PHYSICS B

You must take the entire B Exam as follows:

First 90 minutes	Section I — Multiple Choice 70 Questions This booklet, pp. 3-19 No calculators allowed Percent of Total Grade — 50
2-minute interval	Survey Questions 7 Questions (101-107) This booklet, pp. 20-21
Second 90 minutes	Section II — Free Response 8 Questions Pink Booklet, pp. 4-20 Any battery-operated, hand-held calculator allowed Percent of Total Grade — 50

Each multiple-choice question has equal weight. Rulers or straightedges may be used in both sections. However, calculators may be used in Section II only, NOT in Section I. Calculators may not be shared. A table of information that may be helpful is found on page 2 of this book.

Section I of this examination contains 70 multiple-choice questions. Therefore, please be careful to fill in only the ovals that are preceded by numbers 1 through 70 on your answer sheet. Also, please be careful to fill in the ovals preceded by the numbers 101 through 107 when answering the survey questions.

General Instructions

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE INSTRUCTED TO DO SO.

INDICATE ALL YOUR ANSWERS TO QUESTIONS IN SECTION I ON THE SEPARATE ANSWER SHEET. No credit will be given for anything written in this examination booklet, but you may use the booklet for notes or scratchwork. After you have decided which of the suggested answers is best, COMPLETELY fill in the corresponding oval on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely.

Example:

Chicago is a

(A) state
(B) city
(C) country
(D) continent
(E) village

Sample Answer

Ⓐ ● Ⓒ Ⓓ Ⓔ

Many candidates wonder whether or not to guess the answers to questions about which they are not certain. In this section of the examination, as a correction for haphazard guessing, one-fourth of the number of questions you answer incorrectly will be subtracted from the number of questions you answer correctly. It is improbable, therefore, that mere guessing will improve your score significantly; it may even lower your score, and it does take time. If, however, you are not sure of the correct answer but have some knowledge of the question and are able to eliminate one or more of the answer choices as wrong, your chance of getting the right answer is improved, and it may be to your advantage to answer such a question.

Use your time effectively, working as rapidly as you can without losing accuracy. Do not spend too much time on questions that are too difficult. Go on to other questions and come back to the difficult ones later if you have time. It is not expected that everyone will be able to answer all the multiple-choice questions.

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{u} = 1.66 \times 10^{-27}$ kg
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}$ C
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol} \cdot \text{K})$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K
Speed of light,	$c = 3.00 \times 10^8$ m/s
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}(\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5$ Pa
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}$ J
1 angstrom,	$1\ \text{Å} = 1 \times 10^{-10}$ m

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

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	$\sin\theta$	$\cos\theta$	$\tan\theta$
$0°$	0	1	0
$30°$	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
$37°$	3/5	4/5	3/4
$45°$	$\sqrt{2}/2$	$\sqrt{2}/2$	1
$53°$	4/5	3/5	4/3
$60°$	$\sqrt{3}/2$	1/2	$\sqrt{3}$
$90°$	1	0	∞

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. The work done by a thermodynamic system is defined as a positive quantity.

PHYSICS B

SECTION I

Time—90 minutes

70 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding oval on the answer sheet.

Note: To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.

1. A solid metal ball and a hollow plastic ball of the same external radius are released from rest in a large vacuum chamber. When each has fallen 1 m, they both have the same

(A) inertia
(B) speed
(C) momentum
(D) kinetic energy
(E) change in potential energy

2. A student weighing 700 N climbs at constant speed to the top of an 8 m vertical rope in 10 s. The average power expended by the student to overcome gravity is most nearly

(A) 1.1 W
(B) 87.5 W
(C) 560 W
(D) 875 W
(E) 5,600 W

3. A railroad car of mass m is moving at speed v when it collides with a second railroad car of mass M which is at rest. The two cars lock together instantaneously and move along the track. What is the speed of the cars immediately after the collision?

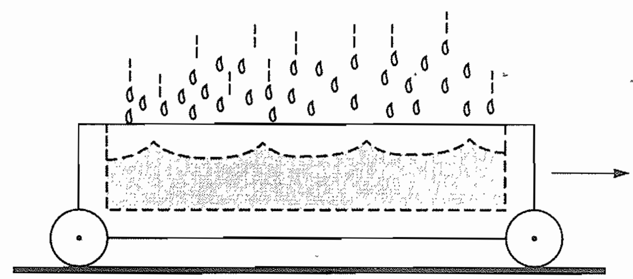
(A) $\frac{v}{2}$

(B) $\frac{mv}{M}$

(C) $\frac{Mv}{m}$

(D) $\frac{(m+M)v}{m}$

(E) $\frac{mv}{m+M}$



4. An open cart on a level surface is rolling without frictional loss through a vertical downpour of rain, as shown above. As the cart rolls, an appreciable amount of rainwater accumulates in the cart. The speed of the cart will

(A) increase because of conservation of momentum
(B) increase because of conservation of mechanical energy
(C) decrease because of conservation of momentum
(D) decrease because of conservation of mechanical energy
(E) remain the same because the raindrops are falling perpendicular to the direction of the cart's motion

5. Units of power include which of the following?

I. Watt
II. Joule per second
III. Kilowatt-hour

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

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6. A 2 kg object moves in a circle of radius 4 m at a constant speed of 3 m/s. A net force of 4.5 N acts on the object. What is the angular momentum of the object with respect to an axis perpendicular to the circle and through its center?

(A) $9\,\dfrac{\text{N}\cdot\text{m}}{\text{kg}}$

(B) $12\,\dfrac{\text{m}^2}{\text{s}}$

(C) $13.5\,\dfrac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$

(D) $18\,\dfrac{\text{N}\cdot\text{m}}{\text{kg}}$

(E) $24\,\dfrac{\text{kg}\cdot\text{m}^2}{\text{s}}$

7. Three forces act on an object. If the object is in translational equilibrium, which of the following must be true?

I. The vector sum of the three forces must equal zero.
II. The magnitudes of the three forces must be equal.
III. All three forces must be parallel.

(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

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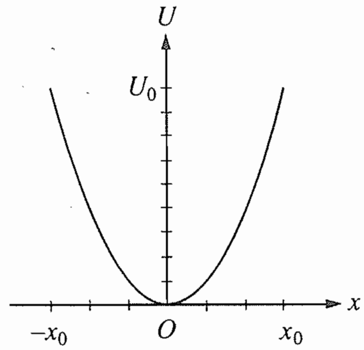
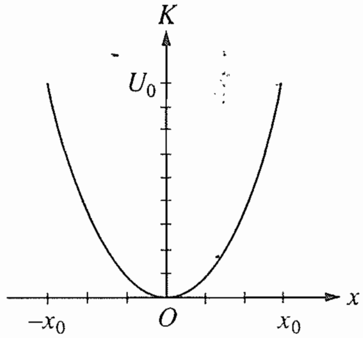
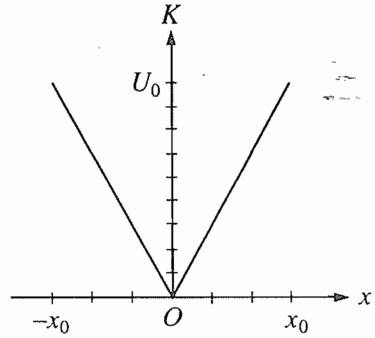


8. The graph above represents the potential energy U as a function of displacement x for an object on the end of a spring oscillating in simple harmonic motion with amplitude x_0. Which of the following graphs represents the kinetic energy K of the object as a function of displacement x ?

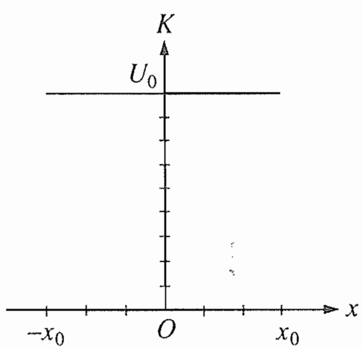
(A)



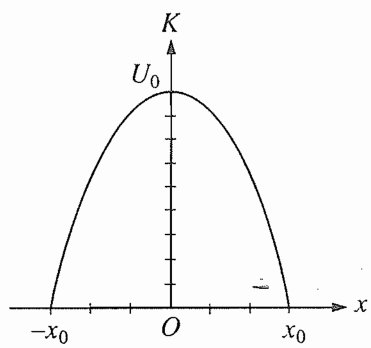
(B)



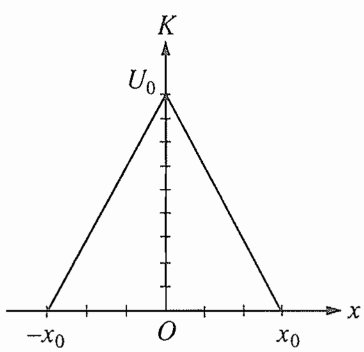
(C)



(D)



(E)



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9. A child pushes horizontally on a box of mass m which moves with constant speed v across a horizontal floor. The coefficient of friction between the box and the floor is μ. At what rate does the child do work on the box?

(A) μmgv
(B) mgv
(C) $v/\mu mg$
(D) $\mu mg/v$
(E) μmv^2

10. Quantum transitions that result in the characteristic sharp lines of the X-ray spectrum always involve

(A) the inner electron shells
(B) electron energy levels that have the same principal quantum number
(C) emission of beta particles from the nucleus
(D) neutrons within the nucleus
(E) protons within the nucleus

11. Which of the following experiments provided evidence that electrons exhibit wave properties?

I. Millikan oil-drop experiment
II. Davisson-Germer electron-diffraction experiment
III. J. J. Thomson's measurement of the charge-to-mass ratio of electrons

(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

12. Quantities that are conserved in all nuclear reactions include which of the following?

I. Electric charge
II. Number of nuclei
III. Number of protons

(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

13. Which of the following is true about the net force on an uncharged conducting sphere in a uniform electric field?

(A) It is zero.
(B) It is in the direction of the field.
(C) It is in the direction opposite to the field.
(D) It produces a torque on the sphere about the direction of the field.
(E) It causes the sphere to oscillate about an equilibrium position.

14. Two parallel conducting plates are connected to a constant voltage source. The magnitude of the electric field between the plates is 2,000 N/C. If the voltage is doubled and the distance between the plates is reduced to 1/5 the original distance, the magnitude of the new electric field is

(A) 800 N/C
(B) 1,600 N/C
(C) 2,400 N/C
(D) 5,000 N/C
(E) 20,000 N/C

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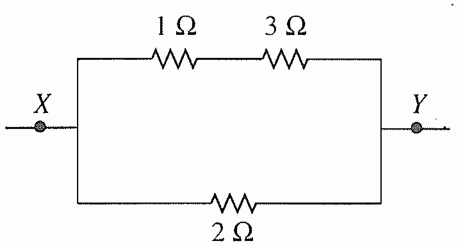
Questions 15-16 refer to the following diagram that shows part of a closed electrical circuit.



15. The electrical resistance of the part of the circuit shown between point X and point Y is

(A) $1\frac{1}{3}\ \Omega$

(B) $2\ \Omega$

(C) $2\frac{3}{4}\ \Omega$

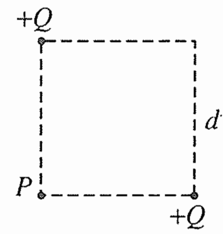
(D) $4\ \Omega$

(E) $6\ \Omega$

16. When there is a steady current in the circuit, the amount of charge passing a point per unit of time is

(A) the same everywhere in the circuit
(B) greater at point X than at point Y
(C) greater in the 1 Ω resistor than in the 2 Ω resistor
(D) greater in the 1 Ω resistor than in the 3 Ω resistor
(E) greater in the 2 Ω resistor than in the 3 Ω resistor

Questions 17-18



The figure above shows two particles, each with a charge of $+Q$, that are located at the opposite corners of a square of side d.

17. What is the direction of the net electric field at point P ?

(A) ↖

(B) ↗

(C) ↙

(D) ↘

(E) ↓

18. What is the potential energy of a particle of charge $+q$ that is held at point P ?

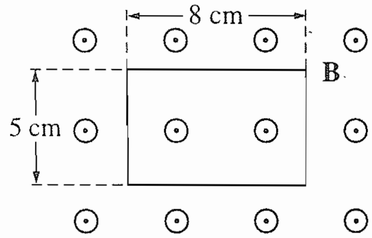
(A) Zero

(B) $\frac{\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

(C) $\frac{1}{4\pi\epsilon_0}\frac{qQ}{d}$

(D) $\frac{2}{4\pi\epsilon_0}\frac{qQ}{d}$

(E) $\frac{2\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

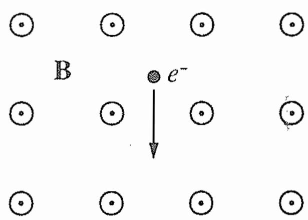


19. A rectangular wire loop is at rest in a uniform magnetic field **B** of magnitude 2 T that is directed out of the page. The loop measures 5 cm by 8 cm, and the plane of the loop is perpendicular to the field, as shown above. The total magnetic flux through the loop is

(A) zero
(B) 2×10^{-3} T·m^2
(C) 8×10^{-3} T·m^2
(D) 2×10^{-1} T·m^2
(E) 8×10^{-1} T·m^2

20. A certain coffeepot draws 4.0 A of current when it is operated on 120 V household lines. If electrical energy costs 10 cents per kilowatt-hour, how much does it cost to operate the coffeepot for 2 hours?

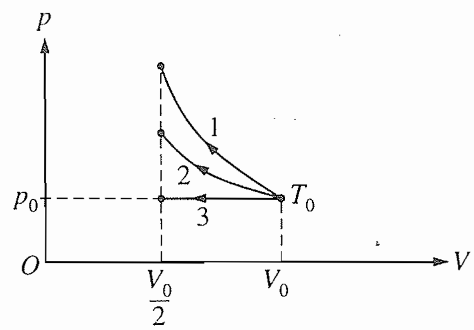
(A) 2.4 cents
(B) 4.8 cents
(C) 8.0 cents
(D) 9.6 cents
(E) 16 cents



21. An electron is in a uniform magnetic field **B** that is directed out of the plane of the page, as shown above. When the electron is moving in the plane of the page in the direction indicated by the arrow, the force on the electron is directed

(A) toward the right
(B) out of the page
(C) into the page
(D) toward the top of the page
(E) toward the bottom of the page

Questions 22-23



A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

22. Which of the following is true of the mechanical work done on the gas?

(A) It is greatest for process 1.
(B) It is greatest for process 3.
(C) It is the same for processes 1 and 2 and less for process 3.
(D) It is the same for processes 2 and 3 and less for process 1.
(E) It is the same for all three processes.

23. Which of the following is true of the final temperature of this gas?

(A) It is greatest for process 1.
(B) It is greatest for process 2.
(C) It is greatest for process 3.
(D) It is the same for processes 1 and 2.
(E) It is the same for processes 1 and 3.

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24. In a certain process, 400 J of heat is added to a system and the system simultaneously does 100 J of work. The change in internal energy of the system is

(A) 500 J
(B) 400 J
(C) 300 J
(D) −100 J
(E) −300 J

25. An ice cube of mass m and specific heat c_i is initially at temperature T_1, where $T_1 < 273$ K. If L is the latent heat of fusion of water, and the specific heat of water is c_w, how much energy is required to convert the ice cube to water at temperature T_2, where $273\text{ K} < T_2 < 373$ K?

(A) $m[c_i(273 - T_1) + L + c_w(373 - T_2)]$

(B) $m[c_i(273 - T_1) + L + c_w(T_2 - 273)]$

(C) $c_i(273 - T_1) + c_w(T_2 - 273)$

(D) $mL + c_w(T_2 - T_1)$

(E) $mL + \left(\frac{c_w + c_i}{2}\right)(T_2 - T_1)$

26. A concave mirror with a radius of curvature of 1.0 m is used to collect light from a distant star. The distance between the mirror and the image of the star is most nearly

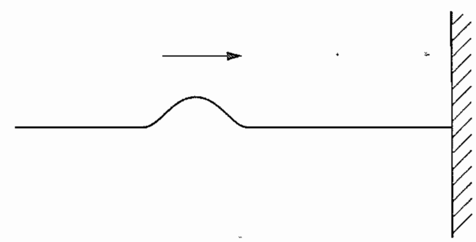
(A) 0.25 m
(B) 0.50 m
(C) 0.75 m
(D) 1.0 m
(E) 2.0 m

27. When light passes from air into water, the frequency of the light remains the same. What happens to the speed and the wavelength of light as it crosses the boundary in going from air into water?

	Speed	Wavelength
(A)	Increases	Remains the same
(B)	Remains the same	Decreases
(C)	Remains the same	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Decreases

28. A physics student places an object 6.0 cm from a converging lens of focal length 9.0 cm. What is the magnitude of the magnification of the image produced?

(A) 0.6
(B) 1.5
(C) 2.0
(D) 3.0
(E) 3.6



29. One end of a horizontal string is fixed to a wall. A transverse wave pulse is generated at the other end, moves toward the wall as shown above, and is reflected at the wall. Properties of the reflected pulse include which of the following?

I. It has a greater speed than that of the incident pulse.
II. It has a greater amplitude than that of the incident pulse.
III. It is on the opposite side of the string from the incident pulse.

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

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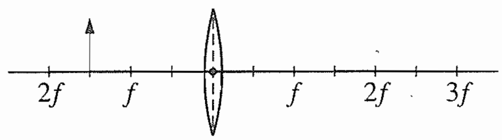
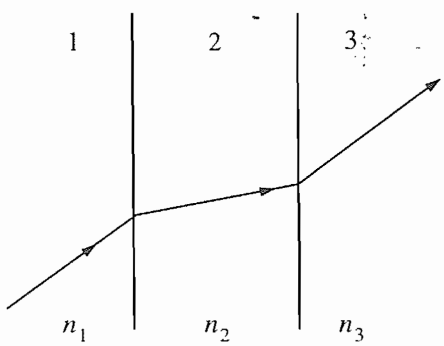


30. An object is placed at a distance of $1.5f$ from a converging lens of focal length f, as shown above. What type of image is formed and what is its size relative to the object?

	Type	Size
(A)	Virtual	Larger
(B)	Virtual	Same size
(C)	Virtual	Smaller
(D)	Real	Larger
(E)	Real	Smaller



31. A light ray passes through substances 1, 2, and 3, as shown above. The indices of refraction for these three substances are n_1, n_2, and n_3, respectively. Ray segments in 1 and in 3 are parallel. From the directions of the ray, one can conclude that

(A) n_3 must be the same as n_1
(B) n_2 must be less than n_1
(C) n_2 must be less than n_3
(D) n_1 must be equal to 1.00
(E) all three indices must be the same

32. At noon a radioactive sample decays at a rate of 4,000 counts per minute. At 12:30 P.M. the decay rate has decreased to 2,000 counts per minute. The predicted decay rate at 1:30 P.M. is

(A) 0 counts per minute
(B) 500 counts per minute
(C) 667 counts per minute
(D) 1,000 counts per minute
(E) 1,333 counts per minute

33. A negative beta particle and a gamma ray are emitted during the radioactive decay of a nucleus of $^{214}_{82}\text{Pb}$. Which of the following is the resulting nucleus?

(A) $^{210}_{80}\text{Hg}$

(B) $^{214}_{81}\text{Tl}$

(C) $^{213}_{83}\text{Bi}$

(D) $^{214}_{83}\text{Bi}$

(E) $^{218}_{84}\text{Po}$

34. If the momentum of an electron doubles, its de Broglie wavelength is multiplied by a factor of

(A) $\frac{1}{4}$

(B) $\frac{1}{2}$

(C) 1

(D) 2

(E) 4

35. Quantum concepts are critical in explaining all of the following EXCEPT

(A) Rutherford's scattering experiments
(B) Bohr's theory of the hydrogen atom
(C) Compton scattering
(D) the blackbody spectrum
(E) the photoelectric effect

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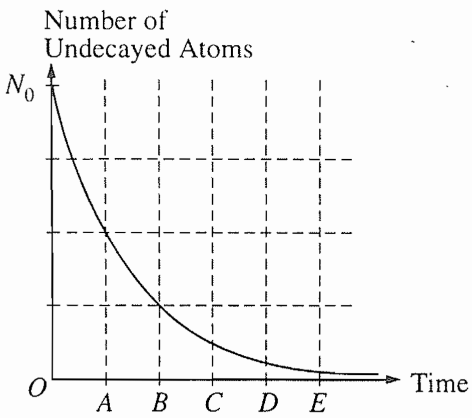


36. The graph above shows the decay of a sample of carbon 14 that initially contained N_0 atoms. Which of the lettered points on the time axis could represent the half-life of carbon 14 ?

(A) A
(B) B
(C) C
(D) D
(E) E

37. If photons of light of frequency f have momentum p, photons of light of frequency $2f$ will have a momentum of

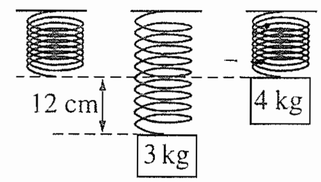
(A) $2p$

(B) $\sqrt{2}\,p$

(C) p

(D) $\frac{p}{\sqrt{2}}$

(E) $\frac{1}{2}p$



38. A block of mass 3.0 kg is hung from a spring, causing it to stretch 12 cm at equilibrium, as shown above. The 3.0 kg block is then replaced by a 4.0 kg block, and the new block is released from the position shown above, at which the spring is unstretched. How far will the 4.0 kg block fall before its direction is reversed?

(A) 9 cm
(B) 18 cm
(C) 24 cm
(D) 32 cm
(E) 48 cm

39. An object has a weight W when it is on the surface of a planet of radius R. What will be the gravitational force on the object after it has been moved to a distance of $4R$ from the center of the planet?

(A) $16W$

(B) $4W$

(C) W

(D) $\frac{1}{4}W$

(E) $\frac{1}{16}W$

40. What is the kinetic energy of a satellite of mass m that orbits the Earth, of mass M, in a circular orbit of radius R ?

(A) Zero

(B) $\frac{1}{2}\frac{GMm}{R}$

(C) $\frac{1}{4}\frac{GMm}{R}$

(D) $\frac{1}{2}\frac{GMm}{R^2}$

(E) $\frac{GMm}{R^2}$

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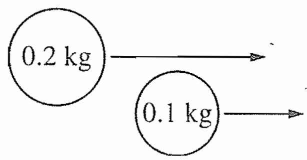
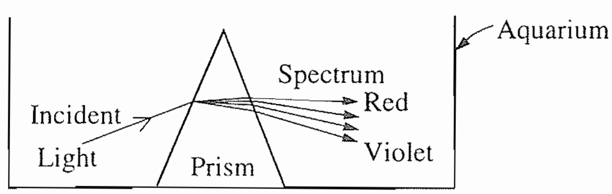


41. Two objects of mass 0.2 kg and 0.1 kg, respectively, move parallel to the x-axis, as shown above. The 0.2 kg object overtakes and collides with the 0.1 kg object. Immediately after the collision, the y-component of the velocity of the 0.2 kg object is 1 m/s upward. What is the y-component of the velocity of the 0.1 kg object immediately after the collision?

(A) 2 m/s downward
(B) 0.5 m/s downward
(C) 0 m/s
(D) 0.5 m/s upward
(E) 2 m/s upward

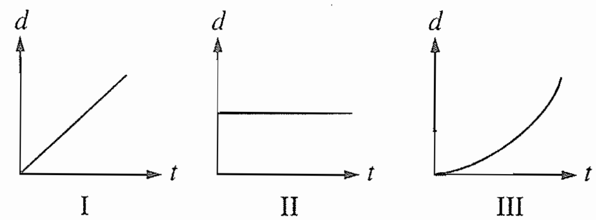


42. A beam of white light is incident on a triangular glass prism with an index of refraction of about 1.5 for visible light, producing a spectrum. Initially, the prism is in a glass aquarium filled with air, as shown above. If the aquarium is filled with water with an index of refraction of 1.3, which of the following is true?

(A) No spectrum is produced.
(B) A spectrum is produced, but the deviation of the beam is opposite to that in air.
(C) The positions of red and violet are reversed in the spectrum.
(D) The spectrum produced has greater separation between red and violet than that produced in air.
(E) The spectrum produced has less separation between red and violet than that produced in air.

Questions 43-44

Three objects can only move along a straight, level path. The graphs below show the position d of each of the objects plotted as a function of time t.



43. The magnitude of the momentum of the object is increasing in which of the cases?

(A) II only
(B) III only
(C) I and II only
(D) I and III only
(E) I, II, and III

44. The sum of the forces on the object is zero in which of the cases?

(A) II only
(B) III only
(C) I and II only
(D) I and III only
(E) I, II, and III

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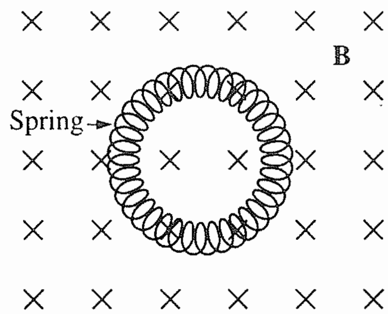

45. A metal spring has its ends attached so that it forms a circle. It is placed in a uniform magnetic field, as shown above. Which of the following will NOT cause a current to be induced in the spring?

(A) Changing the magnitude of the magnetic field
(B) Increasing the diameter of the circle by stretching the spring
(C) Rotating the spring about a diameter
(D) Moving the spring parallel to the magnetic field
(E) Moving the spring in and out of the magnetic field

Questions 46-47

A magnetic field of 0.1 T forces a proton beam of 1.5 mA to move in a circle of radius 0.1 m. The plane of the circle is perpendicular to the magnetic field.

46. Of the following, which is the best estimate of the work done by the magnetic field on the protons during one complete orbit of the circle?

(A) 0 J
(B) 10^{-22} J
(C) 10^{-5} J
(D) 10^{2} J
(E) 10^{20} J

47. Of the following, which is the best estimate of the speed of a proton in the beam as it moves in the circle?

(A) 10^{-2} m/s
(B) 10^{3} m/s
(C) 10^{6} m/s
(D) 10^{8} m/s
(E) 10^{15} m/s

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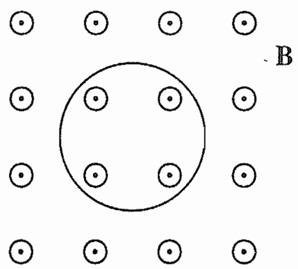
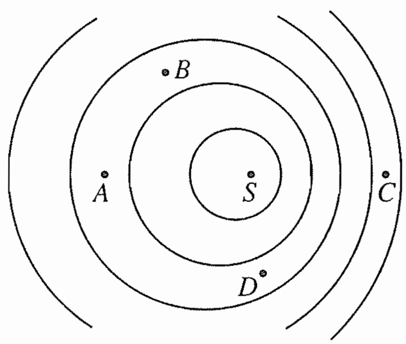


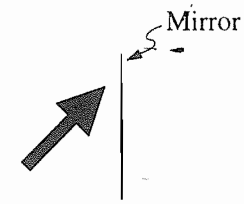
48. A single circular loop of wire in the plane of the page is perpendicular to a uniform magnetic field **B** directed out of the page, as shown above. If the magnitude of the magnetic field is decreasing, then the induced current in the wire is

(A) directed upward out of the paper
(B) directed downward into the paper
(C) clockwise around the loop
(D) counterclockwise around the loop
(E) zero (no current is induced)

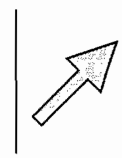


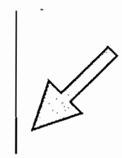
49. A small vibrating object on the surface of a ripple tank is the source of waves of frequency 20 Hz and speed 60 cm/s. If the source S is moving to the right, as shown above, with speed 20 cm/s, at which of the labeled points will the frequency measured by a stationary observer be greatest?

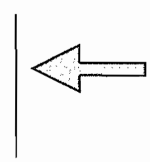
(A) A
(B) B
(C) C
(D) D
(E) It will be the same at all four points.

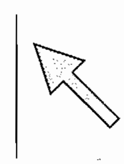


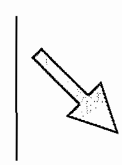
50. An object, slanted at an angle of 45°, is placed in front of a vertical plane mirror, as shown above. Which of the following shows the apparent position and orientation of the object's image?

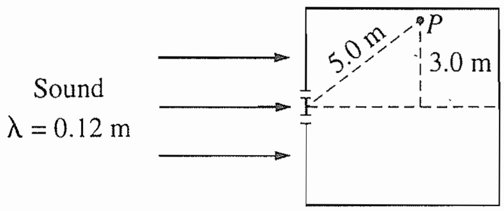
(A)


(B)


(C)


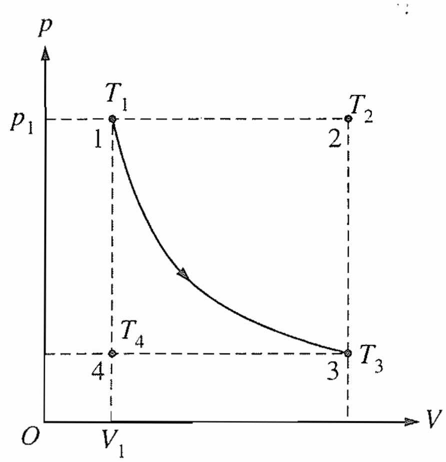
(D)


(E)




51. Plane sound waves of wavelength 0.12 m are incident on two narrow slits in a box with nonreflecting walls, as shown above. At a distance of 5.0 m from the center of the slits, a first-order maximum occurs at point P, which is 3.0 m from the central maximum. The distance between the slits is most nearly

(A) 0.07 m
(B) 0.09 m
(C) 0.16 m
(D) 0.20 m
(E) 0.24 m



52. An ideal gas is initially in a state that corresponds to point 1 on the graph above, where it has pressure p_1, volume V_1, and temperature T_1. The gas undergoes an isothermal process represented by the curve shown, which takes it to a final state 3 at temperature T_3. If T_2 and T_4 are the temperatures the gas would have at points 2 and 4, respectively, which of the following relationships is true?

(A) $T_1 < T_3$
(B) $T_1 < T_2$
(C) $T_1 < T_4$
(D) $T_1 = T_2$
(E) $T_1 = T_4$

53. The absolute temperature of a sample of monatomic ideal gas is doubled at constant volume. What effect, if any, does this have on the pressure and density of the sample of gas?

	Pressure	Density
(A)	Remains the same	Remains the same
(B)	Remains the same	Doubles
(C)	Doubles	Remains the same
(D)	Doubles	Is multiplied by a factor of 4
(E)	Is multiplied by a factor of 4	Doubles

54. The disk-shaped head of a pin is 1.0 mm in diameter. Which of the following is the best estimate of the number of atoms in the layer of atoms on the top surface of the pinhead?

(A) 10^4
(B) 10^{14}
(C) 10^{24}
(D) 10^{34}
(E) 10^{50}

55. In an experiment, light of a particular wavelength is incident on a metal surface, and electrons are emitted from the surface as a result. To produce more electrons per unit time but with less kinetic energy per electron, the experimenter should do which of the following?

(A) Increase the intensity and decrease the wavelength of the light.
(B) Increase the intensity and the wavelength of the light.
(C) Decrease the intensity and the wavelength of the light.
(D) Decrease the intensity and increase the wavelength of the light.
(E) None of the above would produce the desired result.

56. An object moves up and down the y-axis with an acceleration given as a function of time t by the expression $a = A \sin \omega t$, where A and ω are constants. What is the period of this motion?

(A) ω

(B) $2\pi\omega$

(C) $\omega^2 A$

(D) $\frac{2\pi}{\omega}$

(E) $\frac{\omega}{2\pi}$

57. A ball of mass 0.4 kg is initially at rest on the ground. It is kicked and leaves the kicker's foot with a speed of 5.0 m/s in a direction 60° above the horizontal. The magnitude of the impulse imparted by the ball to the foot is most nearly

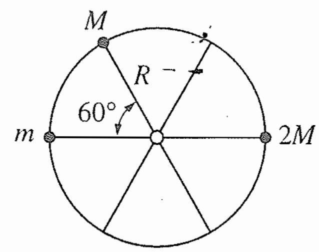
(A) 1 N·s

(B) $\sqrt{3}$ N·s

(C) 2 N·s

(D) $\frac{2}{\sqrt{3}}$ N·s

(E) 4 N·s



58. A wheel of radius R and negligible mass is mounted on a horizontal frictionless axle so that the wheel is in a vertical plane. Three small objects having masses m, M, and $2M$, respectively, are mounted on the rim of the wheel, as shown above. If the system is in static equilibrium, what is the value of m in terms of M ?

(A) $\frac{M}{2}$

(B) M

(C) $\frac{3M}{2}$

(D) $2M$

(E) $\frac{5M}{2}$

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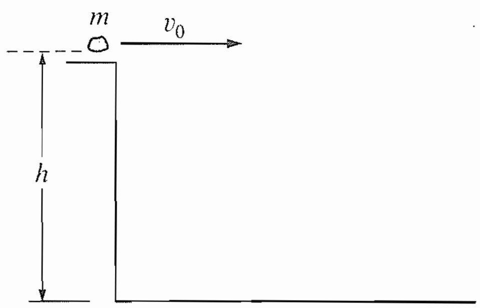
Questions 59-60



A rock of mass m is thrown horizontally off a building from a height h, as shown above. The speed of the rock as it leaves the thrower's hand at the edge of the building is v_0.

59. How much time does it take the rock to travel from the edge of the building to the ground?

(A) $\sqrt{hv_0}$

(B) h/v_0

(C) hv_0/g

(D) $2h/g$

(E) $\sqrt{2h/g}$

60. What is the kinetic energy of the rock just before it hits the ground?

(A) mgh

(B) $\frac{1}{2}mv_0^2$

(C) $\frac{1}{2}mv_0^2 - mgh$

(D) $\frac{1}{2}mv_0^2 + mgh$

(E) $mgh - \frac{1}{2}mv_0^2$

61. Which of the following statements is NOT a correct assumption of the classical model of an ideal gas?

(A) The molecules are in random motion.
(B) The volume of the molecules is negligible compared with the volume occupied by the gas.
(C) The molecules obey Newton's laws of motion.
(D) The collisions between molecules are inelastic.
(E) The only appreciable forces on the molecules are those that occur during collisions.

62. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If v_1 is the average speed of the gas molecules before the absorption of heat and v_2 is their average speed after the absorption of heat, what is the ratio v_2/v_1 ?

(A) $\frac{1}{2}$

(B) 1

(C) $\sqrt{2}$

(D) 2

(E) 4

63. Two people of unequal mass are initially standing still on ice with negligible friction. They then simultaneously push each other horizontally. Afterward, which of the following is true?

(A) The kinetic energies of the two people are equal.
(B) The speeds of the two people are equal.
(C) The momenta of the two people are of equal magnitude.
(D) The center of mass of the two-person system moves in the direction of the less massive person.
(E) The less massive person has a smaller initial acceleration than the more massive person.

64. Two parallel conducting plates, separated by a distance d, are connected to a battery of emf $\mathcal{E}$. Which of the following is correct if the plate separation is doubled while the battery remains connected?

(A) The electric charge on the plates is doubled.
(B) The electric charge on the plates is halved.
(C) The potential difference between the plates is doubled.
(D) The potential difference between the plates is halved.
(E) The capacitance is unchanged.

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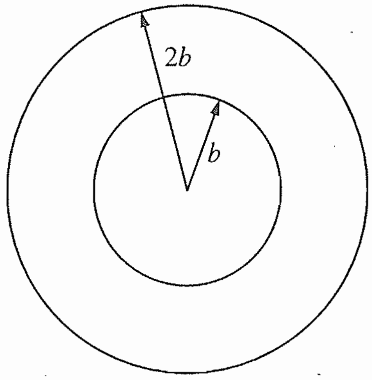
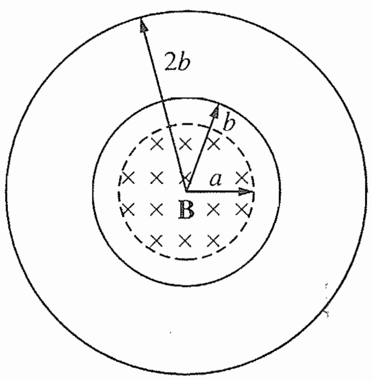
Questions 65-66



Two concentric circular loops of radii b and $2b$, made of the same type of wire, lie in the plane of the page, as shown above.

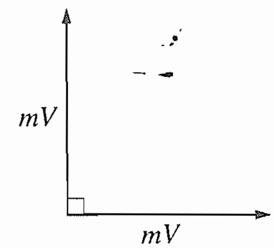
65. The total resistance of the wire loop of radius b is R. What is the resistance of the wire loop of radius $2b$?

(A) $R/4$
(B) $R/2$
(C) R
(D) $2R$
(E) $4R$



66. A uniform magnetic field **B** that is perpendicular to the plane of the page now passes through the loops, as shown above. The field is confined to a region of radius a, where $a < b$, and is changing at a constant rate. The induced emf in the wire loop of radius b is $\mathcal{E}$. What is the induced emf in the wire loop of radius $2b$?

(A) Zero
(B) $\mathcal{E}/2$
(C) $\mathcal{E}$
(D) $2\mathcal{E}$
(E) $4\mathcal{E}$



67. A stationary object explodes, breaking into three pieces of masses m, m, and $3m$. The two pieces of mass m move off at right angles to each other with the same magnitude of momentum mV, as shown in the diagram above. What are the magnitude and direction of the velocity of the piece having mass $3m$?

	Magnitude	Direction
(A)	$\frac{V}{\sqrt{3}}$	↗
(B)	$\frac{V}{\sqrt{3}}$	↙
(C)	$\frac{\sqrt{2}\,V}{3}$	↗
(D)	$\frac{\sqrt{2}\,V}{3}$	↙
(E)	$\sqrt{2}\,V$	↙

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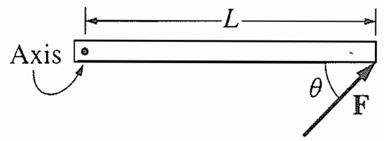


View from Above

68. A rod on a horizontal tabletop is pivoted at one end and is free to rotate without friction about a vertical axis, as shown above. A force **F** is applied at the other end, at an angle θ to the rod. If **F** were to be applied perpendicular to the rod, at what distance from the axis should it be applied in order to produce the same torque?

(A) $L \sin \theta$
(B) $L \cos \theta$
(C) L
(D) $L \tan \theta$
(E) $\sqrt{2}\, L$

69. Which of the following imposes a limit on the number of electrons in an energy state of an atom?

(A) The Heisenberg uncertainty principle
(B) The Pauli exclusion principle
(C) The Bohr model of the hydrogen atom
(D) The theory of relativity
(E) The law of conservation of energy

70. A 4 μF capacitor is charged to a potential difference of 100 V. The electrical energy stored in the capacitor is

(A) 2×10^{-10} J
(B) 2×10^{-8} J
(C) 2×10^{-6} J
(D) 2×10^{-4} J
(E) 2×10^{-2} J

S T O P

END OF SECTION I

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON THIS SECTION.

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

PHYSICS B

SECTION II

Free-Response Questions

Time—90 minutes

Required questions 1-2 on pages 4-7—15 points each

Required questions 3-8 on pages 8-19—10 points each

Percent of total grade—50

General Instructions

When you are told to begin, carefully tear out the green insert, and start work. The questions in the green insert are duplicates of those in this booklet, except that in this booklet space has been left after each part of each question for you to write your answers. The green insert may be used for reference only as you answer the free-response questions. NO CREDIT WILL BE GIVEN FOR ANYTHING WRITTEN IN THE GREEN INSERT.

A table of information and lists of equations that may be helpful are on pages 1-3 of the green insert. Show your work and write your answers to each question in the pink booklet only. Be sure to write CLEARLY and LEGIBLY. Credit for your answers depends on your demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will NOT be awarded for work that is not clearly designated as the solution to a specific part of a question. Credit for your work also depends on the quality of your solutions and explanations, so you should SHOW YOUR WORK. If you make an error, you may save time by crossing it out rather than trying to erase it. Crossed-out work will not be graded. You may lose credit for incorrect work that is not crossed out.

The College Board
Advanced Placement Examination
PHYSICS B
SECTION II

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{u} = 1.66 \times 10^{-27}$ kg
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}$ C
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol} \cdot \text{K})$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K
Speed of light,	$c = 3.00 \times 10^8$ m/s
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^{3}\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5$ Pa
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}$ J
1 angstrom,	$1\ \text{Å} = 1 \times 10^{-10}$ m

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

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	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

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. The work done by a thermodynamic system is defined as a positive quantity.

This insert may be used for reference and/or scratchwork as you answer the free-response questions, but be sure to show all your work and your answers in the pink booklet. No credit will be given for work shown on this green insert.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 1998

NEWTONIAN MECHANICS

$v = v_0 + at$

$s = s_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(s - s_0)$

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

$F_{fric} \leq \mu N$

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

$\tau = rF \sin \theta$

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

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

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

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \mathbf{s} = Fs \cos \theta$

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

$P = Fv$

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

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

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

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

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

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

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

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 = distance
s = displacement
T = period
t = time
U = potential energy
v = velocity or speed
W = work
x = displacement
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

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

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

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

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

$V = \frac{1}{4\pi\epsilon_0} \sum \frac{q}{r}$

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

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

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

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

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

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
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 1998

THERMAL PHYSICS

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

$Q = mL$

$Q = mc\Delta T$

$p = \dfrac{F}{A}$

$pV = nRT$

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

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

$W = p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q - W$

$\Delta U = nc_V \Delta T$

$e = \dfrac{W}{Q_H} = \dfrac{Q_H - Q_C}{Q_H}$

$e_C = \dfrac{T_H - T_C}{T_H}$

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molar mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred
T = temperature
U = internal energy
V = volume
v_{rms} = root-mean-square velocity
W = work done by system
α = coefficient of linear expansion
μ = mass of molecule

WAVES AND OPTICS

$v = \nu\lambda$

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

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

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

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

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

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

$d \sin\theta = m\lambda$

$x_m \approx \dfrac{m\lambda L}{d}$

d = separation
f = focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = distance
λ = wavelength
ν = frequency
θ = angle

ATOMIC AND NUCLEAR PHYSICS

$E = h\nu = pc$

$K_{max} = h\nu - \phi$

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

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

E = energy
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ν = frequency
ϕ = work function

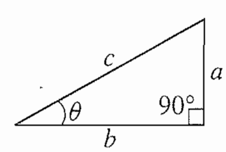
GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \dfrac{1}{2} bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \dfrac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$

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

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

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



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

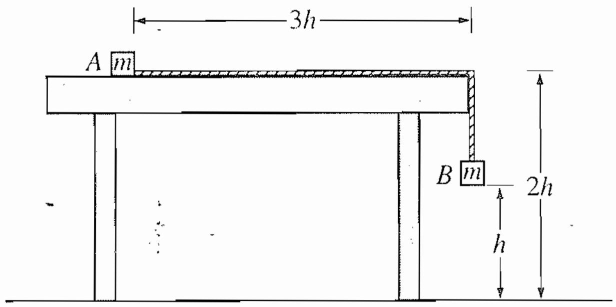
PHYSICS B

SECTION II

Time — 90 minutes

8 Questions

Directions: Answer all eight questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1 and 2, which are worth 15 points each, and about 10 minutes for answering each of questions 3-8, which are worth 10 points each. 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 green insert.



1. (15 points)
Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

(e) Determine the distance between the landing points of the two blocks.

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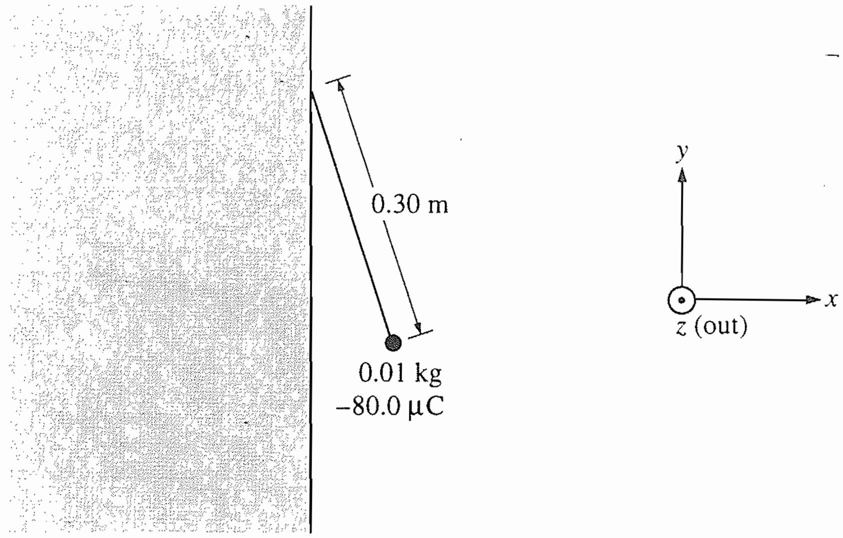
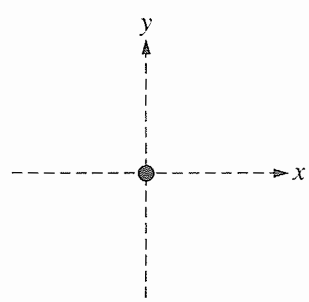


2. (15 points)
A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

(a) On the diagram below, draw and label the forces acting on the ball.



(b) Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

(c) Determine the perpendicular distance from the wall to the center of the ball.

(d) The string is now cut.

i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.

ii. Describe the resulting path of the ball.

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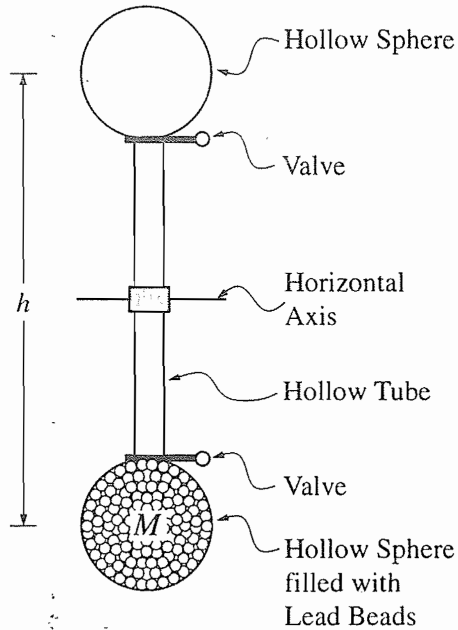

3. (10 points)
Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass M and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance h. What minimum amount of work must the student do to accomplish this?

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

GO ON TO THE NEXT PAGE

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg • K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical cumulative temperature increase after the 100 repetitions.

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

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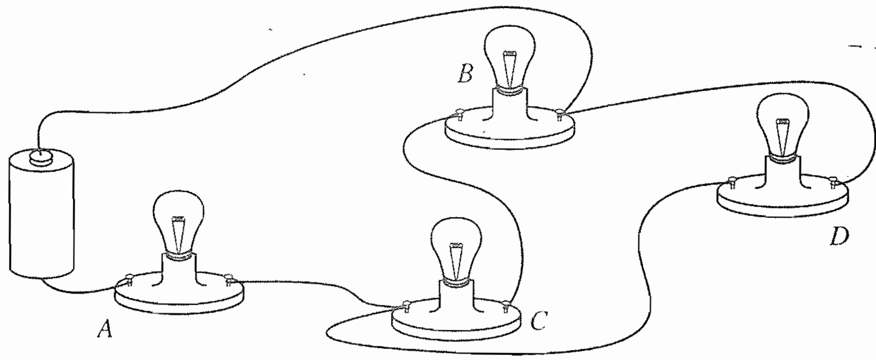
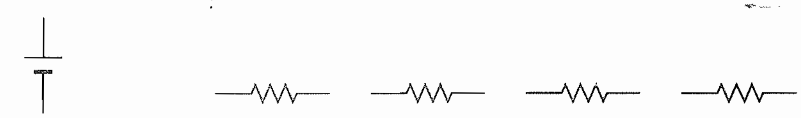


4. (10 points)
In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

(a) Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



Battery Resistors

Draw your diagram in this box only.

GO ON TO THE NEXT PAGE

(b) List the bulbs in order of their brightnesses, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.

(c) Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.

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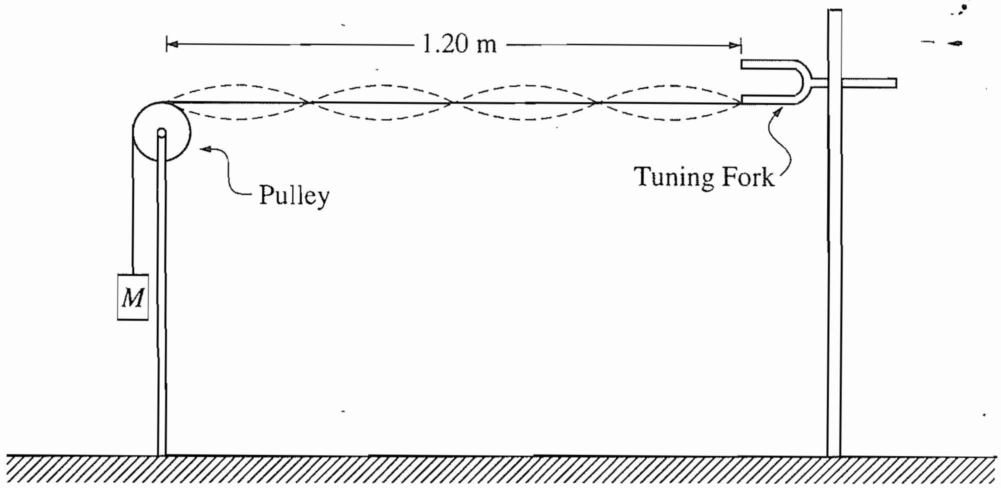

5. (10 points)
To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

(a) Determine the wavelength of the standing wave.

(b) Determine the speed of transverse waves along the string.

GO ON TO THE NEXT PAGE

(c) The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

(d) If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

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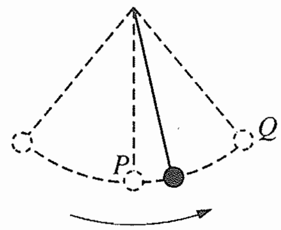
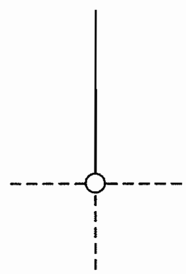


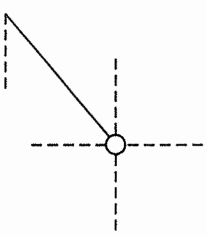
6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P

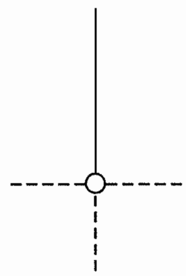


ii. Point Q

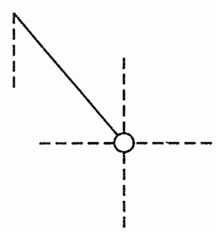


(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

i. Point P



ii. Point Q



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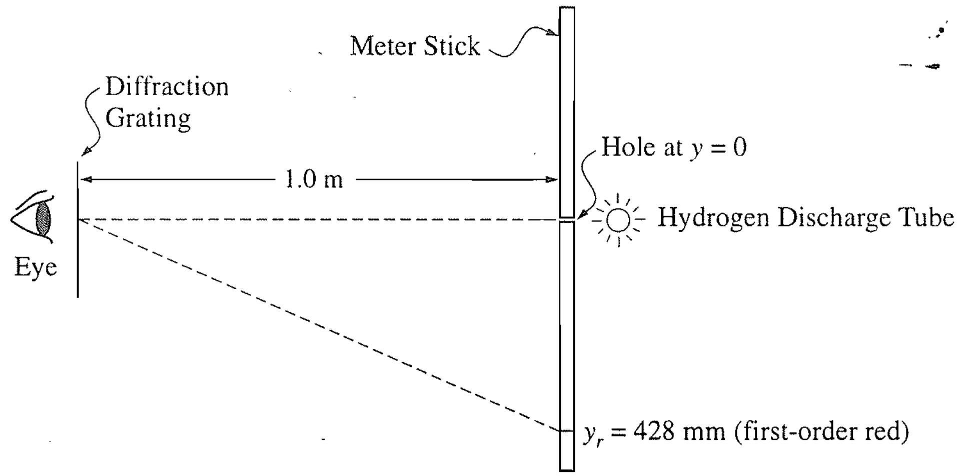

Note: Figure is drawn to scale.

7. (10 points)

A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance $y_r = 428$ mm from the hole.

(a) Calculate the wavelength of the red line in the hydrogen spectrum.

GO ON TO THE NEXT PAGE

(b) According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6\ \text{eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with $n = 2$. Use the Bohr model to determine the value of n for the initial level of the transition.

(c) Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.

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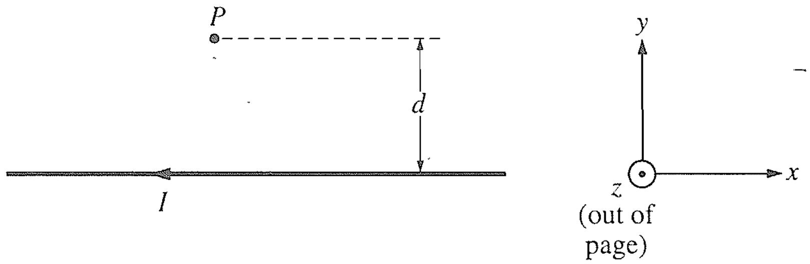

Figure 1

8. (10 points)
The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

(a) With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

A particle of mass m and positive charge q is initially moving parallel to the wire with a speed v_0 when it is at point P, as shown in Figure 2 below.

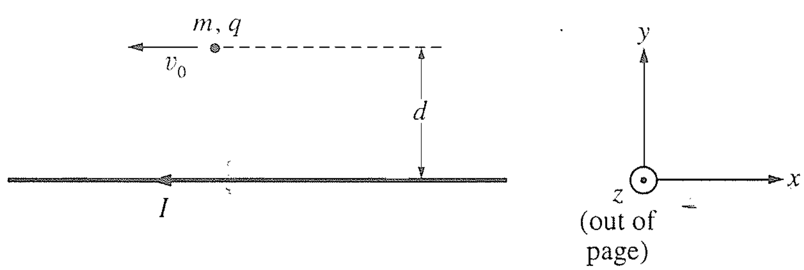

Figure 2

(b) With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?

GO ON TO THE NEXT PAGE

(c) Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.

(d) An electric field is applied that causes the net force on the particle to be zero at point P.

i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?

ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.

End of Examination

Chapter III Answers to the 1998 AP Physics B Examination

- Section I: Multiple Choice
  - Blank Answer Sheet
- Section II: Free Response

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions and the percentage of AP candidates who answered each question correctly. A copy of the blank answer sheet appears on the following pages.

Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct	Item No.	Correct Answer	Percent Correct	Item No.	Correct Answer	Percent Correct
1	B	77%	25	B	41%	48	D	39%
2	C	76%	26	B	33%	49	C	72%
3	E	70%	27	E	51%	50	D	78%
4	C	59%	28	D	43%	51	D	19%
5	C	50%	29	B	84%	52	B	45%
6	E	22%	30	D	48%	53	C	59%
7	A	71%	31	A	77%	54	B	14%
8	D	82%	32	B	84%	55	B	19%
9	A	47%	33	D	32%	56	D	38%
10	A	9%	34	B	42%	57	C	39%
11	B	59%	35	A	18%	58	C	45%
12	A	17%	36	A	79%	59	E	66%
13	A	51%	37	A	49%	60	D	30%
14	E	53%	38	D	15%	61	D	53%
15	A	66%	39	E	69%	62	C	16%
16	E	37%	40	B	23%	63	C	56%
17	C	68%	41	A	74%	64	B	24%
18	D	17%	42	E	53%	65	D	37%
19	C	32%	43	B	62%	66	C	9%
20	D	48%	44	C	53%	67	D	45%
21	A	72%	45	D	45%	68	A	50%
22	A	53%	46	A	23%	69	B	34%
23	A	59%	47	C	17%	70	E	27%
24	C	75%						

Answer Sheet for May 1998, Form 3UBP

Advanced Placement Program®
THE COLLEGE BOARD

PAGE 1

AREA 1 – COMPLETE THIS AREA AT EVERY EXAMINATION.

PLACE AP® NUMBER LABEL HERE.

A. SIGNATURE

To maintain the security of the exam and the validity of my AP grade, I will allow no one other than myself to see the multiple-choice questions and will seal the appropriate section when asked to do so. In addition, I am aware of and agree to the Program's policies and procedures as outlined in the 1998 *AP Bulletin for Students and Parents*.

Sign your name as it will appear on your college applications.

B. YOUR AP NUMBER

C. NAME Omit spaces, hyphens, apostrophes, Jr. or II.

Last Name - first 15 letters | First Name - first 12 letters | MI

D. ADMIN. DAY IN MAY

E. TIME OF DAY

- 6 AM
- 7 AM
- 8 AM
- 9 AM
- 10 AM
- 11 AM
- 12 PM
- 1 PM
- 2 PM
- 3 PM
- 4 PM
- 5 PM

F. AP EXAMINATION TO BE TAKEN USING THIS ANSWER SHEET

Print examination name:____________________

Fill in the appropriate oval below for examination name and number.

07	U.S. History	55	German Language
13	Art: History of	57	Gov. & Pol.: **U.S.**
14	Art: Studio Drawing	58	Gov. & Pol.: **Comp.**
15	Art: Studio General	59	International English Language
20	Biology	60	Latin: Vergil
25	Chemistry	60	Latin: Literature
31	Computer Science A	66	Calculus AB
33	Computer Science AB	68	Calculus BC
34	Economics: **Micro**	75	Music Theory
35	Economics: **Macro**	78	Physics B
36	Eng. Language & Comp.	80	Physics C: **Mech.**
37	Eng. Literature & Comp.	80	Physics C: **E & M**
40	Environmental Science	85	Psychology
43	European History	87	Spanish Language
48	French Language	89	Spanish Literature
51	French Literature	90	Statistics

G. What language do you know best?

- English
- English and another language about the same
- Another language

H. DO NOT COMPLETE THIS SECTION UNLESS INSTRUCTED TO DO SO.

Essay Choices
Fill in the ovals under the numbers of the essay questions you answered in this examination.

1 2 3 4 5 6 7 8 9 10 11 12

SCHOOL USE ONLY

Fee Reduction Granted | Report to Teachers Section Designation

I.N. 240045 18002 • 00657 • TF18M1300 Q2800-06 CHW97329 1 2 3 4

AREA 2 – COMPLETE THIS AREA ONLY ONCE.

I. SEX

1. Male
2. Female

J. PRESENT GRADE LEVEL

1. 9th grade
2. 10th grade
3. 11th grade
4. 12th grade
5. College
6. Other

K. DATE OF BIRTH

Month | Day | Year

01 Jan. 02 Feb. 03 Mar. 04 Apr. 05 May 06 June 07 July 08 Aug. 09 Sept. 10 Oct. 11 Nov. 12 Dec.

L. SOCIAL SECURITY NUMBER

M. ETHNIC GROUP

1. American Indian or Alaskan native
2. Black or African American
3. Mexican American or Chicano
4. Asian, Asian American, or Pacific Islander
5. Puerto Rican
6. South American, Latin American, Central American, or other Hispanic
7. White
8. Other

N. EXPECTED DATE OF COLLEGE ENTRANCE

- F Fall
- W Winter/Spring
- S Summer
- U Undecided
- 8 1998
- 9 1999
- 0 2000
- 1 2001

O. Will you be applying for Sophomore Standing at college?

Yes No

ETS USE ONLY

Exam 1 2 | Exam 1 2

P. STUDENT SEARCH SERVICE OF THE COLLEGE BOARD
(Complete ONLY if you are a SOPHOMORE or a JUNIOR.)

- Yes, I want the College Board to send information about me to colleges, universities, and governmental scholarship programs interested in students like me.
- No, I do not want the College Board to send information about me to colleges, universities, and governmental scholarship programs through the Student Search Service.

Q. THIS SECTION IS FOR THE SURVEY QUESTIONS IN THE CANDIDATE PACK. (DO NOT PUT RESPONSES TO EXAM QUESTIONS IN THIS SECTION.) BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL.

1	A	B	C	D	E	4	A	B	C	D	E
2	A	B	C	D	E	5	A	B	C	D	E
3	A	B	C	D	E						

DO NOT COMPLETE THIS SECTION UNLESS INSTRUCTED TO DO SO.

R. If this answer sheet is for the French Language, French Literature, German Language, Spanish Language, or Spanish Literature Examination, please answer the following questions. (Your responses will not affect your grade.)

1. Have you lived or studied for one month or more in a country where the language of the exam you are now taking is spoken? ◯ Yes ◯ No
2. Do you regularly speak or hear the language at home? ◯ Yes ◯ No

INDICATE YOUR ANSWERS TO THE EXAM QUESTIONS IN THIS SECTION. IF A QUESTION HAS ONLY FOUR ANSWER OPTIONS, DO NOT MARK OPTION (E). YOUR ANSWER SHEET WILL BE SCORED BY MACHINE. USE ONLY NO. 2 PENCILS TO MARK YOUR ANSWERS ON PAGES 2 AND 3 (ONE RESPONSE PER QUESTION). AFTER YOU HAVE DETERMINED YOUR RESPONSE, BE SURE TO COMPLETELY FILL IN THE OVAL CORRESPONDING TO THE NUMBER OF THE QUESTION YOU ARE ANSWERING. STRAY MARKS AND SMUDGES COULD BE READ AS ANSWERS, SO ERASE CAREFULLY AND COMPLETELY. ANY IMPROPER GRIDDING MAY AFFECT YOUR GRADE.

1	A	B	C	D	E	26	A	B	C	D	E	51	A	B	C	D	E
2	A	B	C	D	E	27	A	B	C	D	E	52	A	B	C	D	E
3	A	B	C	D	E	28	A	B	C	D	E	53	A	B	C	D	E
4	A	B	C	D	E	29	A	B	C	D	E	54	A	B	C	D	E
5	A	B	C	D	E	30	A	B	C	D	E	55	A	B	C	D	E
6	A	B	C	D	E	31	A	B	C	D	E	56	A	B	C	D	E
7	A	B	C	D	E	32	A	B	C	D	E	57	A	B	C	D	E
8	A	B	C	D	E	33	A	B	C	D	E	58	A	B	C	D	E
9	A	B	C	D	E	34	A	B	C	D	E	59	A	B	C	D	E
10	A	B	C	D	E	35	A	B	C	D	E	60	A	B	C	D	E
11	A	B	C	D	E	36	A	B	C	D	E	61	A	B	C	D	E
12	A	B	C	D	E	37	A	B	C	D	E	62	A	B	C	D	E
13	A	B	C	D	E	38	A	B	C	D	E	63	A	B	C	D	E
14	A	B	C	D	E	39	A	B	C	D	E	64	A	B	C	D	E
15	A	B	C	D	E	40	A	B	C	D	E	65	A	B	C	D	E
16	A	B	C	D	E	41	A	B	C	D	E	66	A	B	C	D	E
17	A	B	C	D	E	42	A	B	C	D	E	67	A	B	C	D	E
18	A	B	C	D	E	43	A	B	C	D	E	68	A	B	C	D	E
19	A	B	C	D	E	44	A	B	C	D	E	69	A	B	C	D	E
20	A	B	C	D	E	45	A	B	C	D	E	70	A	B	C	D	E
21	A	B	C	D	E	46	A	B	C	D	E	71	A	B	C	D	E
22	A	B	C	D	E	47	A	B	C	D	E	72	A	B	C	D	E
23	A	B	C	D	E	48	A	B	C	D	E	73	A	B	C	D	E
24	A	B	C	D	E	49	A	B	C	D	E	74	A	B	C	D	E
25	A	B	C	D	E	50	A	B	C	D	E	75	A	B	C	D	E

FOR QUESTIONS 76-151, SEE PAGE 3.

DO NOT WRITE IN THIS AREA.

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MULTIPLE-CHOICE BOOKLET SERIAL NUMBER

BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL. IF A QUESTION HAS ONLY FOUR ANSWER OPTIONS, DO NOT MARK OPTION E.

76 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	101 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	126 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
77 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	102 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	127 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
78 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	103 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	128 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
79 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	104 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	129 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
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87 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	112 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	137 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
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93 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	118 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	143 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
94 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	119 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	144 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
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98 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	123 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	148 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
99 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	124 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	149 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
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ETS USE ONLY

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PT1			
PT2			
PT3			
PT4			
TOT			
EQ			
TA1			
TA2			

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AREA 3 – COMPLETE THIS AREA ONLY ONCE.

1. YOUR MAILING ADDRESS

- YOUR GRADE REPORT WILL BE MAILED TO THIS ADDRESS IN JULY.
- USING THE ABBREVIATIONS GIVEN IN YOUR CANDIDATE PACK, FILL ADDRESS INTO BOXES PROVIDED. IF YOUR ADDRESS DOES NOT FIT, SEE ITEM 2 BELOW.
- INDICATE A SPACE IN YOUR ADDRESS BY LEAVING A BLANK BOX AND FILLING IN THE CORRESPONDING DIAMOND (◇) BELOW THE BOX.

Street

City

STATE

1	AL	28	NE
2	AK	29	NV
3	AZ	30	NH
4	AR	31	NJ
5	CA	32	NM
6	CO	33	NY
7	CT	34	NC
8	DE	35	ND
9	DC	36	OH
10	FL	37	OK
11	GA	38	OR
12	HI	39	PA
13	ID	40	RI
14	IL	41	SC
15	IN	42	SD
16	IA	43	TN
17	KS	44	TX
18	KY	45	UT
19	LA	46	VT
20	ME	47	VA
21	MD	48	WA
22	MA	49	WV
23	MI	50	WI
24	MN	51	WY
25	MS	52	Puerto Rico
26	MO		
27	MT	53	Other

ZIP OR POSTAL CODE

1a. COUNTRY CODE

3. TELEPHONE NUMBER

Area Code

2. If the address gridded above is not complete enough for delivery of your grade report, please fill in this oval → ○ and print your complete address below.

Address

Address

City

State or Province

Country

Zip or Postal Code

4. SCHOOL YOU ATTEND

School Code

School Name, City, and State

← Make sure you have correctly entered your School Code and filled in the appropriate ovals.

School Name

City

State

5. COLLEGE TO RECEIVE YOUR AP GRADES

College Code

College Name and Address

Using the College Code list in the AP Candidate Pack, indicate the one college that has *accepted you* and that *you plan to attend.*

College Name

City

State

Section II: Free Response

On the next several pages, you will find a general analysis of each question, and the students' performance on it, by the Chief Faculty Consultant. Following these are the scoring guidelines used by the faculty consultants at the AP Reading. There are also sample student responses for each question, along with comments indicating why they received the score they did. A distribution of student scores on each free-response question appears on page 217.

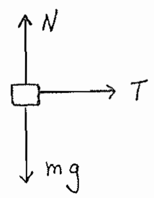
Question 1 (15 points) — Scoring Guidelines

This mechanics question uses a modification of the classic Atwood's machine arrangement of two connected masses. In a very traditional way it tests the student's understanding of Newton's laws, straight-line kinematics, and projectile motion. The different conditions before and after the hanging mass strikes the floor provide for a good test of the student's depth of understanding. The symbolic nature of the solutions provides another challenge to the less able student. Most parts of the problem could be correctly solved by more than one method. Many students were clearly not comfortable with describing physical situations verbally.

Distribution of points

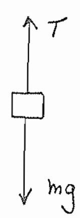
(a) 3 points

For a force diagram or a correct application of Newton's second law for block A — 1 point



OR $ma = T$

For a force diagram or a correct application of Newton's second law for block B — 1 point



OR $ma = mg - T$

Combining the two equations to eliminate T

$ma = mg - ma$

$2ma = mg$

For the correct answer — 1 point

$a = \dfrac{g}{2}$

(Alternate solution) — *(Alternate points)*

For treating the system as a one-body problem (of mass $2m$), with the proper gravitational force acting — *1 point*

For correctly applying Newton's second law — *1 point*

$2ma = mg$

For the correct answer — *1 point*

$a = \dfrac{g}{2}$

Distribution of points

Question 1 (continued)

(b) 3 points

For using the kinematic equation for distance — 1 point

$$s = s_0 + v_0 t + \frac{1}{2}at^2$$

For correctly substituting values, including the value of acceleration from part (a) — 1 point

$$h = \frac{1}{2}\left(\frac{g}{2}\right)t^2$$

For the correct answer — 1 point

$$t = 2\sqrt{\frac{h}{g}}$$

(Alternate solution) — *(Alternate points)*

For equating the work done as block B falls to the change in kinetic energy of the blocks during this time — *1 point*

$$W = \Delta K$$

$$mgh = \frac{1}{2}(2m)v^2$$

For using the kinematic equation for speed to determine the velocity of the blocks just before block B strikes the floor — *1 point*

$$v = v_0 + at$$

$$v = \frac{g}{2}t$$

Combining the two equations

$$mgh = \frac{1}{2}(2m)\left(\frac{g}{2}t\right)^2$$

$$gh = \left(\frac{g}{2}t\right)^2$$

$$\sqrt{gh} = \frac{g}{2}t$$

For the correct answer — *1 point*

$$t = 2\sqrt{\frac{h}{g}}$$

Distribution of points

Question 1 (continued)

(c) 2 points

For indicating that block A accelerates across the table — 1 point

For also having no incorrect statements about the block's motion — 1 point
(This point was only awarded if the previous point was received.)

(d) 2 points

For any indication that block A is still in motion after block B strikes the floor (e.g. referring to the block's velocity) — 1 point

For indicating that the block's velocity is constant — 1 point

One point was awarded for a statement that the velocity would decrease if friction was present

(e) 5 points

Since block B falls straight to the floor and stops, the distance between the landing points is equal to the horizontal distance of block A from the edge of the table

Determining the constant horizontal speed v at which block A travels:
For equating the work done as block B falls to the change in kinetic energy of the blocks during this time — 1 point

$W = \Delta K$

$mgh = \frac{1}{2}(2m)v^2$

For determining the velocity of the blocks just before block B strikes the floor — 1 point

$v = \sqrt{hg}$

For the correct kinematic equation for the horizontal distance x traveled by block A, with zero acceleration — 1 point

$x = vt$

Determining the time t during which block A falls:
For using the correct kinematic equation for the distance y that block A falls — 1 point

$y = y_0 + v_{0y}t + \frac{1}{2}at^2$

Question 1 (continued)

(e) (continued)

Substituting the appropriate values and solving for the time of fall

$$2h = \frac{1}{2}gt^2$$

$$t = 2\sqrt{\frac{h}{g}}$$

Substituting into the equation for x

$$x = \sqrt{hg}\left(2\sqrt{\frac{h}{g}}\right)$$

For the correct answer (consistent with values obtained for v and t) — 1 point

$x = 2h$

(Alternate solution for first two points) — *(Alternate points)*

For using the kinematic equation for speed to determine the velocity of the blocks just before block B strikes the floor — *1 point*

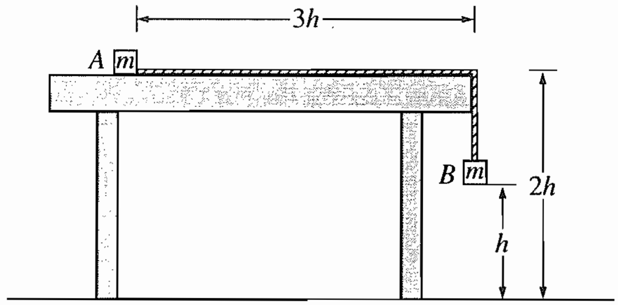
$v = v_0 + at$

Substituting the correct values

$$v = \frac{g}{2}\sqrt{\frac{2h}{g}}$$

For determining the velocity of the blocks just before block B strikes the floor — *1 point*

$v = \sqrt{hg}$



1. (15 points)
Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

$mg - T = ma$

$T = ma$

$mg - ma = ma$

$mg = 2ma$

$\frac{\cancel{m}g}{2\cancel{m}} = a$

$a = \frac{g}{2}$

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

$\Delta y = v_0 t + \frac{1}{2} a t^2$

$-h = 0 - \frac{1}{2} g t^2$

$h = \frac{1}{2} g t^2$

$2\frac{h}{g} = t^2$

$t_1 = \sqrt{\frac{2h}{g}}$

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

BLOCK A WILL MOVE FROM LEFT TO RIGHT ON THE SURFACE OF THE TABLE. THE MAGNITUDE OF ACCELERATION FOR BLOCK A WILL BE EQUAL TO THE MAGNITUDE OF ACCELERATION FOR BLOCK B $(\frac{g}{2})$.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

ONCE BLOCK B STRIKES THE FLOOR, BLOCK A WILL CEASE TO ACCELERATE. IT WILL CONTINUE AT A CONSTANT VELOCITY UNTIL IT REACHES THE END OF THE TABLE.

(e) Determine the distance between the landing points of the two blocks.

$at = v$

$\frac{g}{2}\left(\sqrt{\frac{2h}{g}}\right) = v_x$

$\Delta y = v_0 t + \frac{1}{2}at^2$

$-2h = -\frac{1}{2}gt^2$

$\frac{4h}{g} = t^2$

$t = 2\sqrt{\frac{h}{g}}$

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

$\Delta x = \left(\frac{g}{2}\sqrt{\frac{2h}{g}}\right)\left(2\sqrt{\frac{h}{g}}\right)$

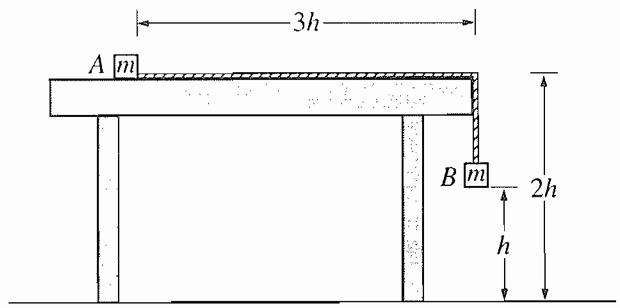
$\Delta x = \frac{\cancel{g}\sqrt{2}\sqrt{h}\,\cancel{2}\sqrt{h}}{\cancel{2}\cancel{\sqrt{g}}\cancel{\sqrt{g}}}$

$\Delta x = \sqrt{2}\,h$

$\sqrt{2}h$

Commentary:

This student does a very good job in solving the problem. The only error is in using g instead of $g/2$ in part (b). In part (e), the student uses the alternate method for determining the velocity of the blocks just before block B strikes the floor, and receives full credit for a final answer that is consistent with the incorrect time calculated in part (b).



1. (15 points)
Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

no friction, so acceleration is g, or $9.8 m/s^2$

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

$d = \frac{1}{2}at^2$

$h = \frac{1}{2}gt^2$

$t^2 = \frac{2h}{g}$

$t = \sqrt{2h/g}$

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

The block A moves h units to the right as it is pulled by the falling block, block B.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

After block B strikes the ground, block A continues to move horizontally to the right at a velocity of $g\sqrt{2h/g}$; that being the velocity of block B at time of impact.

$V = at$

$V = g\left(\sqrt{2h/g}\right)$

(e) Determine the distance between the landing points of the two blocks.

$2h = \frac{1}{2}gt^2$

$t^2 = 4h/g$

$t_A = 2\sqrt{\frac{h}{g}}$

horiz. distance

$d = v(t)$

$= g\left(\sqrt{2h/g}\right) \cdot 2\sqrt{\frac{h}{g}}$

$= \cancel{g}(2\sqrt{2}) \cdot \frac{h}{\cancel{g}}$

$= 2\sqrt{2}\,h$

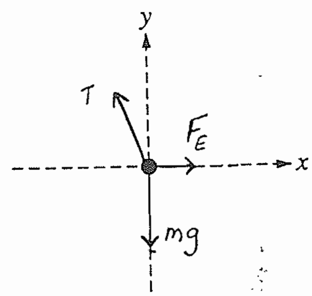
Commentary:

This student receives no credit for part (a), or for part (c). The remaining parts correctly calculate expressions based on the initial incorrect assumption about the acceleration, and thus receive full credit.

The conditions of static equilibrium and the force on a charge in an electrostatic field are examined in this question. A common mistake was to treat the electric field as one that decreased with distance from the charged wall. The physical scenario of this problem makes for a somewhat unusual situation in the last part of this problem. Constant acceleration in both the horizontal and vertical directions is seldom encountered in textbook problems. As a result the last part is an excellent test of physical understanding.

Distribution of points

(a) 3 points



One point for each correctly drawn and labeled force — 3 points

One point was deducted (up to a maximum of three points) for each extra force, for any missing arrowheads, and for any missing labels

(b) 3 points

For using the correct expression for the magnitude of the electric field (as indicated by either of the following two equations) — 1 point

$E = F/q$

$E = 0.032\ \text{N}/80.0\times10^{-6}\ \text{C}$

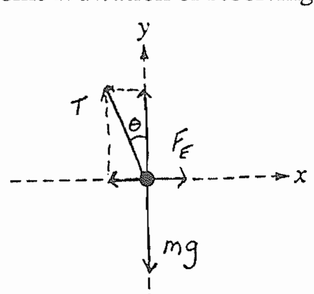
For the correct magnitude of the field — 1 point

$E = 400$ N/C

For indicating the correct direction for the field (e.g. $-x$, or to the left) — 1 point

(c) 4 points

For some indication of resolving the tension into x and y components — 1 point



For the correct force equations using these components — 1 point

$T \sin\theta = mg$

$T \cos\theta = mg$

Distribution
of points

Question 2 (continued)

(c) (continued)

Dividing these equations

$$\tan\theta = \frac{F_E}{mg}$$

For determining the value of the angle θ — 1 point

$$\tan\theta = \frac{(0.032\text{ N})}{(9.8\text{ m/s}^2)(0.01\text{ kg})}$$

$\theta = 18°$

Using trigonometry to find the perpendicular distance x from the wall

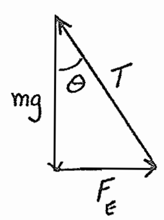
$$\sin\theta = \frac{x}{0.30\text{ m}}$$

For the correct value for x — 1 point

$x = 0.09$ m

(Alternate solution I) — *(Alternate points)*

For some indication that the three forces are in equilibrium, e.g. drawing the triangle representing the vector addition — *1 point*



For using trigonometry to find the angle θ — *1 point*

$$\tan\theta = \frac{F_E}{mg}$$

For determining the value of the angle θ — *1 point*

$$\tan\theta = \frac{(0.032\text{ N})}{(9.8\text{ m/s}^2)(0.01\text{ kg})}$$

$\theta = 18°$

Question 2 (continued)

(c) (continued)

Using trigonometry to find the perpendicular distance x from the wall

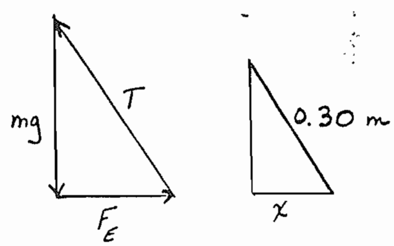
$$\sin\theta = \frac{x}{0.30\ \text{m}}$$

For the correct value for x — *1 point*

$x = 0.09\ \text{m}$

(Alternate solution II) — *(Alternate points)*

For indicating both triangles to be used in the method of similar triangles — *2 points*



Calculating the length of the hypotenuse (the tension) in the force triangle

$$T = \sqrt{(0.098\ \text{N})^2 + (0.032\ \text{N})^2} = 0.103\ \text{N}$$

For correctly setting up the proportionality between the sides of the triangles — *1 point*

$$\frac{x}{0.30\text{m}} = \frac{0.032\ \text{N}}{0.103\ \text{N}}$$

For the correct answer — *1 point*

$x = 0.09\ \text{m}$

Distribution of points

Question 2 (continued)

(d)

i. 4 points

For using Newton's law to calculate the acceleration due to the electric force — 1 point

$$a = \frac{F}{m} = \frac{0.032\,\text{N}}{0.01\,\text{kg}} = 3.2\ \text{m/s}^2$$

For vector addition of the two accelerations — 1 point

$$a^2 = \left(3.2\ \text{m/s}^2\right)^2 + \left(9.8\ \text{m/s}^2\right)^2$$

For the correct magnitude of the resultant acceleration — 1 point

$$a = 10.3\ \text{m/s}^2$$

Using trigonometry to calculate the angle θ

$$\tan\theta = \frac{\left(9.8\ \text{m/s}^2\right)}{\left(3.2\ \text{m/s}^2\right)}$$

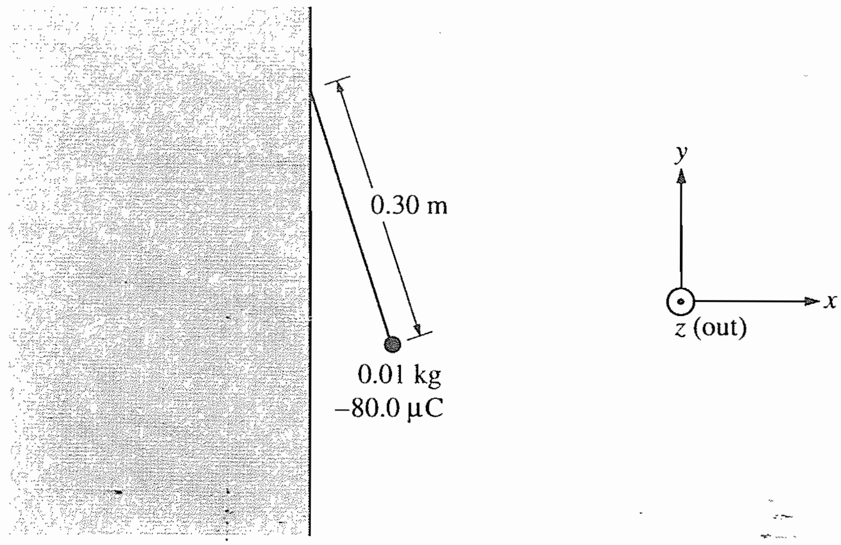
(One could also realize that the acceleration must be opposite the tension, whose angle may have been determined in part (c))

For the correct value of θ — 1 point

$\theta = 72°$ below the x-axis or $18°$ to the right of the y-axis

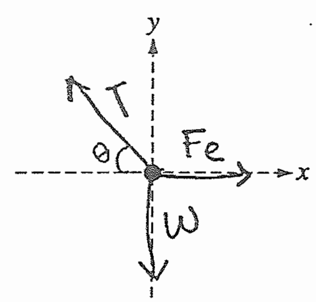
ii. 1 point

For correctly indicating that the ball moves in a straight line, down and to the right (via words or a figure), or indicating that the ball has a horizontal acceleration and a vertical acceleration due to gravity — 1 point



2. (15 points)
A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

(a) On the diagram below, draw and label the forces acting on the ball.



(b) Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

$F_e = qE$

$.032N = (-80 \times 10^{-6} C) E$

$E = -400\ N/C$

toward the left of x axis

(c) Determine the perpendicular distance from the wall to the center of the ball.

$\Sigma F_y = 0 = W - T\sin\theta = 0$

$.1N - T\sin\theta = 0$ | $.1N = T\sin\theta$

$\Sigma F_x = 0 = F_e - T\cos\theta = 0$

$.032N - T\cos\theta = 0$ | $.032N = T\cos\theta$

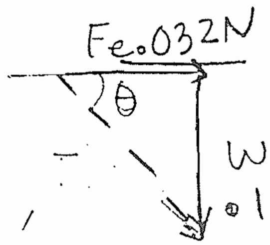
$3.125N = \tan\theta$

$\theta = 72.25°$

$\therefore S_\perp = .3m\cos(72.25°) = .09m$

(d) The string is now cut.

i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.



Fresultant ≈ .1N

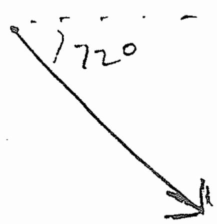
$\theta = \text{Arc}\tan\frac{.1N}{.032N} = 72.25°$

$F = ma =$

$.1N = (.01kg)a$ $a = 10m/s^2$ at $72.25°$ below x axis

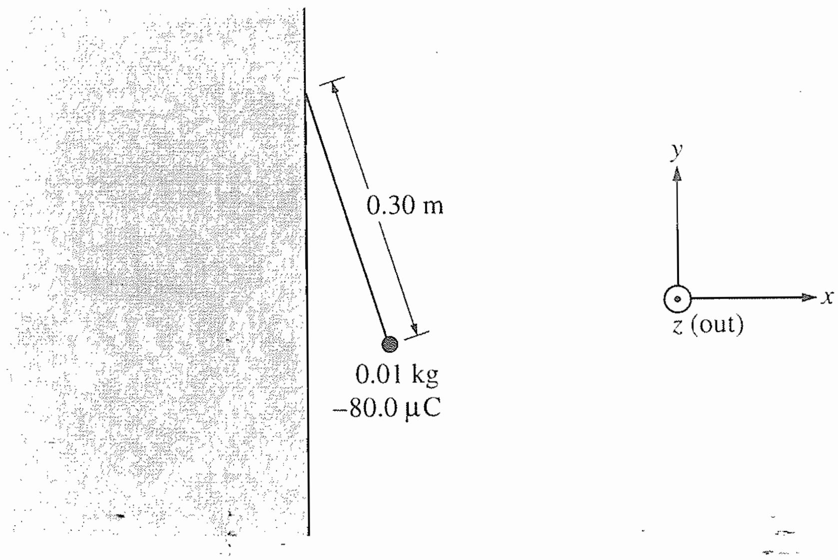
ii. Describe the resulting path of the ball.

The ball would move along a straigh path at 72.25° below x axis



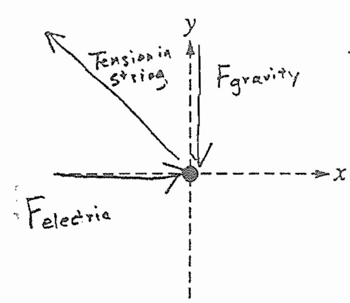
Commentary:

This student presents an extremely good solution. Note that for part (c) the student has defined θ as the larger acute angle of the triangle, so that the sine and cosine are switched when comparing these answers to the scoring guide. In part (d), the student shows an understanding of the need to add the two force vectors and then makes a reasonable approximation for the resultant force.



2. (15 points)
A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

(a) On the diagram below, draw and label the forces acting on the ball.



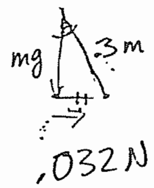
(b) Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

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

$$E = \frac{.032\,N}{(-80.0 \times 10^{-6})C}$$

$$E = -400\ N/C = 400\ N/C = \text{magnitude of } E \text{ in } y \text{ direction}$$

(c) Determine the perpendicular distance from the wall to the center of the ball.



θ

$\tan\theta = \dfrac{.032N}{(.01kg)(9.8)}$

$\theta = 18^\circ$

$\sin 18^\circ = \dfrac{x}{.3m}$

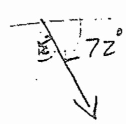
$.09\ m = x$

(d) The string is now cut.

i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.

$F = ma$

$T = ma$



$\sin 18^\circ = \dfrac{.032N}{T}$

$T_{\text{Tension}} = .0099\ N = ma$

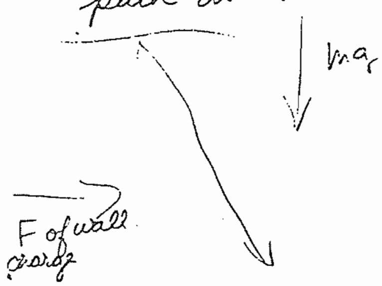
$.0099\ N = (.01)\ a$

$.99\ m/s = a$

at -72°

ii. Describe the resulting path of the ball.

it will go in a straight path at -72°



Commentary:

This student only makes two errors. The direction in part (b) is wrong. Also, an algebra error in part (d)i results in a calculation of the inverse of the tension, and thus an incorrect magnitude for the acceleration.

Question 3 (10 points) — Scoring Guidelines

This calorimetry question deals with a classic experimentally based situation, some version of which many students have probably encountered in their laboratory experience. Students are required to equate the gravitational potential energy of the lead shot to the heat gained by the shot. The last part of the question requires the student to investigate the assumptions made in the ideal treatment of the problem.

	Distribution of points
(a) 1 point	
For the correct value of work required to raise the center of mass of the lead $W = mgh$	1 point
(b) 3 points	
For a correct expression for the change in gravitational potential energy, mgh	1 point
For a correct expression for the change in thermal energy, $mc\Delta T$ This point was also awarded for using the expression $nc_V\Delta T$, but in this case the final point was <u>not</u> awarded	1 point
Equating the two energy changes $mgh = mc\Delta T$	
For the correct answer $\Delta T = \frac{gh}{c}$	1point
(c) 2 points	
For correctly substituting values in the answer to part (b) and a correct calculation	1 point
For multiplying that value by 100	1 point

$$\Delta T_{cum} = 100\frac{(9.8\ \text{m/s}^2)(2.00\ \text{m})}{128\ \text{J/kg}\bullet\text{K}}$$

$\Delta T_{cum} = 15.3\ \text{K}$ (15.6 K when using $g = 10\ \text{m/s}^2$.)

(d) 2 points

The answers to parts (b) and (c) will not change, because ΔT does not depend on the mass.

For correctly saying "no" and including a correct physical explanation	2 points

Full credit was awarded for "yes" plus an explanation if this was consistent with student's answers to (b) and (c).

Distribution of points

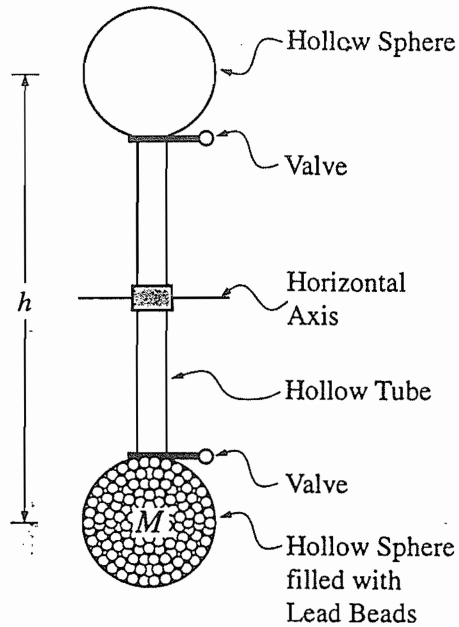
Question 3 (continued)

(e) 2 points

For any completely correct answer referring to energy transfer — 2 points
For example: There is friction between the lead and the apparatus, resulting in a loss of heat to the surroundings.

Only one point was awarded for an answer that had a correct reference to energy transfer but also had incorrect statements.

Only one point was awarded for a correct answer without elaboration, for example, "Friction", "Air resistance", or "Time elapsed"



3. (10 points)
Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass M and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance h. What minimum amount of work must the student do to accomplish this?

Student gives sphere potential energy ∴ $W = PE = Mgh$

∴ the work done is Mgh

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

$PE = Mgh$ $\quad Q = Mc\Delta T$ $\quad PE = Q$ ∴

$\cancel{M}gh = \cancel{M}c\Delta T$ $\quad gh = c\Delta T$ $\quad \Delta T = \frac{gh}{c}$

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg • K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical cumulative temperature increase after the 100 repetitions.

$\Delta T = \frac{gh}{c}$ (from part b) $\therefore$ $\Delta T = \frac{9.8 m/s^2 \cdot 2m}{128 J/kg \cdot K}$

$\Delta T = .153125 K$

$\Delta T_{cumulative} = \Delta T \cdot 100 = .153125K \cdot 100 = 15.3125 K$

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

No, they would not change

Potential Energy and the heat added are both directly proportional to the mass

$PE = Mgh = Mc\Delta T = Q$ $\quad \cancel{M}gh = \cancel{M}c\Delta T$ Any change in mass will not effect the change in Temperature

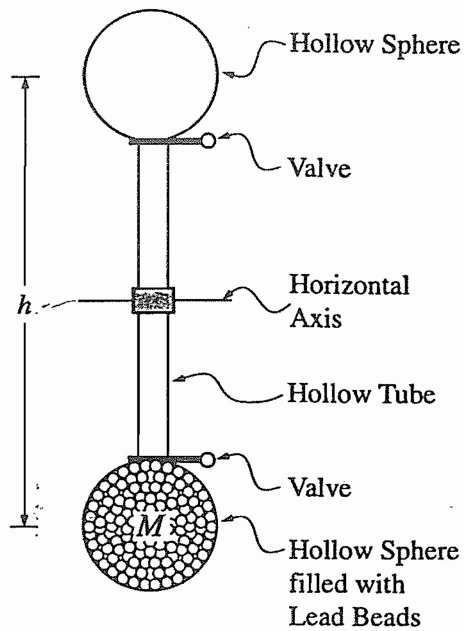
(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

Heat transfer

Heat would be transferred from the beads to the aparatus and from there to the air. Heat will then be lost

Commentary:

This student provides clear and complete answers to all parts of the problem.



3. (10 points)
Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass M and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance h. What minimum amount of work must the student do to accomplish this?

$W = F \cdot \text{distance}$

$W = Ma \cdot h \quad a = g$

$W = mgh$

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

$Q = \cancel{M} c \Delta T = \cancel{M} gh$

$\Delta T = \frac{gh}{c}$

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg · K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical cumulative temperature increase after the 100 repetitions.

$$\Delta T = \frac{(10\frac{m}{s^2})(2m)}{128} = .16°K \quad \times 100 reps = \boxed{16°K}$$

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

they would have remained the same because there would still be the same change in temperature, regardless of mass

(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

Not all of the potential energy would have been converted into thermal energy. Some may have been converted to kinetic energy, or possibly there could have been friction with the tube going down.

Commentary:

This student gets all the calculational parts correct, but has incomplete explanations for the last two parts.

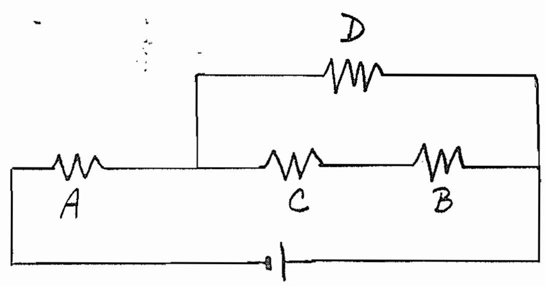
Question 4 (10 points) — Scoring Guidelines

This DC circuit question is completely qualitative, requiring no numerical calculations. To successfully complete this question the student is required to demonstrate a good understanding of Ohm's law, the electrical power's dependence on voltage and current, and the characteristics of series and parallel connections of circuit elements.

Distribution of points

(a) 3 points

Draw your diagram in this box only.



For connecting bulbs A, B, and C end to end, in the correct order	1 point
For connecting bulb D in parallel across both B and C	1 point
For connecting the battery so that current exists in all four bulbs	1 point

(b) 3 points

For indicating that bulb A is brightest, and bulb D is brighter than both bulb B and C	1 point
For indicating that bulbs B and C have the same brightness	1 point
For correct justifications	1 point

For example, bulb A has the largest current through it, making it brightest. The voltage across bulb D is the same as that across bulbs B and C combined, so it is next brightest, leaving B and C as least bright. Bulbs B and C are in series, and thus have the same current through them, so they must be equally bright.

Distribution of points

Question 4 (continued)

(c)

i. 2 points

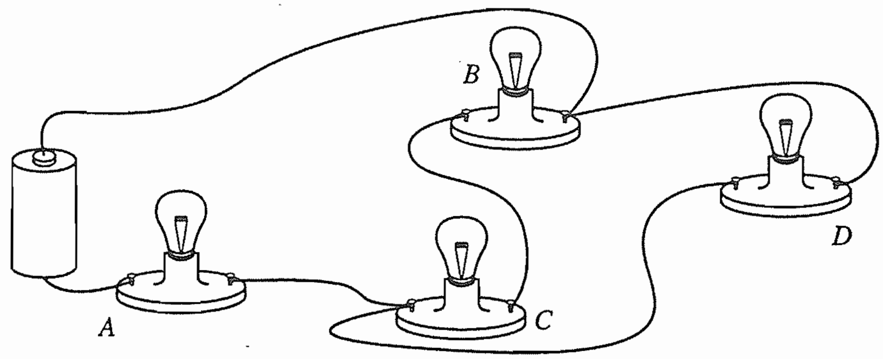
For indicating that the brightness of bulb A decreases — 1 point

For a correct justification — 1 point
For example: The total resistance of the circuit increases, so the current in bulb A decreases

ii. 2 points

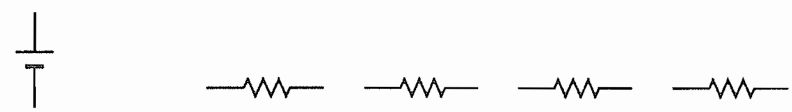
For indicating that the brightness of bulb B increases — 1 point

For a correct justification — 1 point
For example: The current in bulb B increases, or the voltage across it increases



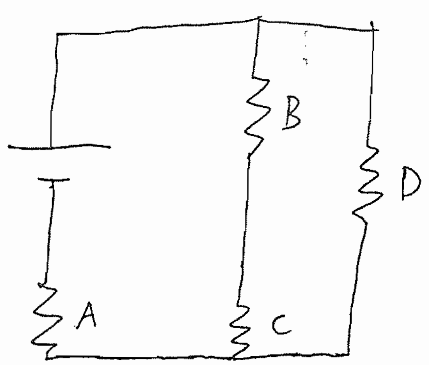
4. (10 points)
In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

(a) Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



Battery Resistors

Draw your diagram in this box only.



(b) List the bulbs in order of their brightnesses, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.

→ A is the brightest, because all of the current must flow through it.

D is in parallel with B and C.

since there is equal voltage across D and B&C, but D alone has less resistance than B and C, more current flows through D, so

→ D is the second brightest.

B and C are in series, so they have the same current. Therefore,

→ B and C are the least bright, but are equal to each other.

(c) Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

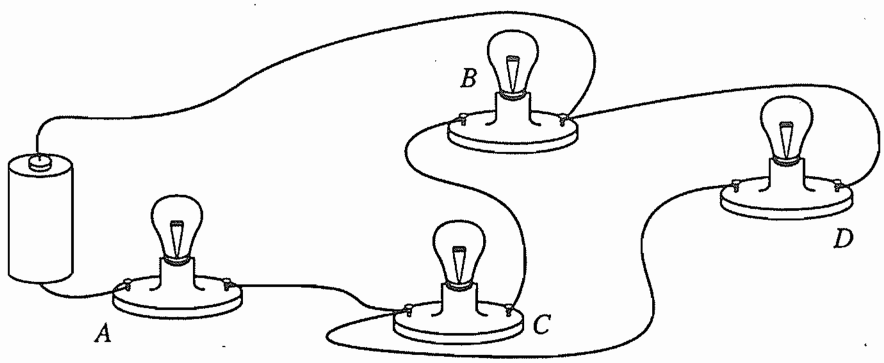
A is less bright because the overall resistance of the circuit increases, causing the current to decrease.

ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.

B is brighter because it is now in series instead of parallel, and all of the current must flow through it.

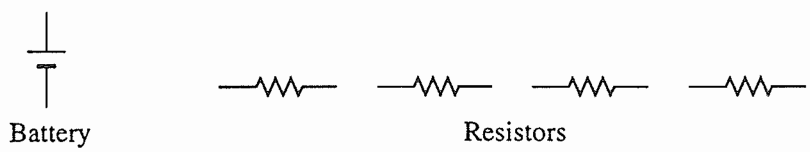
Commentary:

This student gives explanations for the correct answers that are both clear and organized. The circuit diagram is drawn such that a clear comparison with the given figure can be made.

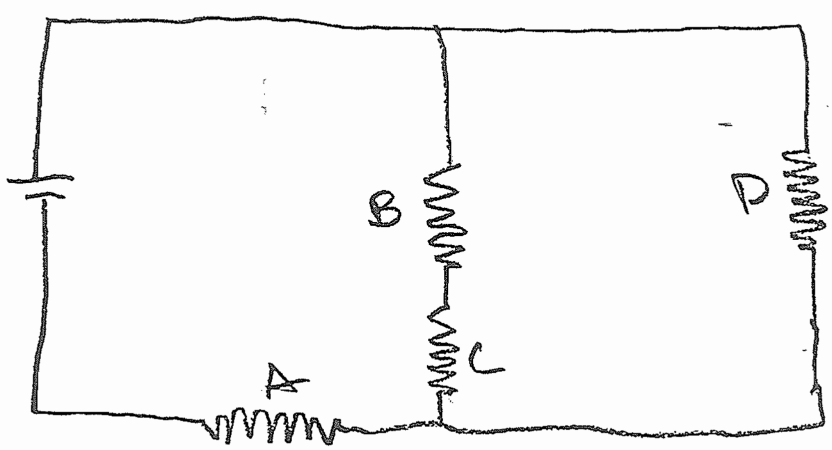


4. (10 points)
In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

(a) Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



Draw your diagram in this box only.



(b) List the bulbs in order of their brightnesses, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.

A is brightest - all of the current flows through it

D is second since more current passes through its branch of the circuit than the other because it has a smaller resistance

B and C both have the least and the same because they are in series and therefore have the same current.

(c) Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

The brightness of bulb A should not change since the same amount of current will be running through it.

ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.

bulb B will be brighter because it will get the full current through it, Not the partial one since there will be no ~~D~~ ~~to~~ draw current on an alternate path

Commentary:

This student's answers are as clear and well organized as the previous paper. However, this student misses the fact that removing bulb D affects the total current in the circuit, and gets part (c)i wrong.

Question 5 (10 points) — Scoring Guidelines

In recent years assessment of student understanding of waves has been primarily accomplished by inclusion of an optics problem involving interference of some sort. In this question the conditions for production of standing waves in a string under tension are investigated. The question is very straightforward, and most students did well on it with the exception of the last part, which required a very careful reading in order to be answered correctly. While specifically intended to see if students understood how the point corresponding to an antinode in a standing wave moved, the widespread misinterpretation of the reference to the distance moved was neither intended nor anticipated. Part (c) tested knowledge of the dependencies of the relevant variables without requiring the student to recall the equation for the velocity of a wave on a string under tension.

	Distribution of points
(a) 2 points	
Using a relationship between the wavelength λ and the length L of the string, for example the general relationship $\lambda = \frac{2L}{n}$, where n is the number of loops in the standing wave pattern, or the specific relationship for this case $2\lambda = L$ which can be developed directly from information in the question	
For correct substitution of values $\lambda = \frac{2(1.20\text{ m})}{4}$	1 point
For the correct answer $\lambda = 0.60\text{ m}$	1 point
(b) 2 points	
Using the relationship for the speed of a wave $v = \nu\lambda$	
For correct substitution of values $v = (120\text{ Hz})(0.60\text{ m})$	1 point
For the correct answer $v = 72\text{ m/s}$	1 point
(c) 3 points	
For indicating that the mass should be decreased	1 point
For any two of the statements in the following explanation, one point each ▪ The wavelength must decrease for there to be more loops on the string ▪ Given that the frequency is constant, the speed of the waves must decrease if the wavelength does ▪ This means that the tension must decrease, so the mass must be decreased	2 points

Distribution of points

Question 5 (continued)

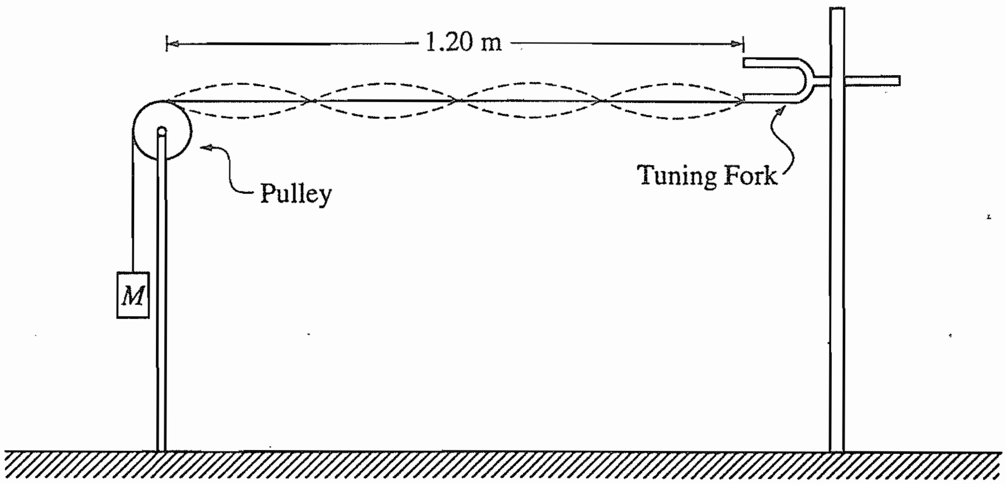
(d) 2 points

In one complete cycle, a point on the string begins at some position and travels until it returns to that position. For example, a point at an antinode that is at its highest point at the beginning of the cycle travels to its lowest point, and then back to the highest point. The amplitude of the standing wave is the distance from the center point (where the string would be straight) to one of these extremes, or one fourth the distance traveled.

For the correct answer — 2 points
Amplitude = 1 cm

One point was awarded for answering 2 cm, which is the result of interpreting "total vertical distance" as the distance between the highest and lowest points of the antinode and then correctly calculating an amplitude of 2 cm based on that interpretation.

For having all units on answers correct — 1 point



5. (10 points)
To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

(a) Determine the wavelength of the standing wave.

$$\lambda = \frac{\text{length}}{\text{\# of waves}}$$

$$\lambda = \frac{1.2\,\text{m}}{2}$$

$$\lambda = .6\,\text{m}$$

(b) Determine the speed of transverse waves along the string.

$$v = \lambda f$$

$$= (.6)(120)$$

$$= 72\,\text{m/sec}$$

(c) The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

If M is decreased! Then to keep it is equilibrium, the tension would decrease ∴ A decrease in tension would decrease the speed of the waves as stated and since frequency is constant, wave length would decrease; A decreased wavelenth means more loops in 1.2m of rope.

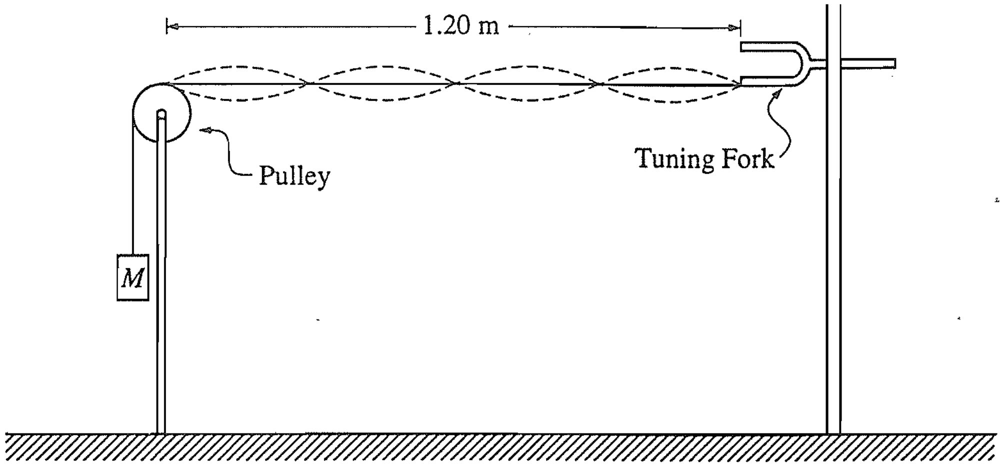
(d) If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

1cm ↑ 2cm ↓ ↑1cm = 4cm

$\boxed{\text{amplitude} = 1\text{cm}}$

Commentary:

This student gives a complete, logical explanation for part (c) that can be easily followed. The arrows drawn in part (d) indicate that the student understands the motion being described.



5. (10 points)
To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

(a) Determine the wavelength of the standing wave.

$\lambda = \frac{1.20\,m}{2\,cycles} = 0.60\,m$

(b) Determine the speed of transverse waves along the string.

$\cancel{V} = f\lambda$

$V = (120\ Hz)(0.60\,m) = 72\,m/s$

(c) The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

The value of M should be decreased to decrease the tension.

$v = f\lambda$

$\lambda = \frac{f}{v}$

$T = (M)g$

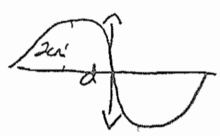
$T \propto M$

$T \propto v$

$\lambda \propto \frac{1}{v}$

(d) If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

The amplitude of the wave is 2cm.



$d = 4cm$

Commentary:

This student is missing one additional statement needed to receive full credit for part (c). Part (d) is an example of the many answers that showed an understanding of amplitude, but a misinterpretation of the description of the string's motion.

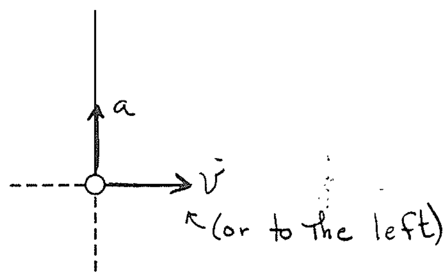
Question 6 (10 points) — Scoring Guidelines

This question deals with the variation of the velocity and acceleration of a mass on the end of a string as it swings as a pendulum. While requiring no numerical calculation, this question proved difficult for many students. It is an excellent test of physical understanding. Performance on this question indicates that many students are not yet comfortable with giving accurate verbal descriptions of a physical phenomenon. A common mistake was to interchange the correct motions in parts (b)-i and (b)-ii, revealing a persisting Aristotelian conception of motion.

Distribution of points

(a)

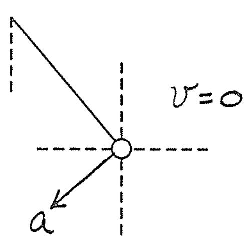
i. 2 points



For a correctly drawn velocity vector, directed along the horizontal line, either to the right or the left	1 point
For the correctly drawn acceleration vector, directed upward along the string	1 point

Vectors must be labeled, and have an arrowhead to show their direction

ii. 3 points



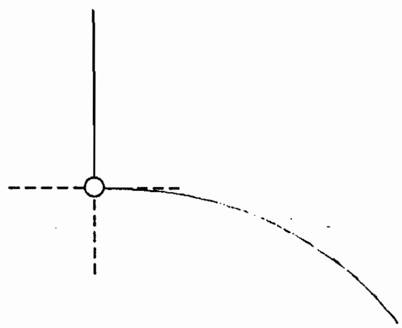
For indicating that the velocity is zero	1 point
For the correctly drawn acceleration vector, pointing down and to the left, perpendicular to the string	2 points

One of these points was awarded if the vector was in the proper quadrant, not perpendicular to the string, and not on either the vertical or horizontal lines

Distribution
of points

Question 6 (continued)

(b)
i. 3 points



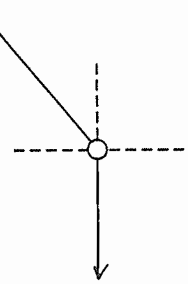
(A path drawn to the left is also correct)

For indicating that the path is initially horizontal (via figure or words)	1 point
For indicating that the horizontal velocity is constant	1 point
For indicating that the vertical motion is under constant acceleration or free-fall	1 point

The last two points were also awarded for describing the path as a parabola, or indicating that the ball is a projectile

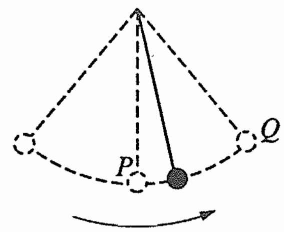
A maximum of 2 points were awarded for a correct figure with no description or a correct description with no path drawn on the figure

ii. 2 points



For correctly indicating that the ball falls straight down	1 point
For indicating that the vertical motion is under constant acceleration or free-fall	1 point

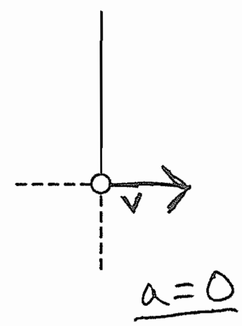
A maximum of 1 point was awarded for a correct figure with no description or a correct description with no path drawn on the figure



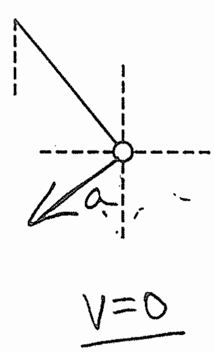
6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P

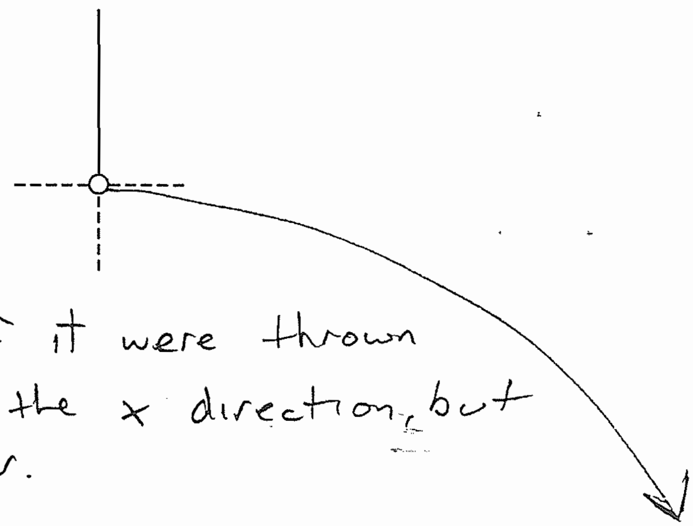


ii. Point Q



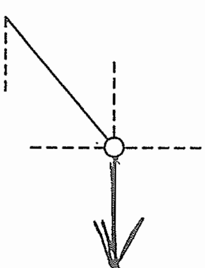
(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

i. Point P



The ball would act as if it were thrown right at a certain velocity in the x direction, but no initial velocity in the y-dir.

ii. Point Q

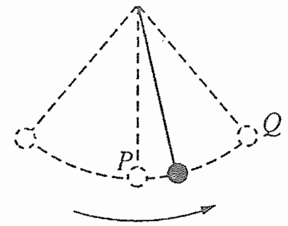


The ball would fall straight down, because at this point its velocity is 0, and its acceleration is ↓, due only to gravity.

Commentary:

Given the correct acceleration vector in (a)ii and the error in (a)i, this student may be thinking only of tangential acceleration. The explanation in (b)i qualifies as describing the ball as a projectile.

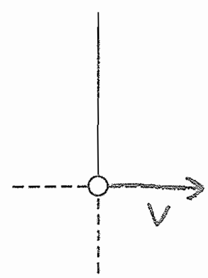
Good Student Response: 7 points



6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

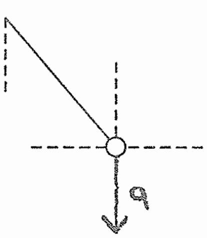
(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P



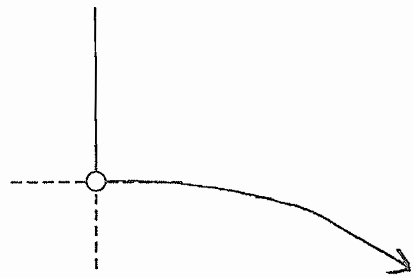
ii. Point Q

Velocity=0



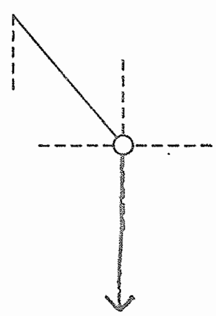
(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

i. Point P



The ball will travel in a parabolic downward arc due to its velocity and the acceleration of gravity.

ii. Point Q



The ball has no velocity, so it will merely fall straight down due to gravity.

Commentary:

This student appears to be treating both cases the same, as if the string breaks, and thus receives only two points for part (a). However, part (b) receives full credit.

Question 7 (10 points) — Scoring Guidelines

This question examines understanding of both diffraction by a grating and the hydrogen spectrum, using an arrangement that is more typically found in a laboratory situation than in a textbook problem. To correctly answer the first part of the problem the student must use the equation giving the locations of the maxima produced by a diffraction grating. The small angle approximation that is heavily emphasized in textbook examples is not applicable under the conditions of this problem. The mean score on this question was the lowest on the exam, no doubt due in part to the somewhat unusual nature of the problem and in part to the inclusion of some atomic physics, which many students have not covered.

	Distribution of points
(a) 4 points	
Using the expression for the location of lines in the diffraction pattern $d \sin\theta = m\lambda$	
For using the correct value for d $$d = \frac{1}{600 \text{ lines/mm}} = 1.67\times10^{-6} \text{ m}$$	1 point
For finding the value of θ, the angle between the two dashed lines in the figure $$\tan\theta = \frac{y}{L} = \frac{428 \text{ mm}}{1.0 \text{ m}}$$ $\theta = 23°$	1 point
For correct substitutions into the first equation $$\left(1.67\times10^{-6} \text{ m}\right)\sin 23° = (1)\lambda$$	1 point
For the correct answer $\lambda = 657 \text{ nm}$ or $6.57\times10^{-7} \text{ m}$	1 point
If the small angle approximation was used ($\sin\theta \approx \tan\theta$, resulting in an answer of 713 nm), the point for finding the angle was <u>not</u> awarded	
(b) 4 points	
For using the correct equation(s) relating energy and wavelength $$E = \frac{hc}{\lambda} \quad \text{OR} \quad E = h\nu \text{ and } c = \nu\lambda$$	1 point
Substituting $$E = \frac{\left(1.24\times10^{3} \text{ eV}\bullet\text{nm}\right)}{657 \text{ nm}} \quad \text{OR} \quad E = \frac{\left(1.99\times10^{-25} \text{ J}\bullet\text{m}\right)}{657 \text{ nm}}$$	
For the correct photon energy $E = 1.89 \text{ eV}$ OR 3.03×10^{-19} J. Credit was also awarded for an energy consistent with a wrong answer for part (a), for example, using 713 nm and obtaining 1.74 eV or 2.79×10^{-19} J	1 point

Distribution of points

Question 7 (continued)

(b) (continued)

For some indication that this photon energy is the difference between two energy levels — 1 point
For example, a statement on conservation of energy, an energy level diagram, a statement saying the photon energy is the energy released when an electron drops to a lower energy level, or an equation involving the appropriate energies

Using the energy-level equation

$$E = E_n - E_2$$

$$1.89 \text{ eV} = (-13.6 \text{ eV})\left(\frac{1}{n^2} - \frac{1}{2^2}\right)$$

$$-0.14 = \left(\frac{1}{n^2} - \frac{1}{4}\right)$$

$$0.11 = \frac{1}{n^2}$$

$$n^2 = 9.1$$

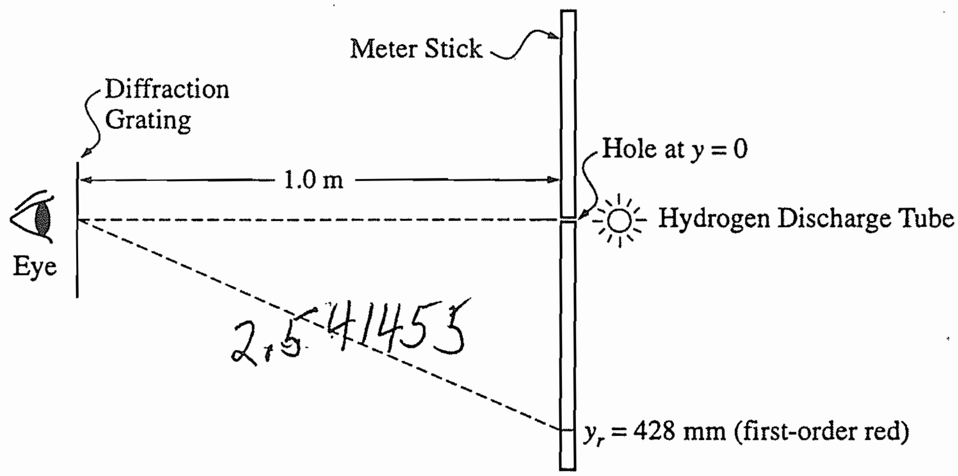
For the correct answer — 1 point
$n = 3$

Full credit was earned using 713 nm (resulting in $n = 2.86$) if the student realized that n must be an integer and indicated $n = 3$

Three points were awarded for an answer of $n = 3$ with no work shown

(c) 2 points

For any reasonable indication that the line would move farther away from the principal axis — 2 points



Note: Figure is drawn to scale.

7. (10 points)
A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance y_r = 428 mm from the hole.

(a) Calculate the wavelength of the red line in the hydrogen spectrum.

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

$$\lambda = \frac{1}{600}\,\text{mm}\ \sin\left(\tan^{-1} .428\right)$$

$$6.56 \times 10^{-7}\ \text{m}$$

(b) According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6 \text{ eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with $n = 2$. Use the Bohr model to determine the value of n for the initial level of the transition.

$f\lambda = c$

$n = 3$

$f = \frac{c}{\lambda}$

$E = fh = \frac{ch}{\lambda}$

$$\frac{ch}{\lambda} = \frac{13.6\text{eV}}{4} - \frac{13.6\text{eV}}{n^2}$$

$$1.89\text{ eV} = 13.6\text{eV}\left(\frac{1}{4} - \frac{1}{n^2}\right)$$

$$.13897 = \frac{1}{4} - \frac{1}{n^2}$$

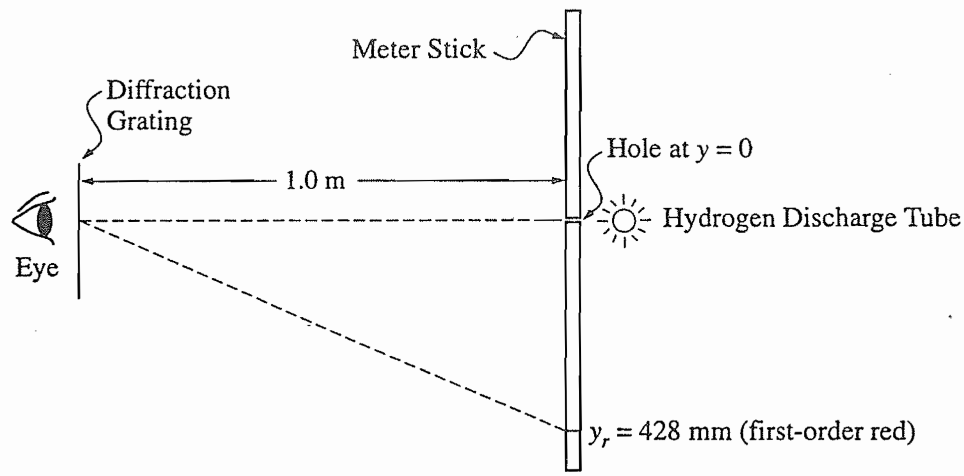
(c) Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.

If the lines were closer together $\sin\theta$ would need to be bigger to keep $d\sin\theta$ constant. Thus, the first-order red line would be farther than .142m from the source

Commentary:

This student packs a lot of physics and geometry into deriving the second line of part (a) from the initial equation. The remaining parts are clear and organized.

Very Good Student Response: 8 points



Note: Figure is drawn to scale.

7. (10 points)
A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance $y_r = 428$ mm from the hole.

(a) Calculate the wavelength of the red line in the hydrogen spectrum.

$$X_m = \frac{m \lambda L}{d}$$

$$428 \text{ mm} = \frac{(1)(\lambda)(1000 \text{ mm})}{.00167 \text{ mm}}$$

$$\lambda = \left(\frac{(428)(.00167)}{1000} \right) \text{mm}$$

$$\lambda = 7.1333 \times 10^{-4} \text{ mm} \quad \frac{10^{-3} \text{ m}}{1 \text{ mm}}$$

$$\boxed{\lambda = 7.1333 \times 10^{-7} \text{ m}}$$

(b) According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6 \text{ eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with $n = 2$. Use the Bohr model to determine the value of n for the initial level of the transition.

$n = 2.79$ ——— 1.738 eV

$n = 2$ ——— -3.4 eV

$E_2 = \frac{-13.6 \text{ ev}}{(2)^2}$

$E_2 = -3.4$ eV

$n = 1$ ——— -13.6 ev

$E_x = \frac{hc}{\lambda} = \frac{-13.6}{x^2}$

$hcx^2 = (-13.6)(713 \text{ nm})$

$x^2 = 7.82$

$x = \pm 2.79$

$\boxed{n = 3}$

(c) Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.

The location of the red line would be farther from ($y = 0$) because the distance between slits would be smaller and $\left(x_m = \frac{m\lambda L}{d}\right)$ would produce a larger x_m.

shown: $x_m = \frac{(1)(7.133 \times 10^{-4} \text{ mm})(1000 \text{ mm})}{(.00125 \text{ mm})}$

$x_m = 570.64$ mm (farther away)

Commentary:

This student uses the small angle approximation in part (a). In part (b), there is no clear indication that the student realizes that a difference in energy levels is required.

Question 8 (10 points) — Scoring Guidelines

Each part of this question is individually straightforward, but the student is required to use understanding of a number of topics to successfully complete the entire question. The question deals with the production of a magnetic field by a long straight wire, magnetic forces on moving electric charges, and the electrostatic force on an electric charge. An important part of a complete solution to the problem also requires the student to understand the relationships between the directions of the various forces and fields.

	Distribution of points
(a) 2 points	
For indicating that the magnetic field is along the z axis, or indicating that the right-hand rule applies	1 point
For indicating the correct direction along the z axis (e.g. $-z$, or into the page)	1 point
(b) 2 points	
For indicating that the magnetic force is along the y axis, or indicating that the right-hand rule applies	1 point
For indicating the correct direction along the y axis (e.g. $-y$, down, toward wire)	1 point
Full credit was awarded for an answer that was consistent with the answer to part (a) according to the right-hand rule	
(c) 3 points	
For using the appropriate equation for the magnetic force $F = qvB \sin\theta$	1 point
For using the appropriate equation for the magnetic field $B = \dfrac{\mu_0 I}{2\pi r}$ or $\dfrac{2k'I}{r}$	1 point
For the correct answer (which must have the substitutions $\sin\theta = 1$ and $r = d$) $F = \dfrac{q v_0 \mu_0 I}{2\pi d}$ or $\dfrac{2k' q v_0 I}{d}$	1 point
Two points were awarded if one of the equations for F or B was incorrect, but the above substitutions were made.	

Distribution of points

Question 8 (continued)

(d)

i. 1 point

For indicating that the electric field is in the $+y$-direction (e.g. up, opposite the magnetic force) — 1 point

Full credit was awarded for an answer that was consistent with the answer to part (b)

ii. 2 points

For any indication that the electric and magnetic forces are equal and opposite — 1 point

$$F_E = F_B$$
$$qE = qvB$$
$$qE = \frac{qv_0\mu_0 I}{2\pi d}$$

For the correct answer — 1 point

$$E = \frac{v_0\mu_0 I}{2\pi d}$$

Excellent Student Response: 10 points

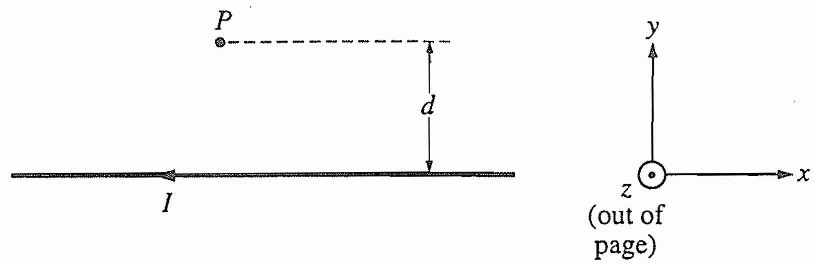


Figure 1

8. (10 points)
The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

(a) With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

Due to the current in the wire, the magnetic field at point P will be pointing into the paper. (Right-hand Rule)

A particle of mass m and positive charge q is initially moving parallel to the wire with a speed v_0 when it is at point P, as shown in Figure 2 below.

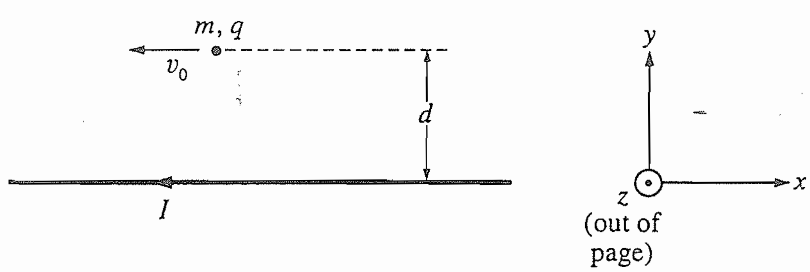


Figure 2

(b) With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?

The magnetice force acting on the particle at point P is towarding down to the botton of the page. (Right-hand Rule)

(c) Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.

The magnetic force acting on the particle at point P is given by

$F_B = qVB\sin\theta$

and since, the particle has charge q and speed V_0, the θ between magnetic field and its v direction is $90°$.

$\therefore F_B = qV_0B$.

and $B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} I}{2\pi d} = 2\times10^{-7}\frac{I}{d}$.

$\therefore F_B = qV_0B = qV_0\left(2\times10^{-7}\frac{I}{d}\right)$

$= \frac{2\times10^{-7} qV_0 I}{d}$

(d) An electric field is applied that causes the net force on the particle to be zero at point P.

i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?

The direction of electric field should be towarding up to the top of the page, so the magnetic force and electric force would cancel out, and net force become zero.

ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.

Since $|F_e| = |F_B|$

$\therefore F_e = \frac{2\times10^{-7} qV_0 I}{d}$

and since $E = \frac{F}{q}$, and charge of the particle is q.

$\therefore E = \frac{\frac{2\times10^{-7} qV_0 I}{d}}{q}$

$= \frac{2\times10^{-7} qV_0 I}{d \cdot q}$

$= \frac{2\times10^{-7} V_0 I}{d}$.

$\therefore$ The magnitude of the electric field is $\frac{2\times10^{-7} V_0 I}{d}$.

Commentary:

This is an exemplary solution. Note that the student substituted the values of the constants in the answers to parts (c) and (d)ii.

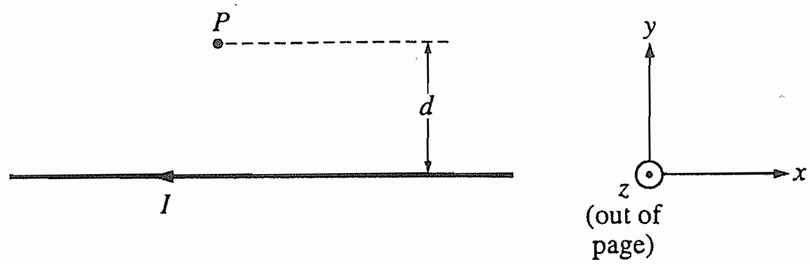


Figure 1

8. (10 points)
The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

(a) With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

Using Right-Hand Rule
The magnetic field at P is
directed along Z axis into page.

A particle of mass m and positive charge q is initially moving parallel to the wire with a speed v_0 when it is at point P, as shown in Figure 2 below.

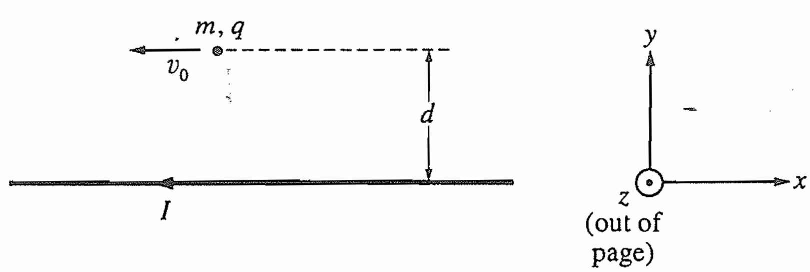


Figure 2

(b) With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?

Using Right-Hand Rule,
the magnetic force is along
y-axis, downward.

(c) Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.

$$F = qvB\sin\theta$$

$$\theta = 90^\circ$$

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

$$F = \frac{qv\mu_0 I}{2\pi d}$$

(d) An electric field is applied that causes the net force on the particle to be zero at point P.

i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?

The electric field is directed ~~and~~ along y-axis, upward.

ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.

$$F = \frac{kq}{r}$$

$$F = \frac{kq}{d}$$

Commentary:

This student's responses are correct until the last part, where the student tries to start with an expression for electric force that is incorrect.

Table 4.2 — Scoring Worksheet — AP Physics B

Section I: Multiple Choice

[______ − (1/4 × ______)] × 1.2857 = ______ = ______

Number correct (out of 70) — Number wrong — Multiple-Choice Score (Do not round. If less than zero, enter zero.) — Weighted Section I Score

Section II: Free Response

Question 1	______ (out of 15)	× 1.000 =	______
Question 2	______ (out of 15)	× 1.000 =	______
Question 3	______ (out of 10)	× 1.000 =	______
Question 4	______ (out of 10)	× 1.000 =	______
Question 5	______ (out of 10)	× 1.000 =	______
Question 6	______ (out of 10)	× 1.000 =	______
Question 7	______ (out of 10)	× 1.000 =	______
Question 8	______ (out of 10)	× 1.000 =	______

Sum = ______

Weighted Section II Score

Composite Score

______ + ______ = ______

Weighted Section I Score — Weighted Section II Score — Composite Score (Round to nearest whole number.)

AP Grade Conversion Chart Physics B

Composite Score Range*	AP Grade
106-180	5
83-105	4
54-82	3
40-53	2
0-39	1

*The candidates' scores are weighted according to formulas determined in advance each year by the Development Committee to yield raw composite scores; the Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.