PHYSICS C

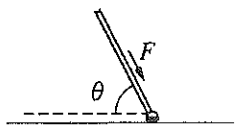
SECTION I, MECHANICS

Time—45 minutes

35 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 force F is exerted by a broom handle on the head of the broom, which has a mass m. The handle is at an angle θ to the horizontal, as shown above. The work done by the force on the head of the broom as it moves a distance d across a horizontal floor is

   (A) $Fd \sin \theta$
   (B) $Fd \cos \theta$
   (C) $Fm \cos \theta$
   (D) $Fm \tan \theta$
   (E) $Fmd \sin \theta$

2. The velocity of a projectile at launch has a horizontal component v_h and a vertical component v_v. Air resistance is negligible. When the projectile is at the highest point of its trajectory, which of the following show the vertical and horizontal components of its velocity and the vertical component of its acceleration?

	Vertical Velocity	Horizontal Velocity	Vertical Acceleration
(A)	v_v	v_h	0
(B)	v_v	0	0
(C)	0	v_h	0
(D)	0	0	g
(E)	0	v_h	g

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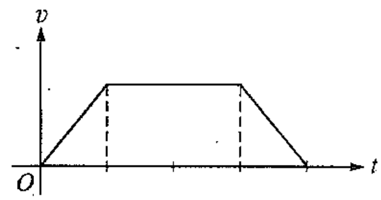
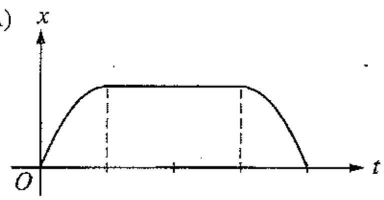
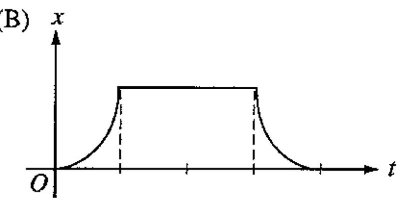


3. The graph above shows the velocity v as a function of time t for an object moving in a straight line. Which of the following graphs shows the corresponding displacement x as a function of time t for the same time interval?

(A)



(B)



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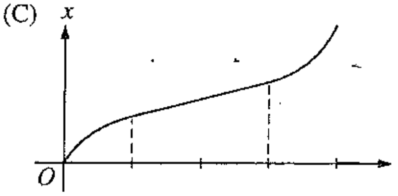
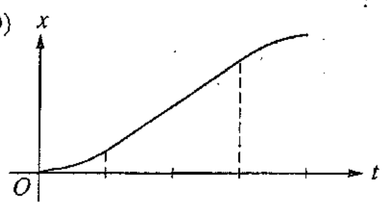
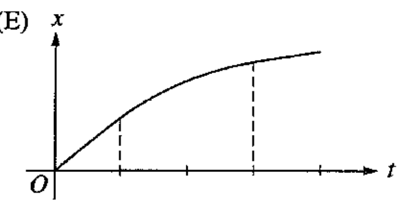


(D)



(E)



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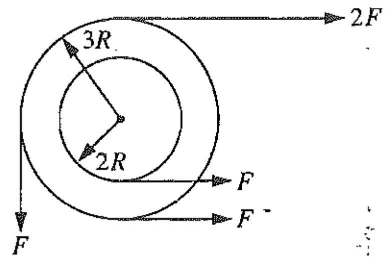
4. The position of a toy locomotive moving on a straight track along the x-axis is given by the equation $x = t^3 - 6t^2 + 9t$, where x is in meters and t is in seconds. The net force on the locomotive is equal to zero when t is equal to

   (A) zero
   (B) 2 s
   (C) 3 s
   (D) 4 s
   (E) 5 s



5. A system of two wheels fixed to each other is free to rotate about a frictionless axis through the common center of the wheels and perpendicular to the page. Four forces are exerted tangentially to the rims of the wheels, as shown above. The magnitude of the net torque on the system about the axis is

   (A) zero
   (B) FR
   (C) $2FR$
   (D) $5FR$
   (E) $14FR$

6. A wheel of mass M and radius R rolls on a level surface without slipping. If the angular velocity of the wheel is ω, what is its linear momentum?

   (A) $M\omega R$
   (B) $M\omega^2 R$
   (C) $M\omega R^2$
   (D) $\frac{M\omega^2 R^2}{2}$
   (E) Zero

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Questions 7-8 refer to a ball that is tossed straight up from the surface of a small, spherical asteroid with no atmosphere. The ball rises to a height equal to the asteroid's radius and then falls straight down toward the surface of the asteroid.

7. What forces, if any, act on the ball while it is on the way up?
   (A) Only a decreasing gravitational force that acts downward
   (B) Only an increasing gravitational force that acts downward
   (C) Only a constant gravitational force that acts downward
   (D) Both a constant gravitational force that acts downward and a decreasing force that acts upward
   (E) No forces act on the ball.

8. The acceleration of the ball at the top of its path is
   (A) at its maximum value for the ball's flight
   (B) equal to the acceleration at the surface of the asteroid
   (C) equal to one-half the acceleration at the surface of the asteroid
   (D) equal to one-fourth the acceleration at the surface of the asteroid
   (E) zero

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9. The equation of motion of a simple harmonic oscillator is $\frac{d^2x}{dt^2} = -9x$, where x is displacement and t is time. The period of oscillation is
   (A) 6π
   (B) $\frac{9}{2\pi}$
   (C) $\frac{3}{2\pi}$
   (D) $\frac{2\pi}{3}$
   (E) $\frac{2\pi}{9}$

10. A pendulum with a period of 1 s on Earth, where the acceleration due to gravity is g, is taken to another planet, where its period is 2 s. The acceleration due to gravity on the other planet is most nearly
    (A) $g/4$
    (B) $g/2$
    (C) g
    (D) $2g$
    (E) $4g$

11. A satellite of mass M moves in a circular orbit of radius R with constant speed v. True statements about this satellite include which of the following?
    I. Its angular speed is v/R.
    II. Its tangential acceleration is zero.
    III. The magnitude of its centripetal acceleration is constant.

    (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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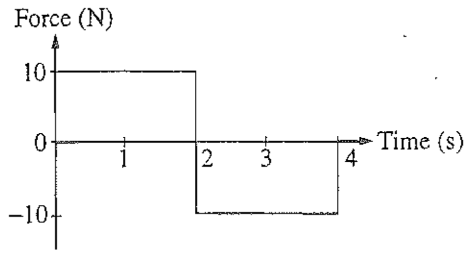
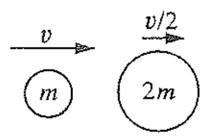


12. The graph above shows the force on an object of mass M as a function of time. For the time interval 0 to 4 s, the total change in the momentum of the object is

(A) 40 kg·m/s
(B) 20 kg·m/s
(C) 0 kg·m/s
(D) –20 kg·m/s
(E) indeterminable unless the mass M of the object is known

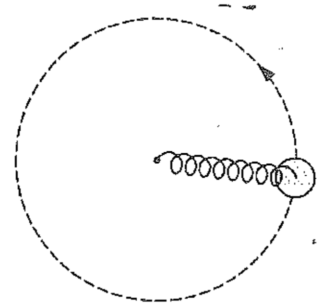


Top View

13. As shown in the top view above, a disc of mass m is moving horizontally to the right with speed v on a table with negligible friction when it collides with a second disc of mass $2m$. The second disc is moving horizontally to the right with speed $\frac{v}{2}$ at the moment of impact. The two discs stick together upon impact. The speed of the composite body immediately after the collision is

(A) $\frac{v}{3}$
(B) $\frac{v}{2}$
(C) $\frac{2v}{3}$
(D) $\frac{3v}{2}$
(E) $2v$

Questions 14-15



Top View

A spring has a force constant of 100 N/m and an unstretched length of 0.07 m. One end is attached to a post that is free to rotate in the center of a smooth table, as shown in the top view above. The other end is attached to a 1 kg disc moving in uniform circular motion on the table, which stretches the spring by 0.03 m. Friction is negligible.

14. What is the centripetal force on the disc?

(A) 0.3 N
(B) 3 N
(C) 10 N
(D) 300 N
(E) 1,000 N

15. What is the work done on the disc by the spring during one full circle?

(A) 0 J
(B) 94 J
(C) 186 J
(D) 314 J
(E) 628 J

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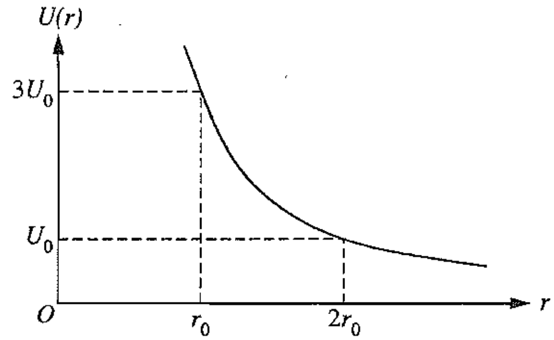
Questions 16-17 refer to the following graph, which represents a hypothetical potential energy curve for a particle of mass m.



16. If the particle is released from rest at position r_0, its speed at position $2r_0$ is most nearly

(A) $\sqrt{\frac{8U_0}{m}}$

(B) $\sqrt{\frac{6U_0}{m}}$

(C) $\sqrt{\frac{4U_0}{m}}$

(D) $\sqrt{\frac{2U_0}{m}}$

(E) $\sqrt{\frac{U_0}{m}}$

17. If the potential energy function is given by $U(r) = br^{-3/2} + c$, where b and c are constants, which of the following is an expression for the force on the particle?

(A) $\frac{3b}{2} r^{-5/2}$

(B) $\frac{3b}{2} r^{-1/2}$

(C) $\frac{3}{2} r^{-1/2}$

(D) $2br^{-1/2} + cr$

(E) $\frac{2b}{5} r^{-5/2} + cr$

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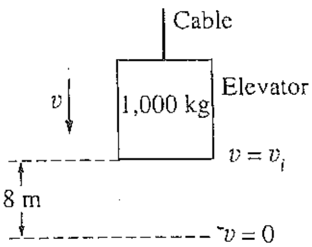
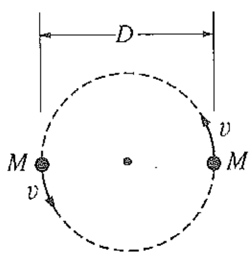
18. A frictionless pendulum of length 3 m swings with an amplitude of 10°. At its maximum displacement, the potential energy of the pendulum is 10 J. What is the kinetic energy of the pendulum when its potential energy is 5 J ?

    (A) 3.3 J
    (B) 5 J
    (C) 6.7 J
    (D) 10 J
    (E) 15 J



19. A descending elevator of mass 1,000 kg is uniformly decelerated to rest over a distance of 8 m by a cable in which the tension is 11,000 N. The speed v_i of the elevator at the beginning of the 8 m descent is most nearly

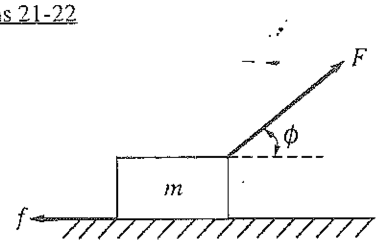
    (A) 4 m/s
    (B) 10 m/s
    (C) 13 m/s
    (D) 16 m/s
    (E) 21 m/s



20. Two identical stars, a fixed distance D apart, revolve in a circle about their mutual center of mass, as shown above. Each star has mass M and speed v. G is the universal gravitational constant. Which of the following is a correct relationship among these quantities?

    (A) $v^2 = GM/D$
    (B) $v^2 = GM/2D$
    (C) $v^2 = GM/D^2$
    (D) $v^2 = MGD$
    (E) $v^2 = 2GM^2/D$

Questions 21-22



A block of mass m is accelerated across a rough surface by a force of magnitude F that is exerted at an angle ϕ with the horizontal, as shown above. The frictional force on the block exerted by the surface has magnitude f.

21. What is the acceleration of the block?

    (A) $\frac{F}{m}$
    (B) $\frac{F\cos\phi}{m}$
    (C) $\frac{F-f}{m}$
    (D) $\frac{F\cos\phi - f}{m}$
    (E) $\frac{F\sin\phi - mg}{m}$

22. What is the coefficient of friction between the block and the surface?

    (A) $\frac{f}{mg}$
    (B) $\frac{mg}{f}$
    (C) $\frac{mg - F\cos\phi}{f}$
    (D) $\frac{f}{mg - F\cos\phi}$
    (E) $\frac{f}{mg - F\sin\phi}$

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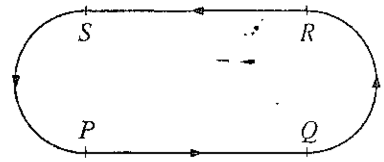
23. This question was not counted when the exam was scored.

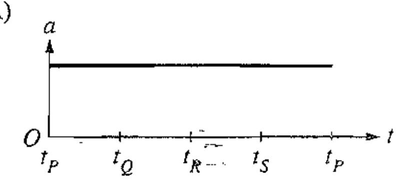
24. Two people are initially standing still on frictionless ice. They push on each other so that one person, of mass 120 kg, moves to the left at 2 m/s, while the other person, of mass 80 kg, moves to the right at 3 m/s. What is the velocity of their center of mass?

(A) Zero
(B) 0.5 m/s to the left
(C) 1 m/s to the right
(D) 2.4 m/s to the left
(E) 2.5 m/s to the right

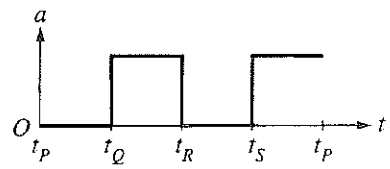


25. A figure of a dancer on a music box moves counterclockwise at constant speed around the path shown above. The path is such that the lengths of its segments, PQ, QR, RS, and SP, are equal. Arcs QR and SP are semicircles. Which of the following best represents the magnitude of the dancer's acceleration as a function of time t during one trip around the path, beginning at point P ?

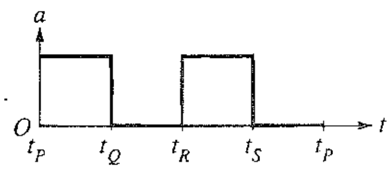
(A)



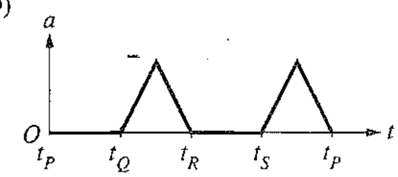
(B)



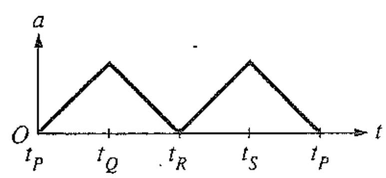
(C)



(D)



(E)



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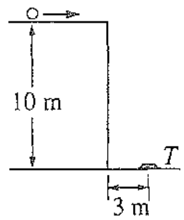


26. A target T lies flat on the ground 3 m from the side of a building that is 10 m tall, as shown above. A student rolls a ball off the horizontal roof of the building in the direction of the target. Air resistance is negligible. The horizontal speed with which the ball must leave the roof if it is to strike the target is most nearly

    (A) $\frac{3}{10}$ m/s

    (B) $\sqrt{2}$ m/s

    (C) $\frac{3}{\sqrt{2}}$ m/s

    (D) 3 m/s

    (E) $10\sqrt{\frac{5}{3}}$ m/s

27. To stretch a certain nonlinear spring by an amount x requires a force F given by $F = 40x - 6x^2$, where F is in newtons and x is in meters. What is the change in potential energy when the spring is stretched 2 meters from its equilibrium position?

    (A) 16 J
    (B) 28 J
    (C) 56 J
    (D) 64 J
    (E) 80 J

28. When a block slides a certain distance down an incline, the work done by gravity is 300 J. What is the work done by gravity if this block slides the same distance up the incline?

    (A) 300 J
    (B) Zero
    (C) −300 J
    (D) It cannot be determined without knowing the distance the block slides.
    (E) It cannot be determined without knowing the coefficient of friction.

29. A particle moves in the xy-plane with coordinates given by

    $$x = A\cos\omega t \text{ and } y = A\sin\omega t,$$

    where $A = 1.5$ meters and $\omega = 2.0$ radians per second. What is the magnitude of the particle's acceleration?

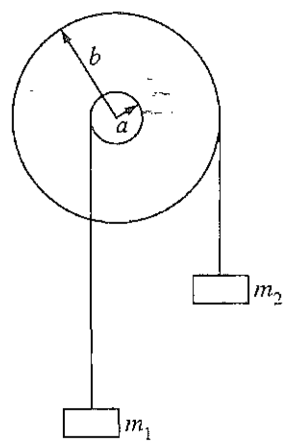
    (A) Zero

    (B) 1.3 m/s^2

    (C) 3.0 m/s^2

    (D) 4.5 m/s^2

    (E) 6.0 m/s^2



30. For the wheel-and-axle system shown above, which of the following expresses the condition required for the system to be in static equilibrium?

    (A) $m_1 = m_2$
    (B) $am_1 = bm_2$
    (C) $am_2 = bm_1$
    (D) $a^2m_1 = b^2m_2$
    (E) $b^2m_1 = a^2m_2$

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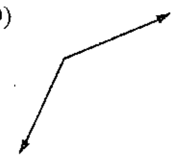
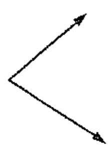
31. An object having an initial momentum that may be represented by the vector above strikes an object that is initially at rest. Which of the following sets of vectors may represent the momenta of the two objects after the collision?

(A)

(B)

(C) 

(D) 

(E) 

Questions 32-33

A wheel with rotational inertia I is mounted on a fixed, frictionless axle. The angular speed ω of the wheel is increased from zero to ω_f in a time interval T.

32. What is the average net torque on the wheel during this time interval?

(A) $\dfrac{\omega_f}{T}$

(B) $\dfrac{\omega_f}{T^2}$

(C) $\dfrac{I\omega_f^2}{T}$

(D) $\dfrac{I\omega_f}{T^2}$

(E) $\dfrac{I\omega_f}{T}$

33. What is the average power input to the wheel during this time interval?

(A) $\dfrac{I\omega_f}{2T}$

(B) $\dfrac{I\omega_f^2}{2T}$

(C) $\dfrac{I\omega_f^2}{2T^2}$

(D) $\dfrac{I^2\omega_f}{2T^2}$

(E) $\dfrac{I^2\omega_f^2}{2T^2}$

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34. An object is released from rest at time $t = 0$ and falls through the air, which exerts a resistive force such that the acceleration a of the object is given by $a = g - bv$, where v is the object's speed and b is a constant. If limiting cases for large and small values of t are considered, which of the following is a possible expression for the speed of the object as an explicit function of time?

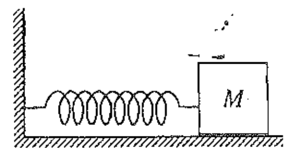
(A) $v = g\left(1 - e^{-bt}\right)/b$

(B) $v = \left(ge^{bt}\right)/b$

(C) $v = gt - bt^2$

(D) $v = (g + a)t/b$

(E) $v = v_0 + gt, v_0 \neq 0$



35. An ideal massless spring is fixed to the wall at one end, as shown above. A block of mass M attached to the other end of the spring oscillates with amplitude A on a frictionless, horizontal surface. The maximum speed of the block is v_m. The force constant of the spring is

(A) $\frac{Mg}{A}$

(B) $\frac{Mgv_m}{2A}$

(C) $\frac{Mv_m^2}{2A}$

(D) $\frac{Mv_m^2}{A^2}$

(E) $\frac{Mv_m^2}{2A^2}$

STOP

END OF SECTION I, MECHANICS

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

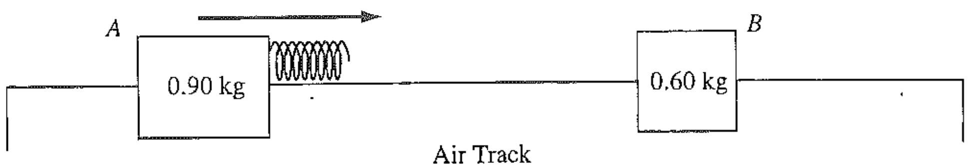
PHYSICS C

SECTION II, MECHANICS

Time—45 minutes

3 Questions

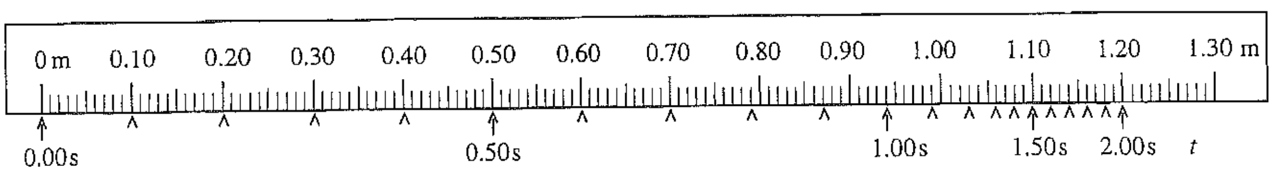
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



Air Track

Mech. 1. Two gliders move freely on an air track with negligible friction, as shown above. Glider A has a mass of 0.90 kg and glider B has a mass of 0.60 kg. Initially, glider A moves toward glider B, which is at rest. A spring of negligible mass is attached to the right side of glider A. Strobe photography is used to record successive positions of glider A at 0.10 s intervals over a total time of 2.00 s, during which time it collides with glider B.

The following diagram represents the data for the motion of glider A. Positions of glider A at the end of each 0.10 s interval are indicated by the symbol $\wedge$ against a metric ruler. The total elapsed time t after each 0.50 s is also indicated.



(a) Determine the average speed of glider A for the following time intervals.

i. 0.10 s to 0.30 s

ii. 0.90 s to 1.10 s

iii. 1.70 s to 1.90 s

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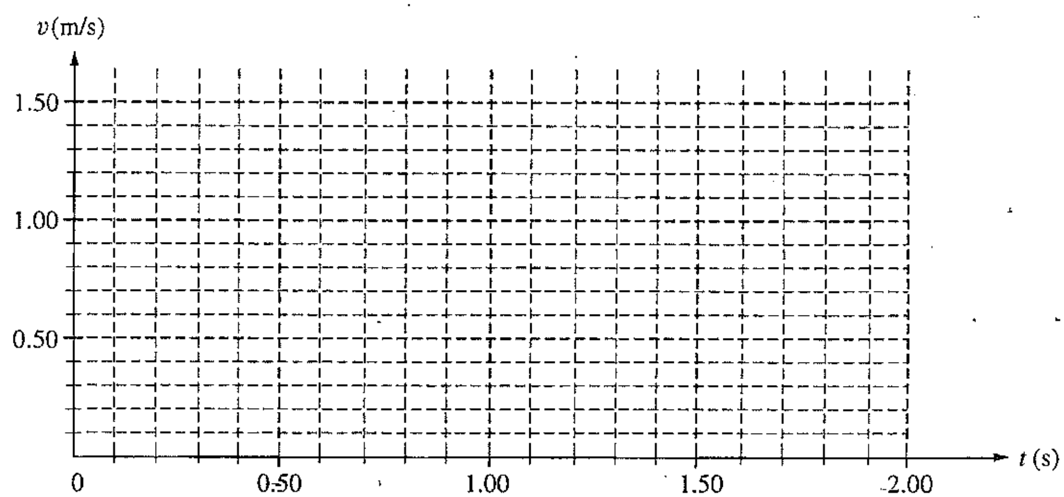
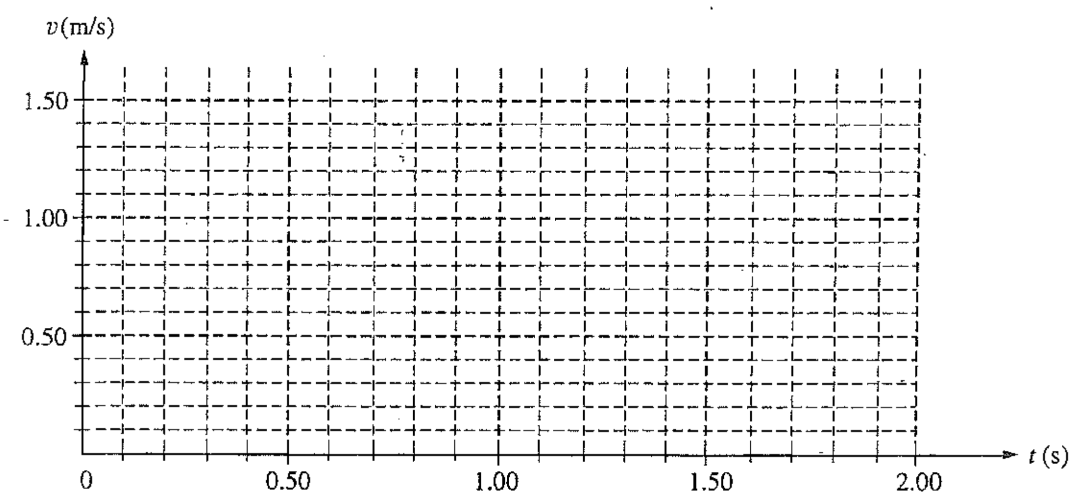
(b) On the axes below, sketch a graph, consistent with the data above, of the speed of glider A as a function of time t for the 2.00 s interval.

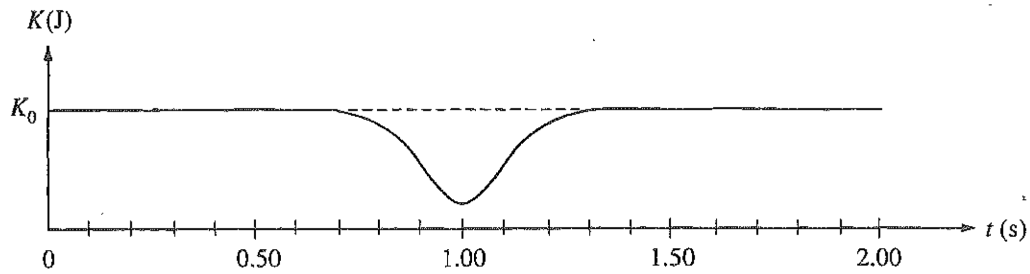


(c) i. Use the data to calculate the speed of glider B immediately after it separates from the spring.

ii. On the axes below, sketch a graph of the speed of glider B as a function of time t.



A graph of the total kinetic energy K for the two-glider system over the 2.00 s interval has the following shape. K_0 is the total kinetic energy of the system at time $t = 0$.



(d) i. Is the collision elastic? Justify your answer.

ii. Briefly explain why there is a minimum in the kinetic energy curve at $t = 1.00$ s.

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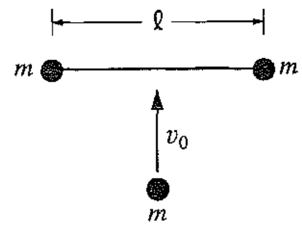
Mech. 2. A space shuttle astronaut in a circular orbit around the Earth has an assembly consisting of two small dense spheres, each of mass m, whose centers are connected by a rigid rod of length ℓ and negligible mass. The astronaut also has a device that will launch a small lump of clay of mass m at speed v_0. Express your answers in terms of m, v_0, ℓ, and fundamental constants.



(a) Initially, the assembly is "floating" freely at rest relative to the cabin, and the astronaut launches the clay lump so that it perpendicularly strikes and sticks to the midpoint of the rod, as shown above.

i. Determine the total kinetic energy of the system (assembly and clay lump) after the collision.

ii. Determine the change in kinetic energy as a result of the collision.

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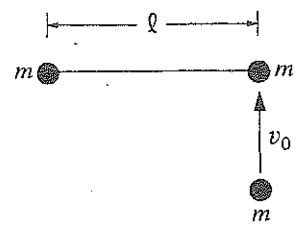

(b) The assembly is brought to rest, the clay lump removed, and the experiment is repeated as shown above, with the clay lump striking perpendicular to the rod but this time sticking to one of the spheres of the assembly.

i. Determine the distance from the left end of the rod to the center of mass of the system (assembly and clay lump) immediately after the collision. (Assume that the radii of the spheres and clay lump are much smaller than the separation of the spheres.)

ii. On the figure above, indicate the direction of the motion of the center of mass immediately after the collision.

iii. Determine the speed of the center of mass immediately after the collision.

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iv. Determine the angular speed of the system (assembly and clay lump) immediately after the collision.

v. Determine the change in kinetic energy as a result of the collision.

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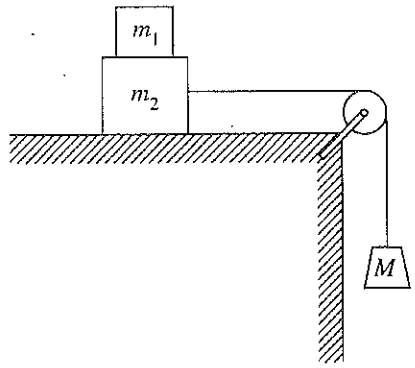


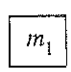
Mech. 3. Block 1 of mass m_1 is placed on block 2 of mass m_2, which is then placed on a table. A string connecting block 2 to a hanging mass M passes over a pulley attached to one end of the table, as shown above. The mass and friction of the pulley are negligible. The coefficients of friction between blocks 1 and 2 and between block 2 and the tabletop are nonzero and are given in the following table.

	Coefficient Between Blocks 1 and 2	Coefficient Between Block 2 and the Tabletop
Static	μ_{s1}	μ_{s2}
Kinetic	μ_{k1}	μ_{k2}

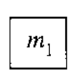
Express your answers in terms of the masses, coefficients of friction, and g, the acceleration due to gravity.

(a) Suppose that the value of M is small enough that the blocks remain at rest when released. For each of the following forces, determine the magnitude of the force and draw a vector on the block provided to indicate the direction of the force if it is nonzero.

i. The normal force N_1 exerted on block 1 by block 2



ii. The friction force f_1 exerted on block 1 by block 2



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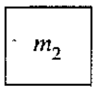
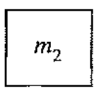
iii. The force T exerted on block 2 by the string

iv. The normal force N_2 exerted on block 2 by the tabletop



v. The friction force f_2 exerted on block 2 by the tabletop



(b) Determine the largest value of M for which the blocks can remain at rest.

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(c) Now suppose that M is large enough that the hanging block descends when the blocks are released. Assume that blocks 1 and 2 are moving as a unit (no slippage). Determine the magnitude a of their acceleration.

(d) Now suppose that M is large enough that as the hanging block descends, block 1 is slipping on block 2. Determine each of the following.

i. The magnitude a_1 of the acceleration of block 1

ii. The magnitude a_2 of the acceleration of block 2

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.

Chapter V Answers to the 1998 AP Physics C 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.

Answer Key and Percent Answering Correctly

Mechanics			Electricity & Magnetism		
Item No.	Correct Answer	Percent Correct	Item No.	Correct Answer	Percent Correct
1	B	82%	36	B	74%
2	E	82%	37	E	65%
3	D	78%	38	C	77%
4	B	67%	39	E	93%
5	C	69%	40	D	79%
6	A	56%	41	C	56%
7	A	56%	42	D	75%
8	D	45%	43	D	29%
9	D	18%	44	A	75%
10	A	53%	45	C	80%
11	E	45%	46	E	61%
12	C	68%	47	D	34%
13	C	81%	48	C	45%
14	B	61%	49	A	49%
15	A	42%	50	D	33%
16	C	54%	51	A	28%
17	A	50%	52	C	45%
18	B	82%	53	E	50%
19	A	35%	54	E	63%
20	B	18%	55	B	26%
21	D	89%	56	E	50%
22	E	42%	57	A	19%
*23	—	—	58	A	53%
24	A	67%	59	C	50%
25	B	56%	60	B	24%
26	C	63%	61	A	74%
27	D	46%	62	D	64%
28	C	59%	63	E	39%
29	E	29%	64	B	71%
30	B	71%	65	D	27%
31	E	48%	66	B	46%
32	E	65%	67	A	24%
33	B	36%	68	E	30%
34	A	37%	69	B	62%
35	D	58%	70	A	61%

*This question was not counted when the exam was scored.

Mechanics Question 1 (15 points) — Scoring Guidelines

This question, while not at all difficult from a calculational point of view, provides an excellent test of conceptual understanding. The format in which the information is provided in this question gives it an experimental flavor. Not only does the question test the student's understanding of energy and momentum concepts, but also the ability to extract the necessary information from data which is graphically presented. A correct answer requires an understanding of the relationship between displacement, velocity, and time for both accelerated and non-accelerated motion. In general, students performed very well on this question.

Distribution of points

(a)

i. 1 point

For correct answer — 1 point

$$\overline{v} = \frac{\Delta s}{\Delta t} = \frac{0.30\,\text{m} - 0.10\,\text{m}}{0.30\,\text{s} - 0.10\,\text{s}} = 1.00\,\text{m/s}$$

ii. 1 point

For correct answer — 1 point

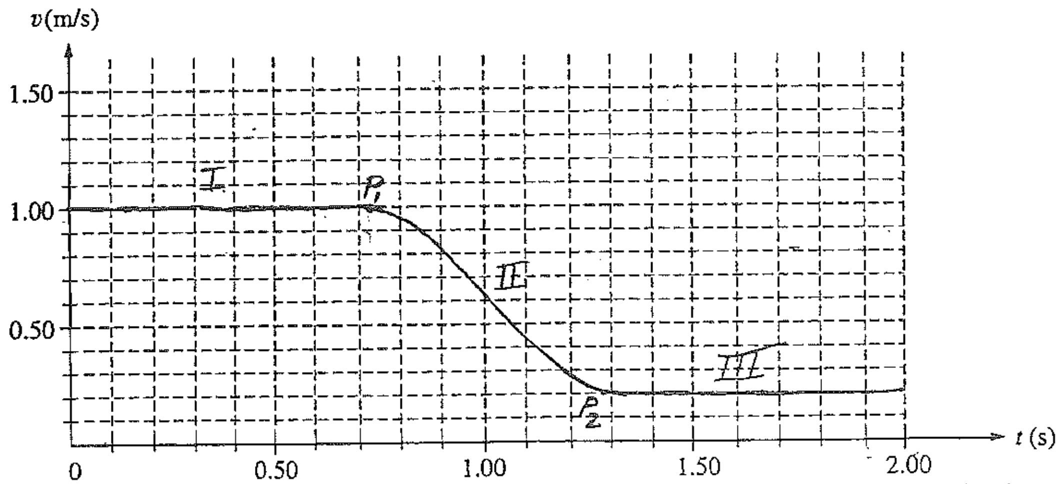
$$\overline{v} = \frac{\Delta s}{\Delta t} = \frac{0.99\,\text{m} - 0.87\,\text{m}}{1.10\,\text{s} - 0.90\,\text{s}} = 0.60\,\text{m/s}$$

iii. 1 point

For correct answer — 1 point

$$\overline{v} = \frac{\Delta s}{\Delta t} = \frac{1.18\,\text{m} - 1.14\,\text{m}}{1.90\,\text{s} - 1.70\,\text{s}} = 0.20\,\text{m/s}$$

(b) 3 points



For line I horizontal at $v = 1.00$ m/s or at answer obtained for (a)i. — 1 point

For line II with monotonic, negative slope between points P_1 and P_2,
P_1 at (0.70 - 0.80, 1.00) or (0.70 - 0.80, answer to (a)i.), and
P_2 at (1.20 - 1.30, 0.20) or (1.20 - 1.30, answer to (a)iii.) — 1 point
(This line may be straight, which is consistent with the data, or slightly curved as shown, which is consistent with the behavior of springs)

For line III horizontal at $v = 0.20$ m/s or at answer obtained for (a)iii. — 1 point

Distribution of points

Mech. 1 (continued)

(c)

i. 3 points

For any statement of conservation of momentum or energy — 1 point

For proper conservation of momentum or energy equation — 1 point

Method 1: Conservation of momentum

$m_A v_{Ai} = m_A v_{Af} + m_B v_B$

$(0.90\ \text{kg})(1.00\ \text{m/s}) = (0.90\ \text{kg})(0.20\ \text{m/s}) + (0.60\ \text{kg})v_B$

Method 2: Recognize from part (d) that energy is also conserved.

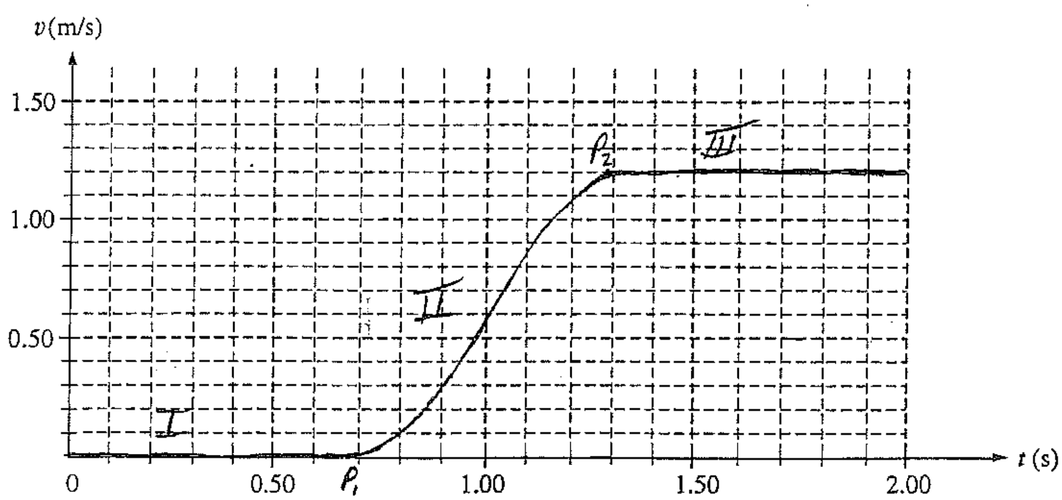
$\frac{1}{2}m_A v_{Ai}^2 = \frac{1}{2}m_A v_{Af}^2 + \frac{1}{2}m_B v_B^2$

$\frac{1}{2}(0.90\ \text{kg})(1.00\ \text{m/s})^2 = \frac{1}{2}(0.90\ \text{kg})(0.20\ \text{m/s})^2 + \frac{1}{2}(0.60\ \text{kg})v_B^2$

For correct answer — 1 point

$v_B = 1.2$ m/s

ii. 3 points



For line I horizontal at $v = 0$ — 1 point

For line II with monotonic, positive slope between points P_1 and P_2,
P_1 at (0.70 - 0.80, 0), and
P_2 at (1.20 - 1.30, 1.20) or (1.20 - 1.30, answer to (c)i.) — 1 point
(This line may be straight, which is consistent with the data, or slightly curved as shown, which is consistent with the behavior of springs)

For line III horizontal at $v = 1.20$ m/s or at answer obtained for (c)i. — 1 point

Distribution of points

Mech. 1 (continued)

(d)

i. 2 points

For correct answer Yes, the collision is elastic.	1 point
For any reasonable justification Examples: The final kinetic energy equals the initial kinetic energy. The spring force is conservative meaning the total energy stored equals the total energy released. The compressed spring stores and releases energy in equal amounts.	1 point

(The justification point was not awarded if student answered "no" to the question.)

ii. 1 point

For any reasonable explanation Examples: The compressed spring stores maximum amount of kinetic energy. At time t = 1 s, there is maximum kinetic energy stored as potential energy. At time t = 1 s, the spring has maximum potential or elastic energy.	1 point

Mechanics Question 2 (15 points) — Scoring Guidelines

This question tests understanding of the concepts of linear and angular momentum conservation, kinetic energy, and center of mass. Just as importantly, the student must understand when kinetic energy is, and is not, conserved. Many students incorrectly assumed that kinetic energy was conserved in these decidedly inelastic collisions. This problem involved no complicated calculations, but rather required real understanding of motion of the center of mass and motion about the center of mass for a correct solution.

Distribution of points

(a)

i. 3 points

For a statement that momentum is conserved <u>or</u> $\mathbf{p}_i = \mathbf{p}_f$ — 1 point

$$mv_0 = (3m)v_f$$

For the correct final speed — 1 point

$$v_f = \frac{v_0}{3}$$

For correct substitutions and answer — 1 point

$$K_{after} = \frac{1}{2}Mv^2 = \frac{1}{2}(3m)\left(\frac{v_0}{3}\right)^2 = \frac{mv_0^2}{6}$$

(1 point awarded for $K_{after} = \frac{1}{2}(3m)v_f^2$ if student found wrong v_f or could not find v_f.)

ii. 2 points

$$\Delta K = K_{after} - K_{before} = \frac{mv_0^2}{6} - \frac{mv_0^2}{2}$$

For correct sign of answer — 1 point

For correct magnitude of answer — 1 point

$$\Delta K = -\frac{mv_0^{\ 2}}{3}$$

(2 points awarded for any wrong answer from (a)i. minus $\frac{1}{2}mv_0^2$.)

(1 point awarded for $\frac{1}{2}mv_0^2$ minus any wrong answer from (a)i.)

Distribution of points

Mech. 2 (continued)

(b)

i. 2 points

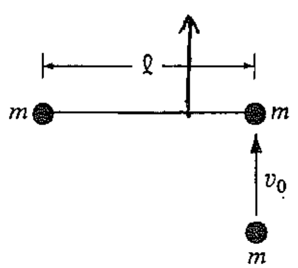
For correct substitutions into the center of mass equation — 1 point

$$r_{cm} = \frac{\Sigma m_i r_i}{\Sigma m_i} = \frac{m(0) + 2m(\ell)}{m + 2m}$$

For correct answer — 1 point

$$r_{cm} = \frac{2}{3}\ell$$

ii. 1 point



For vertical arrow anywhere on diagram or in answer space — 1 point

iii. 1 point

Linear momentum is conserved.

$$\mathbf{p}_i = \mathbf{p}_f$$

$$mv_0 + 3m(0) = (3m)v_f$$

For correct answer — 1 point

$$v_f = \frac{v_0}{3}$$

Distribution of points

Mech. 2 (continued)

iv. 3 points

Angular momentum is conserved.

$L_{before} = L_{after}$

For determining the angular momenta about the center of mass — 1 point

$$L_{before} = mv_0 R\sin\theta = mv_0\left(\frac{1}{3}\ell\right)$$

$$L_{after} = \omega I$$

For determining the moment of inertia — 1 point

$$I = \Sigma mr^2 = m\left(\frac{2}{3}\ell\right)^2 + 2m\left(\frac{1}{3}\ell\right)^2 = \frac{2}{3}m\ell^2$$

Substituting into $L_{before} = L_{after}$,

$$mv_0\left(\frac{1}{3}\ell\right) = \frac{2}{3}m\ell^2\omega$$

For correct answer — 1 point

$$\omega = \frac{v_0}{2\ell}$$

v. 3 points

$$K_i = \frac{1}{2}mv_0^2$$

For recognizing that final kinetic energy is translational plus rotational — 1 point

$$K_f = \frac{1}{2}mv_f^2 + \frac{1}{2}I\omega^2$$

For correct substitutions and final kinetic energy — 1 point

$$K_f = \frac{1}{2}(3m)\left(\frac{v_0}{3}\right)^2 + \frac{1}{2}\left(\frac{2}{3}m\ell^2\right)\left(\frac{v_0}{2\ell}\right)^2 = \frac{1}{4}mv_0^2$$

$$\Delta K = K_f - K_i = \frac{1}{4}mv_0^2 - \frac{1}{2}mv_0^2$$

For correct answer — 1 point

$$\Delta K = -\frac{1}{4}mv_0{}^2$$

(Correct answer point awarded for either positive or negative sign.)

Mechanics Question 3 (15 points) — Scoring Guidelines

This question deals with application of Newton's 2nd and 3rd laws to a system of objects. Although a somewhat complicated problem, this complexity is mitigated by the first part of the question, which requires the student to think carefully about the forces acting on each of the parts of the system and their interrelationships.

Distribution of points

(a) 5 points

For each correct vector -- ½ point
For each correct magnitude -- ½ point
If the score for part (a) contained an odd number of half-points, the total score was truncated by dropping one half-point.

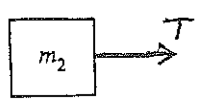
i.

$N_1 = m_1 g$ — 1 point

ii.

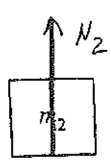
$f_1 = 0$ — 1 point

iii.



$T = Mg$ — 1 point

iv.



$N_2 = (m_1 + m_2)g$ — 1 point

v.

$f_2 = Mg$ — 1 point

(b) 3 points

For expression for the maximum frictional force — 1 point
$f_{2(\max)} = \mu_{s2} N_2 = \mu_{s2}(m_1 + m_2)g$

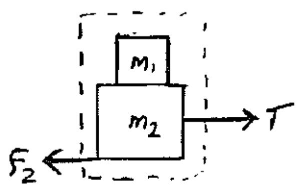
For equating this force to the tension $T = Mg$ — 1 point
$Mg = \mu_{s2}(m_1 + m_2)g$

For the correct answer — 1 point
$M = \mu_{s2}(m_1 + m_2)$

Distribution of points

Mech. 3 (continued)

(c) 3 points



For correctly applying Newton's second law to the hanging block — 1 point

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

$Mg - T = Ma$ (equation 1)

For correctly applying Newton's second law to the system of the two blocks on the plane — 1 point

$\Sigma \mathbf{F} = (m_1 + m_2)\mathbf{a}$

$T - f_2 = (m_1 + m_2)a$ (equation 2)

For combining equations 1 and 2 to eliminate T, substituting for f_2 and solving for a — 1 point

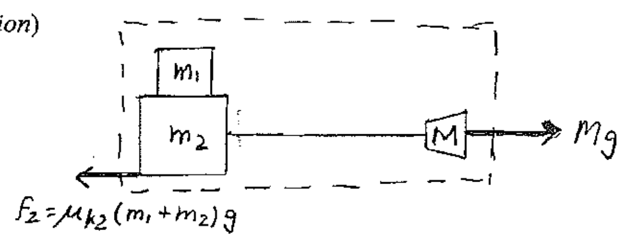
For example, solve each equation for T and set them equal.

$f_2 + (m_1 + m_2)a = Mg - Ma$

$\mu_{k2}(m_1 + m_2)g + (m_1 + m_2)a = Mg - Ma$

$$a = \left[\frac{M - \mu_{k2}(m_1 + m_2)}{M + m_1 + m_2}\right]g$$

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



Apply Newton's second law to the three-block system, realizing that the pulley acts only to change the direction of the force produced by the tension in the string.

$\Sigma \mathbf{F} = m_s\mathbf{a}$

For correct substitutions in left side of equation above — *1 point*

For correct substitutions in right side of equation above — *1 point*

$Mg - \mu_{k2}(m_1 + m_2)g = (M + m_1 + m_2)a$

For correct solution for a — *1 point*

$$a = \left[\frac{M - \mu_{k2}(m_1 + m_2)}{M + m_1 + m_2}\right]g$$

Distribution of points

Mech. 3 (continued)

(d)

i. 2 points

$a_1 = \frac{f_1}{m_1}$

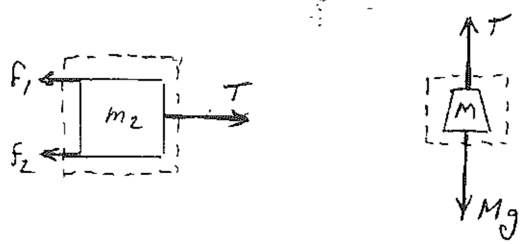
For correct value of f_1 — 1 point

$f_1 = \mu_{k1} m_1 g$

For correct answer — 1 point

$a_1 = \frac{\mu_{k1} m_1 g}{m_1} = \mu_{k1} g$

ii. 2 points



Apply Newton's second law to the hanging block.

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

$Mg - T = Ma_2$ (equation 1)

For correctly applying Newton's second law to block 2 — 1 point

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

$T - f_1 - f_2 = m_2 a_2$ (equation 2)

For combining equations 1 and 2 to eliminate T, substituting for the frictional forces and solving for a_2. — 1 point

For example, solve each equation for T and set them equal.

$f_1 + f_2 + m_2 a_2 = Mg - Ma_2$

$Ma_2 + m_2 a_2 = Mg - \mu_{k1} m_1 g - \mu_{k2}(m_1 + m_2)g$

$a_2 = \left[\frac{M - \mu_{k1} m_1 - \mu_{k2}(m_1 + m_2)}{M + m_2}\right] g$

Physics C: Mechanics

Score	Question 1		Question 2		Question 3	
	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score
15	1,353	10.3	119	0.9	66	0.5
14	641	4.9	119	0.9	92	0.7
13	1,284	9.8	176	1.3	254	1.9
12	789	6.0	255	1.9	372	2.8
11	839	6.4	330	2.5	563	4.3
10	906	6.9	484	3.7	816	6.2
9	1,260	9.6	903	6.9	1,162	8.9
8	1,367	10.4	1,374	10.5	1,347	10.3
7	1,243	9.5	1,560	11.9	1,155	8.8
6	1,049	8.0	1,140	8.7	1,203	9.2
5	795	6.1	1,098	8.4	853	6.5
4	599	4.6	933	7.1	903	6.9
3	362	2.8	811	6.2	1,397	10.7
2	227	1.7	1,127	8.6	1,700	13.0
1	182	1.4	523	4.0	606	4.6
0	121	0.9	1,839	14.1	259	2.0
No response	71	0.5	297	2.3	340	2.6

Physics C: E & M

Score	Question 1		Question 2		Question 3	
	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score
15	167	2.6	441	6.8	25	0.4
14	127	2.0	211	3.3	32	0.5
13	380	5.9	650	10.1	83	1.3
12	287	4.4	291	4.5	123	1.9
11	328	5.1	289	4.5	170	2.6
10	311	4.8	297	4.6	226	3.5
9	338	5.2	354	5.5	178	2.8
8	350	5.4	535	8.3	162	2.5
7	348	5.4	339	5.3	178	2.8
6	381	5.9	412	6.4	333	5.2
5	374	5.8	486	7.5	356	5.5
4	476	7.4	386	6.0	577	8.9
3	487	7.5	433	6.7	519	8.0
2	530	8.2	781	12.1	535	8.3
1	533	8.3	122	1.9	786	12.2
0	850	13.2	250	3.9	1,274	19.7
No response	188	2.9	178	2.8	898	13.9

	Physics C: Mechanics			Physics C: E & M		
	Question 1	Question 2	Question 3	Question 1	Question 2	Question 3
Total Candidates	13,088	13,088	13,088	6,455	6,455	6,455
Mean	9.10	5.24	5.88	5.70	7.27	3.28
Standard Deviation	3.82	3.70	3.52	4.55	4.58	3.71
Mean as % of Maximum Score	61	35	39	38	48	22

Table 4.2 — Scoring Worksheet — AP Physics C: Mechanics

Section I: Multiple Choice

[______ − (1/4 × ______)] × 1.3235 = ______ = ______

Number correct (out of 34) — Number wrong — Multiple-Choice Score (Do not round.) — 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 15)	× 1.000 =	______

Sum = ______

Weighted Section II Score (Do not round)

Composite Score

______ + ______ = ______

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

AP Grade Conversion Chart Physics C: Mechanics

Composite Score Range*	AP Grade
55-90	5
43-54	4
32-42	3
21-31	2
0-20	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.

Table 4.3 — Grade Distributions

Physics B

Nearly two thirds of the AP students who took this exam earned a qualifying grade of 3 or above.

	Examination Grade	Number of Students	Percent at Grade
Extremely well qualified	5	3825	15.9
Well qualified	4	4559	18.9
Qualified	3	7583	31.5
Possibly qualified	2	3440	14.3
No recommendation	1	4688	19.5
Total Number of Students		24,095	
Mean Grade		2.97	
Standard Deviation		1.32	

Physics C — Mechanics

More than two thirds of the AP students who took this exam earned a qualifying grade of 3, or above.

	Examination Grade	Number of Students	Percent at Grade
Extremely well qualified	5	3340	25.5
Well qualified	4	2989	22.8
Qualified	3	2595	19.8
Possibly qualified	2	2111	16.1
No recommendation	1	2053	15.7
Total Number of Students		13,088	
Mean Grade		3.26	
Standard Deviation		1.40	

Physics C — Electricity & Magnetism

Nearly two thirds of the AP students who took this exam earned a qualifying grade of 3, or above.

	Examination Grade	Number of Students	Percent at Grade
Extremely well qualified	5	1644	25.5
Well qualified	4	1499	23.2
Qualified	3	1055	16.3
Possibly qualified	2	1344	20.8
No recommendation	1	913	14.1
Total Number of Students		6,455	
Mean Grade		3.25	
Standard Deviation		1.40	

Table 4.4 — Section I Scores and AP Grades

The following tables give the probabilities that a student would receive a particular grade on each of the 1998 AP Physics Exams given that student's score on the multiple-choice section of that exam.

Physics B

Multiple-Choice Score	AP Grade					Total
	1	2	3	4	5	
41 to 70	0.0%	0.0%	0.9%	13.4%	85.7%	14.4%
32 to 40	0.0%	0.2%	19.1%	62.6%	18.2%	19.2%
21 to 31	1.1%	11.4%	71.7%	15.6%	0.1%	31.7%
16 to 20	18.4%	49.9%	31.6%	0.1%	0.0%	13.9%
0 to 15	79.6%	17.8%	2.6%	0.0%	0.0%	20.8%
Total	19.5%	14.3%	31.5%	18.9%	15.9%	100.0%

Physics C: Mechanics

Multiple-Choice Score	AP Grade					Total
	1	2	3	4	5	
23 to 34	0.0%	0.0%	0.3%	11.6%	88.0%	23.7%
17 to 22	0.0%	0.6%	16.6%	63.6%	19.3%	24.0%
13 to 16	0.1%	12.8%	59.7%	27.2%	0.3%	16.7%
8 to 12	10.3%	56.9%	31.3%	1.5%	0.0%	18.0%
0 to 7	78.3%	20.6%	1.2%	0.0%	0.0%	17.7%
Total	15.7%	16.1%	19.8%	22.8%	25.5%	100.0%