CollegeBoard
Advanced Placement Program

AP® Physics B
2008 Free-Response Questions

The College Board: Connecting Students to College Success

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the association is composed of more than 5,000 schools, colleges, universities, and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT®, and the Advanced Placement Program® (AP®). The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

Visit the College Board on the Web: www.collegeboard.com.
AP Central is the official online home for the AP Program: apcentral.collegeboard.com.

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 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,	$1\ u = 1.66 \times 10^{-27}$ kg $= 931$ 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,	$k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 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 <u>on</u> a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

NEWTONIAN MECHANICS

$v = v_0 + at$

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

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

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

$F_{fric} \leq \mu N$

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

$\tau = rF \sin \theta$

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

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

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

$\Delta U_g = mgh$

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

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

$P = Fv \cos \theta$

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

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

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

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

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

$F_G = -\dfrac{Gm_1 m_2}{r^2}$

$U_G = -\dfrac{Gm_1 m_2}{r}$

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

$F = \dfrac{1}{4\pi\epsilon_0} \dfrac{q_1 q_2}{r^2}$

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

$U_E = qV = \dfrac{1}{4\pi\epsilon_0} \dfrac{q_1 q_2}{r}$

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

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

$\phi_m = BA \cos \theta$

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

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

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

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

FLUID MECHANICS AND THERMAL PHYSICS

$$P = P_0 + \rho g h$$

$$F_{buoy} = \rho V g$$

$$A_1 v_1 = A_2 v_2$$

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

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

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

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

$$PV = nRT = Nk_B T$$

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

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

$$W = -P\Delta V$$

$$\Delta U = Q + W$$

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

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

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 = 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_{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

$$v = f\lambda$$

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

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

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

$$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$$

$$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$$

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

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

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

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
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
$$V = \pi r^2 \ell$$
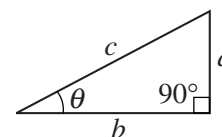$$S = 2\pi r \ell + 2\pi r^2$$
Sphere
$$V = \frac{4}{3}\pi r^3$$
$$S = 4\pi r^2$$
Right Triangle
$$a^2 + b^2 = c^2$$
$$\sin\theta = \frac{a}{c}$$
$$\cos\theta = \frac{b}{c}$$
$$\tan\theta = \frac{a}{b}$$

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
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering Questions 1 and 4-7 and about 17 minutes for answering each of Questions 2 and 3. 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.
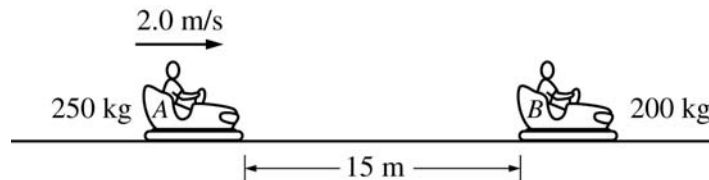

1. (10 points)

Several students are riding in bumper cars at an amusement park. The combined mass of car A and its occupants is 250 kg. The combined mass of car B and its occupants is 200 kg. Car A is 15 m away from car B and moving to the right at 2.0 m/s, as shown, when the driver decides to bump into car B, which is at rest.

(a) Car A accelerates at $1.5 \ \mathrm{m/s^2}$ to a speed of $5.0 \ \mathrm{m/s}$ and then continues at constant velocity until it strikes car B. Calculate the total time for car A to travel the 15 m.

(b) After the collision, car B moves to the right at a speed of $4.8 \ \mathrm{m/s}$.

  i. Calculate the speed of car A after the collision.

  ii. Indicate the direction of motion of car A after the collision.

     ____ To the left   ____ To the right   ____ None; car A is at rest.

(c) Is this an elastic collision?

    ____ Yes   ____ No

   Justify your answer.

GO ON TO THE NEXT PAGE.
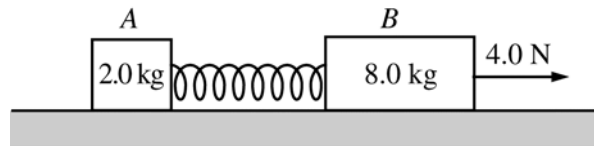
2. (15 points)

Block *A* of mass 2.0 kg and block *B* of mass 8.0 kg are connected as shown above by a spring of spring constant 80 N/m and negligible mass. The system is being pulled to the right across a horizontal frictionless surface by a horizontal force of 4.0 N, as shown, with both blocks experiencing equal constant acceleration.

(a) Calculate the force that the spring exerts on the 2.0 kg block.

(b) Calculate the extension of the spring.

The system is now pulled to the left, as shown below, with both blocks again experiencing equal constant acceleration.
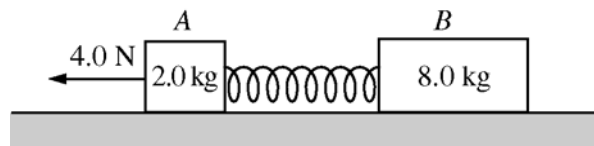
(c) Is the magnitude of the acceleration greater than, less than, or the same as before?

_____ Greater   _____ Less   _____ The same

Justify your answer.

(d) Is the amount the spring has stretched greater than, less than, or the same as before?

_____ Greater   _____ Less   _____ The same

Justify your answer.

(e) In a new situation, the blocks and spring are moving together at a constant speed of 0.50 m/s to the left. Block *A* then hits and sticks to a wall. Calculate the maximum compression of the spring.

GO ON TO THE NEXT PAGE.

3. (15 points)

A rectangular wire loop is connected across a power supply with an internal resistance of $0.50 \ \Omega$ and an emf of 16 V. The wire has resistivity $1.7 \times 10^{-8} \ \Omega\text{•m}$ and cross-sectional area $3.5 \times 10^{-9} \ \text{m}^2$. When the power supply is turned on, the current in the wire is 4.0 A.

(a) Calculate the length of wire used to make the loop.

The wire loop is then used in an experiment to measure the strength of the magnetic field between the poles of a magnet. The magnet is placed on a digital balance, and the wire loop is held fixed between the poles of the magnet, as shown below. The 0.020 m long horizontal segment of the loop is midway between the poles and perpendicular to the direction of the magnetic field. The power supply in the loop is turned on, so that the 4.0 A current is in the direction shown.
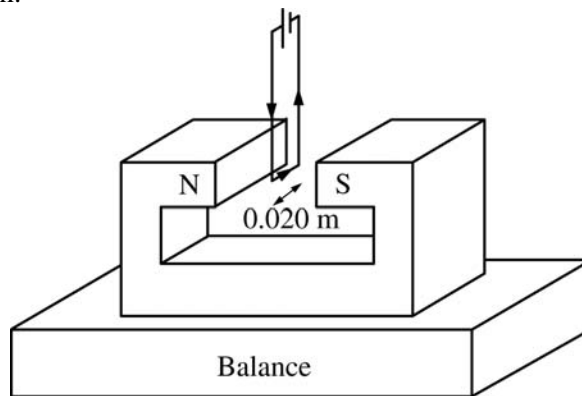
Note: Figure not drawn to scale.

(b) In which direction is the force on the <u>magnet</u> due to the current in the wire segment?

_____Upward   _____Downward

Justify your answer.

(c) The reading on the balance changed by 0.060 N when the power supply was turned on. Calculate the strength of the magnetic field.

Suppose that various rectangular loops with the same total length of wire as found in part (a) were constructed such that the lengths of the horizontal segments of the wire loops varied between 0.02 m and 0.10 m. The horizontal segment of each loop was always centered between the poles, and the current in each loop was always 4.0 A. The following graph represents the theoretical relationship between the magnitude of the force on the magnet and the length of the wire.
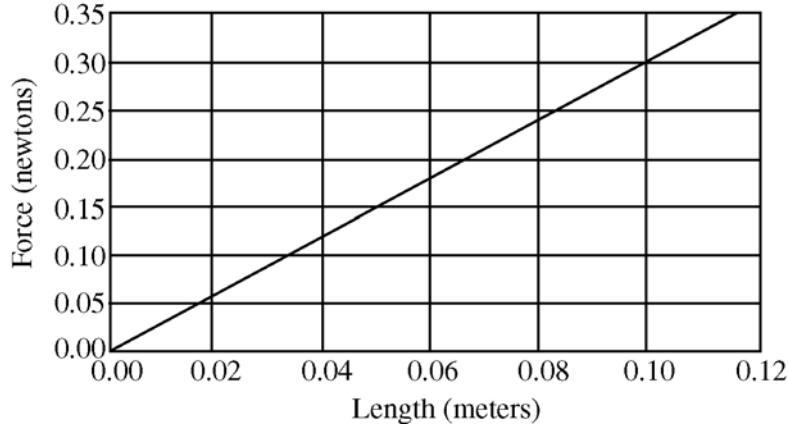
(d) On the graph above, sketch a possible relationship between the magnitude of the force on the magnet and the length of the wire segment if the wire segments were misaligned and placed at a constant nonperpendicular angle to the magnetic field, as shown below.
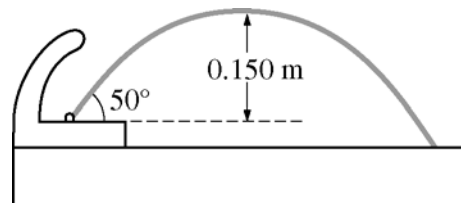

Top view

(e) Suppose the loops are correctly placed perpendicular to the field and the following data are obtained. Describe a likely cause of the discrepancy between the data and the theoretical relationship.

GO ON TO THE NEXT PAGE.
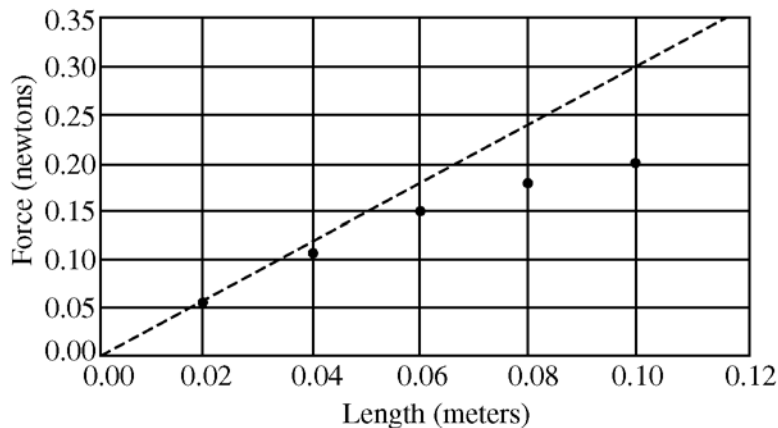
4. (10 points)

A drinking fountain projects water at an initial angle of 50° above the horizontal, and the water reaches a maximum height of 0.150 m above the point of exit. Assume air resistance is negligible.

(a) Calculate the speed at which the water leaves the fountain.

(b) The radius of the fountain's exit hole is 4.00×10^{-3} m . Calculate the volume rate of flow of the water.

(c) The fountain is fed by a pipe that at one point has a radius of 7.00×10^{-3} m and is 3.00 m below the fountain's opening. The density of water is 1.0×10^{3} kg/m^3 . Calculate the gauge pressure in the feeder pipe at this point.
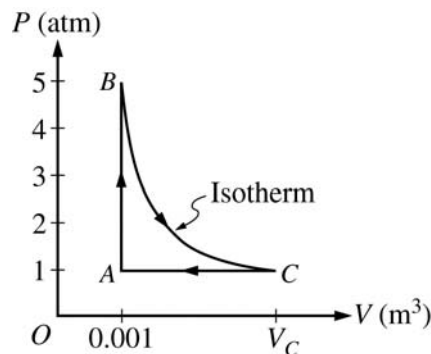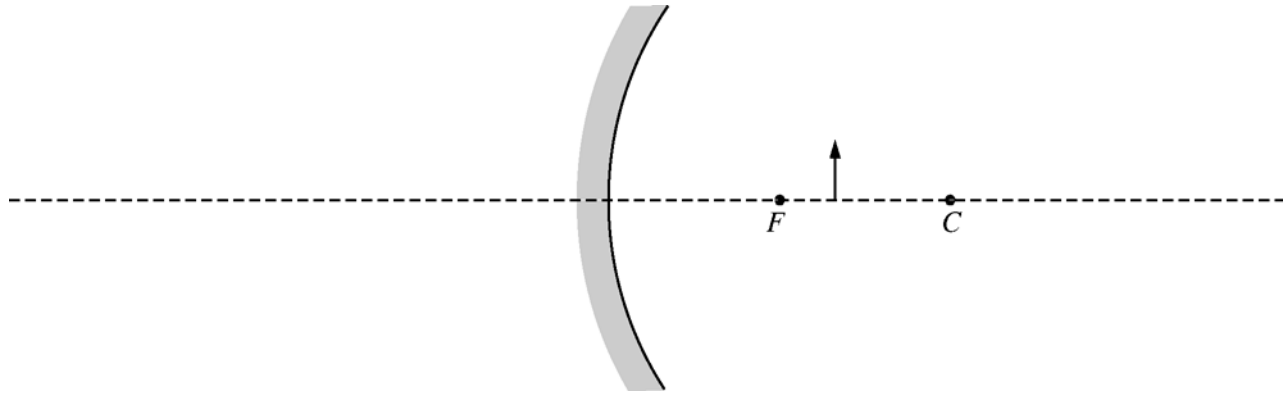

5. (10 points)

A 0.03 mol sample of helium is taken through the cycle shown in the diagram above. The temperature of state A is 400 K.

(a) For each process in this cycle, indicate in the table below whether the quantities W, Q, and ΔU are positive (+), negative (−), or zero (0). W is the work done on the helium sample.

Process	W	Q	ΔU
$A \rightarrow B$			
$B \rightarrow C$			
$C \rightarrow A$			

(b) Explain your response for the signs of the quantities for process $A \rightarrow B$.

(c) Calculate V_C .

GO ON TO THE NEXT PAGE.

6. (10 points)

The figure above shows a converging mirror, its focal point *F*, its center of curvature *C*, and an object represented by the solid arrow.

(a) On the figure above, draw a ray diagram showing at least two incident rays and the image formed by them.

(b) Is the image real or virtual?

____ Real   ____ Virtual

Justify your answer.

(c) The focal length of this mirror is 6.0 cm, and the object is located 8.0 cm away from the mirror. Calculate the position of the image formed by the mirror. (Do NOT simply measure your ray diagram.)

(d) Suppose that the converging mirror is replaced by a diverging mirror with the same radius of curvature that is the same distance from the object, as shown below.
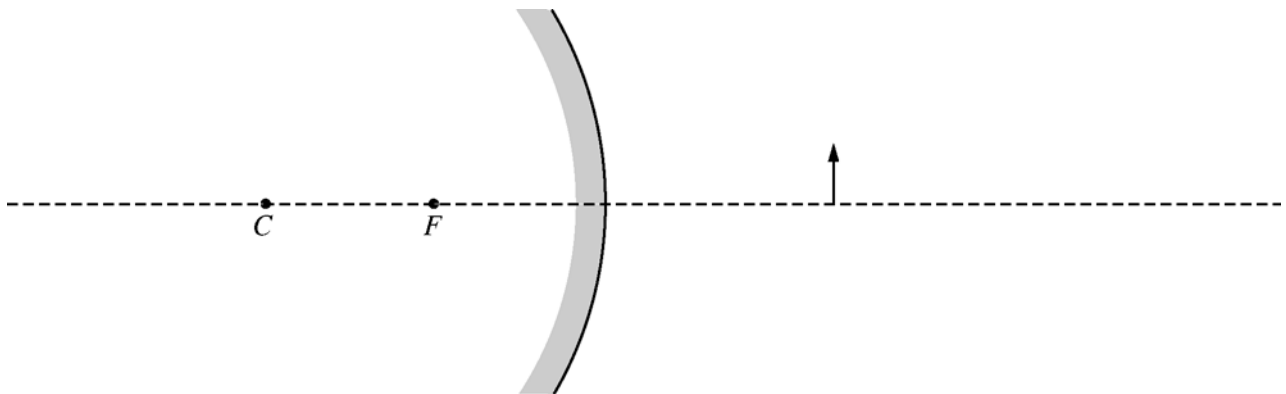
For this mirror, how does the size of the image compare with that of the object?

____ Larger than the object   ____ Smaller than the object   ____ The same size as the object

Justify your answer.

7. (10 points)

In an electron microscope, a tungsten cathode with work function 4.5 eV is heated to release electrons that are then initially at rest just outside the cathode. The electrons are accelerated by a potential difference to create a beam of electrons with a de Broglie wavelength of 0.038 nm. Assume nonrelativistic equations apply to the motion of the electrons.

(a) Calculate the momentum of an electron in the beam, in $kg \cdot m/s$.

(b) Calculate the kinetic energy of an electron in the beam, in joules.

(c) Calculate the accelerating voltage.

(d) Suppose that light, instead of heat, is used to release the electrons from the cathode. What minimum frequency of light is needed to accomplish this?

END OF EXAM