The College Board
Advanced Placement Examination
PHYSICS C
SECTION II

TABLE OF INFORMATION

1 atomic mass unit,	$1\ u = 1.66 \times 10^{-27}$ kilogram
Rest mass of the proton,	$m_p = 1.67 \times 10^{-27}$ kilogram
Rest mass of the neutron,	$m_n = 1.67 \times 10^{-27}$ kilogram
Rest mass of the electron,	$m_e = 9.11 \times 10^{-31}$ kilogram
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}$ coulomb
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ per mole
Universal gas constant,	$R = 8.32$ joules/(mole · K)
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ joule/K
Speed of light,	$c = 3.00 \times 10^{8}$ meters/second
Planck's constant,	$h = 6.63 \times 10^{-34}$ joule · second $= 4.14 \times 10^{-15}$ eV · second
	$hc = 1.99 \times 10^{-25}$ joule · meter $= 1240$ eV · nanometers
1 electron volt,	$1\ eV = 1.60 \times 10^{-19}$ joule
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ coulomb^2/(newton · meter^2)
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ newtons · meter^2/coulomb^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ weber/(ampere · meter)
Magnetic constant,	$k' = k/c^2 = \mu_0/4\pi = 10^{-7}$ weber/(ampere · meter)
Acceleration due to gravity at the Earth's surface,	$g = 9.8$ meters/second^2
Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ meter^3/(kilogram · second^2)
1 atmosphere pressure,	$1\ atm = 1.0 \times 10^{5}$ newtons/meter^2 $= 1.0 \times 10^{5}$ pascals (Pa)
1 angstrom,	$1\ Å = 1 \times 10^{-10}$ meter
1 tesla,	$1\ T = 1$ weber/meter^2

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.

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.

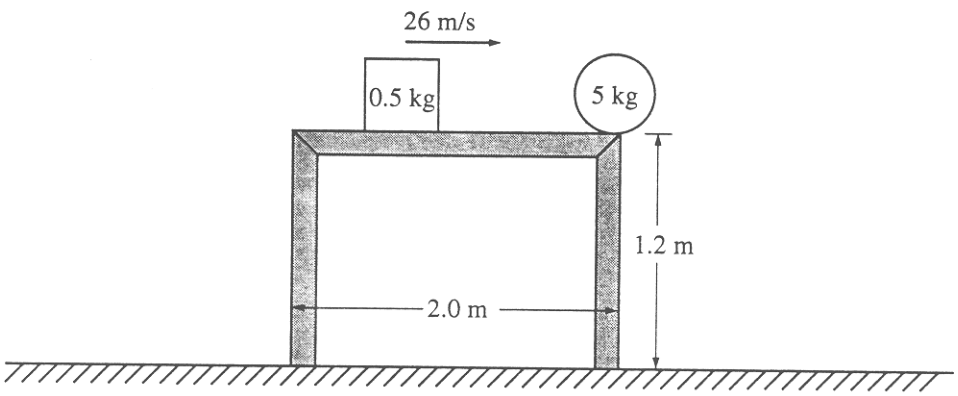
PHYSICS C

SECTION II, MECHANICS

Time—45 minutes

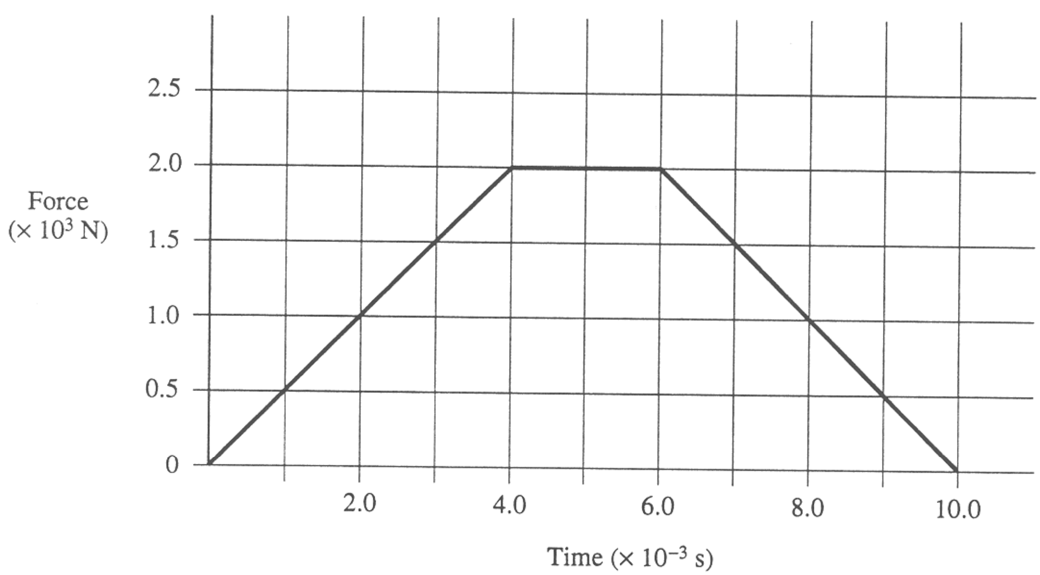
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



Note: Figure not drawn to scale.

Mech. 1. A 5-kilogram ball initially rests at the edge of a 2-meter-long, 1.2-meter-high frictionless table, as shown above. A hard plastic cube of mass 0.5 kilogram slides across the table at a speed of 26 meters per second and strikes the ball, causing the ball to leave the table in the direction in which the cube was moving. The figure below shows a graph of the force exerted on the ball by the cube as a function of time.



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(a) Determine the total impulse given to the ball.

(b) Determine the horizontal velocity of the ball immediately after the collision.

(c) Determine the following for the cube immediately after the collision.

i. Its speed

ii. Its direction of travel (right or left), if moving

(d) Determine the kinetic energy dissipated in the collision.

(e) Determine the distance between the two points of impact of the objects with the floor.

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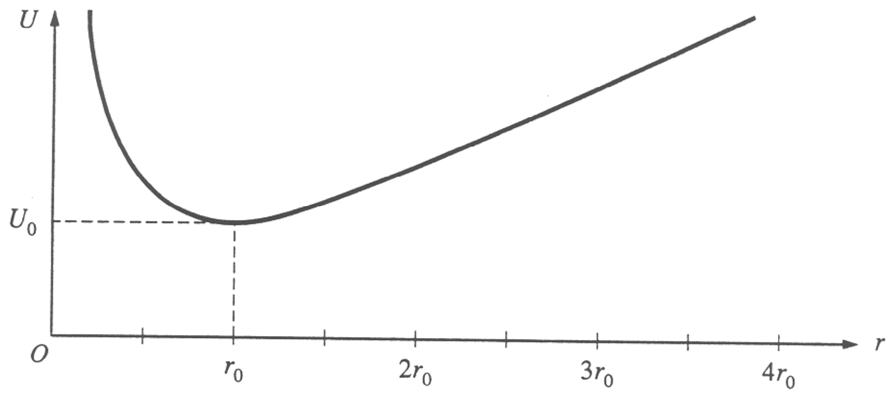
Mech. 2. A particle of mass m moves in a conservative force field described by the potential energy function $U(r) = a(r/b + b/r)$, where a and b are positive constants and r is the distance from the origin. The graph of $U(r)$ has the following shape.

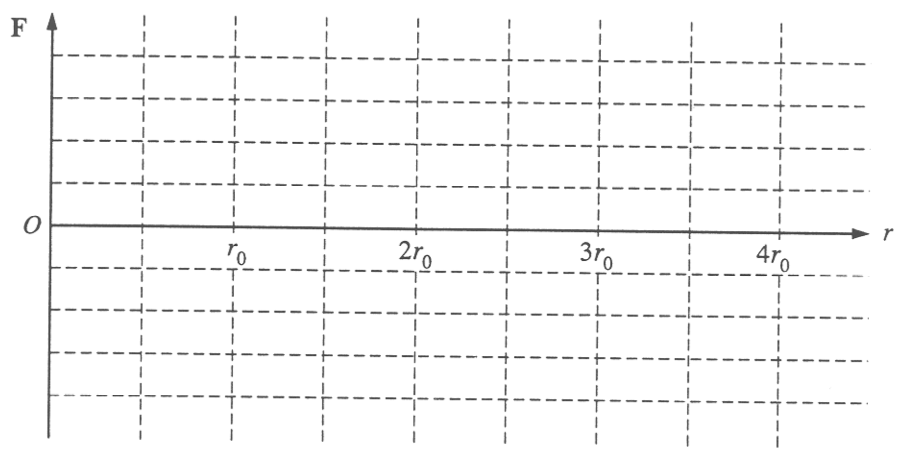


(a) In terms of the constants a and b, determine the following.

i. The position r_0 at which the potential energy is a minimum

ii. The minimum potential energy U_0

(b) Sketch the net force on the particle as a function of r on the graph below, considering a force directed away from the origin to be positive, and a force directed toward the origin to be negative.



The particle is released from rest at $r = r_0/2$.

(c) In terms of U_0 and m, determine the speed of the particle when it is at $r = r_0$.

(d) Write the equation or equations that could be used to determine where, if ever, the particle will again come to rest. It is not necessary to solve for this position.

(e) Briefly and qualitatively describe the motion of the particle over a long period of time.

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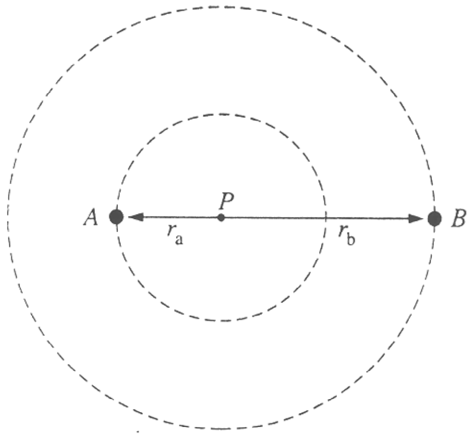


Mech 3. Two stars, A and B, are in circular orbits of radii r_a and r_b, respectively, about their common center of mass at point P, as shown above. Each star has the same period of revolution T.

Determine expressions for the following three quantities in terms of r_a, r_b, T, and fundamental constants.

(a) The centripetal acceleration of star A

(b) The mass M_b of star B

(c) The mass M_a of star A

Determine expressions for the following two quantities in terms of M_a, M_b, r_a, r_b, T, and fundamental constants.

(d) The moment of inertia of the two-star system about its center of mass

(e) The angular momentum of the system about the center of mass

STOP

END OF SECTION II, MECHANICS

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION II, MECHANICS, ONLY. DO NOT TURN TO ANY OTHER TEST MATERIALS.

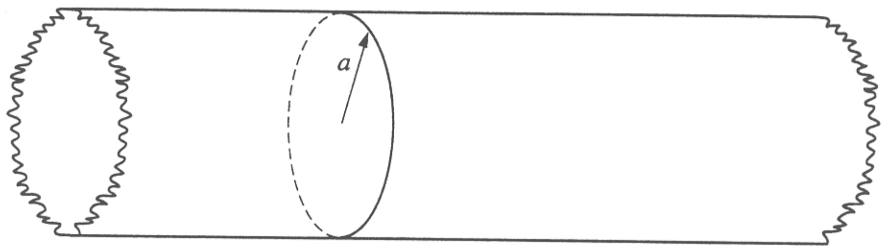
PHYSICS C

SECTION II, ELECTRICITY AND MAGNETISM

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.

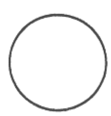


E & M 1. A very long nonconducting rod of radius a has positive charge distributed throughout its volume. The charge distribution is cyclindrically symmetric, and the total charge per unit length of the rod is λ .

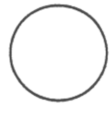
(a) Use Gauss's law to derive an expression for the magnitude of the electric field E outside the rod.

(b) The diagrams below represent cross sections of the rod. On these diagrams, sketch the following.

i. Several equipotential lines in the region $r > a$



ii. Several electric field lines in the region $r > a$



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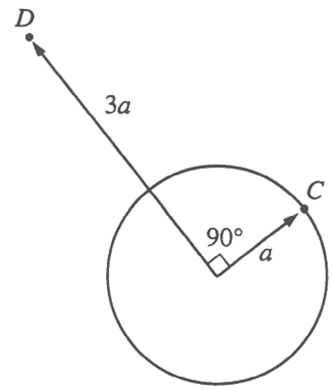


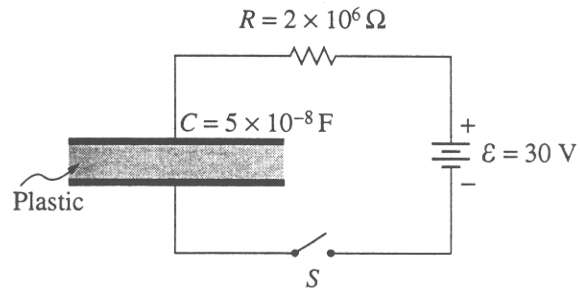
(c) In the diagram above, point C is a distance a from the center of the rod (i.e., on the rod's surface), and point D is a distance $3a$ from the center on a radius that is 90° from point C. Determine the following.

i. The potential difference $V_C - V_D$ between points C and D

ii. The work required by an external agent to move a charge $+Q$ from rest at point D to rest at point C

Inside the rod $(r < a)$, the charge density ρ is a function of radial distance r from the axis of the rod and is given by $\rho = \rho_0 (r/a)^{1/2}$, where ρ_0 is a constant.

(d) Determine the magnitude of the electric field E as a function of r for $r < a$. Express your answer in terms of ρ_0, a, and fundamental constants.



E & M 2. A parallel-plate capacitor is made from two sheets of metal, each with an area of 1.0 square meter, separated by a sheet of plastic 1.0 millimeter (10^{-3} m) thick, as shown above. The capacitance is measured to be 0.05 microfarad (5×10^{-8} F) .

(a) What is the dielectric constant of the plastic?

(b) The uncharged capacitor is connected in series with a resistor $R = 2 \times 10^6$ ohms, a 30-volt battery, and an open switch S, as shown above. The switch is then closed.

i. What is the initial charging current when the switch S is closed?

ii. What is the time constant for this circuit?

iii. Determine the magnitude and sign of the final charge on the bottom plate of the fully charged capacitor.

iv. How much electrical energy is stored in the fully charged capacitor?

After the capacitor is fully charged, it is carefully disconnected, leaving the charged capacitor isolated in space. The plastic sheet is then removed from between the metal plates. The metal plates retain their original separation of 1.0 millimeter.

(c) What is the new voltage across the plates?

(d) If there is now more energy stored in the capacitor, where did it come from? If there is now less energy, what happened to it?

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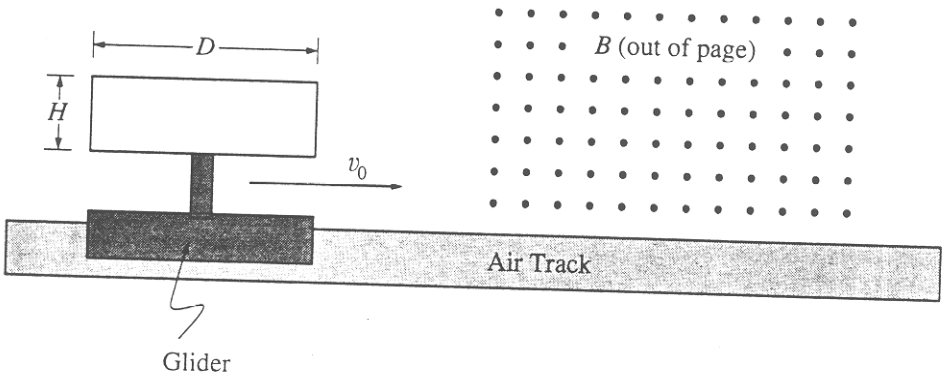


E & M 3. The long, narrow rectangular loop of wire shown above has vertical height H, length D, and resistance R. The loop is mounted on an insulated stand attached to a glider, which moves on a frictionless horizontal air track with an initial speed of v_0 to the right. The loop and glider have a combined mass m. The loop enters a long, narrow region of uniform magnetic field B directed out of the page toward the reader. Express your answers to the parts below in terms of B, D, H, R, m, and v_0.

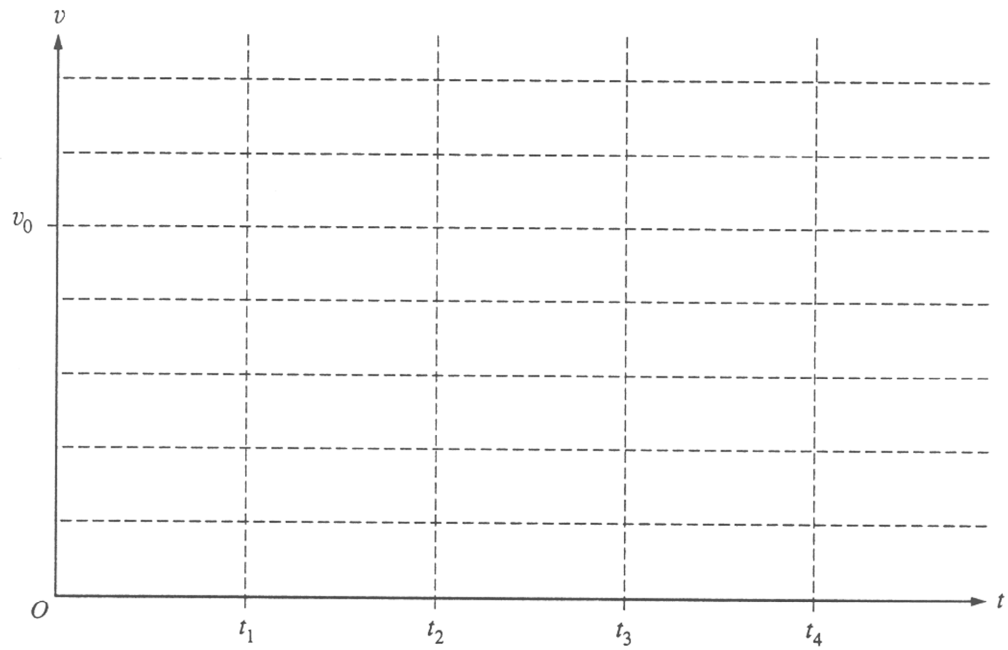
(a) What is the magnitude of the initial induced emf in the loop as the front end of the loop begins to enter the region containing the field?

(b) What is the magnitude of the initial induced current in the loop?

(c) State whether the initial induced current in the loop is clockwise or counterclockwise around the loop.

(d) Derive an expression for the velocity of the glider as a function of time t for the interval after the front edge of the loop has entered the magnetic field but before the rear edge has entered the field.

(e) Using the axes below, sketch qualitatively a graph of speed v versus time t for the glider. The front end of the loop enters the field at $t = 0$. At t_1 the back end has entered and the loop is completely inside the field. At t_2 the loop begins to come out of the field. At t_3 it is completely out of the field. Continue the graph until t_4, a short time after the loop is completely out of the field. These times may not be shown to scale on the t-axis below.



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END OF SECTION II, ELECTRICITY AND MAGNETISM

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