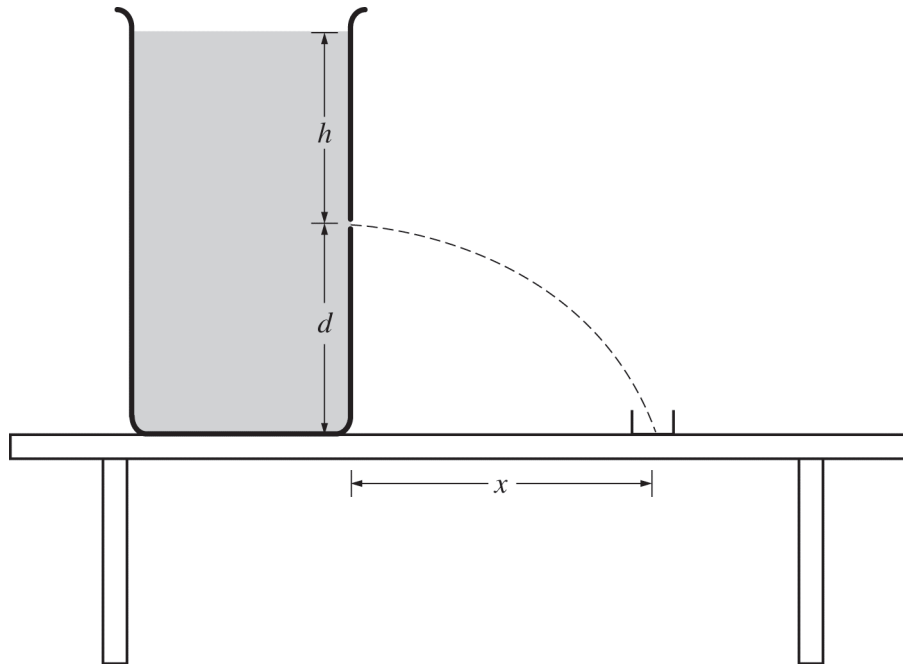
(c) Calculate the equivalent resistance of the circuit.

(d) Calculate the current in resistor  $R_C$ .

(e) The switch  $S$  is opened, resistor  $R_B$  is removed and replaced by a capacitor of capacitance  $2.0 \times 10^{-6} \text{ F}$ , and the switch  $S$  is again closed. Calculate the charge on the capacitor after all the currents have reached their final steady-state values.



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4. (10 points)

The large container shown in the cross section above is filled with a liquid of density  $1.1 \times 10^3 \text{ kg/m}^3$ . A small hole of area  $2.5 \times 10^{-6} \text{ m}^2$  is opened in the side of the container a distance  $h$  below the liquid surface, which allows a stream of liquid to flow through the hole and into a beaker placed to the right of the container. At the same time, liquid is also added to the container at an appropriate rate so that  $h$  remains constant. The amount of liquid collected in the beaker in 2.0 minutes is  $7.2 \times 10^{-4} \text{ m}^3$ .

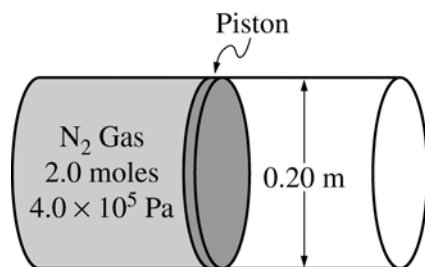
- (a) Calculate the volume rate of flow of liquid from the hole in  $\text{m}^3/\text{s}$ .
- (b) Calculate the speed of the liquid as it exits from the hole.
- (c) Calculate the height  $h$  of liquid needed above the hole to cause the speed you determined in part (b).
- (d) Suppose that there is now less liquid in the beaker so that the height  $h$  is reduced to  $h/2$ . In relation to the beaker, where will the liquid hit the tabletop?

\_\_\_ Left of the beaker      \_\_\_ In the beaker      \_\_\_ Right of the beaker

Justify your answer.

should say "container"

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5. (10 points)

The figure above shows a 0.20 m diameter cylinder fitted with a frictionless piston, initially fixed in place. The cylinder contains 2.0 moles of nitrogen gas at an absolute pressure of  $4.0 \times 10^5$  Pa. Nitrogen gas has a molar mass of 28 g/mole and it behaves as an ideal gas.

- Calculate the force that the nitrogen gas exerts on the piston.
- Calculate the volume of the gas if the temperature of the gas is 300 K.
- In a certain process, the piston is allowed to move, and the gas expands at constant pressure and pushes the piston out 0.15 m. Calculate how much work is done by the gas.
- Which of the following is true of the heat energy transferred to or from the gas, if any, in the process in part (c)?

- Heat is transferred to the gas.
- Heat is transferred from the gas.
- No heat is transferred in the process.

Justify your answer.

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6. (10 points)

You are asked to experimentally determine the focal length of a converging lens.

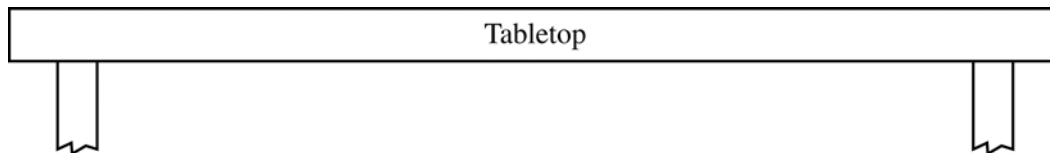
(a) Your teacher first asks you to estimate the focal length by using a distant tree visible through the laboratory window. Explain how you will estimate the focal length.

To verify the value of the focal length, you are to measure several object distances  $s_o$  and image distances  $s_i$  using equipment that can be set up on a tabletop in the laboratory.

(b) In addition to the lens, which of the following equipment would you use to obtain the data?

- |  |                                       |  |                                       |
|--|---------------------------------------|--|---------------------------------------|
| <input type="checkbox"/> Lighted candle  | <input type="checkbox"/> Candleholder | <input type="checkbox"/> Desk lamp           | <input type="checkbox"/> Plane mirror |
| <input type="checkbox"/> Vernier caliper | <input type="checkbox"/> Meterstick   | <input type="checkbox"/> Ruler               | <input type="checkbox"/> Lens holder  |
| <input type="checkbox"/> Stopwatch       | <input type="checkbox"/> Screen       | <input type="checkbox"/> Diffraction grating |                                       |

(c) On the tabletop below, sketch the setup used to obtain the data, labeling the lens, the distances  $s_o$  and  $s_i$ , and the equipment checked in part (b).

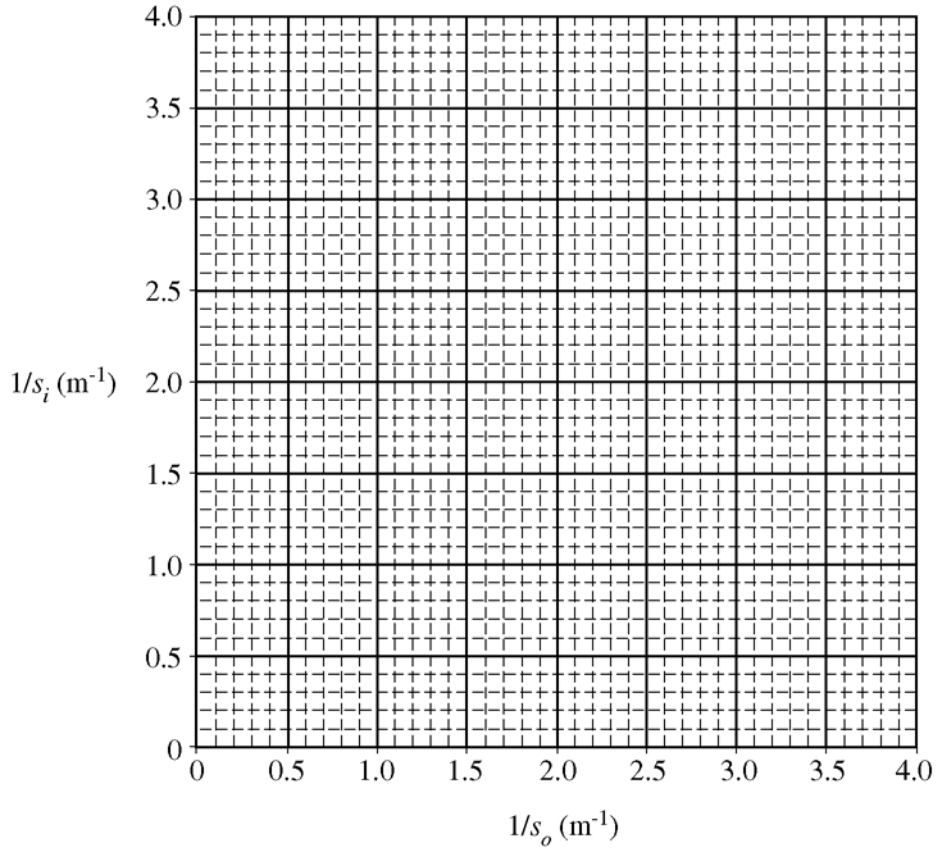


You are to determine the focal length using a linear graph of  $1/s_i$  versus  $1/s_o$ . Assume that you obtain the following data for object distance  $s_o$  and image distance  $s_i$ .

Trial #	$s_o$ (m)	$s_i$ (m)	$1/s_o$ ( $m^{-1}$ )	$1/s_i$ ( $m^{-1}$ )
1	0.40	1.10	2.5	0.91
2	0.50	0.75	2.0	1.3
3	0.60	0.60	1.7	1.7
4	0.80	0.50	1.2	2.0
5	1.20	0.38	0.83	2.6

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(d) On the grid below, plot the points in the last two columns of the table above and draw a best-fit line through the points.



(e) Calculate the focal length from the best-fit line.

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7. (10 points)

It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron-positron pair before annihilation is negligible compared to the energy of the photons created.

- (a) Calculate, in eV, the rest energy of a positron.
- (b) Determine, in eV, the energy each emitted photon must have.
- (c) Calculate the wavelength of each created photon.
- (d) Calculate the magnitude of the momentum of each photon.
- (e) Determine the total momentum of the two-photon system.

**END OF EXAM**