PHYSICS C

You may take the entire C Exam or Mechanics only or Electricity and Magnetism only as follows:

	Entire C Exam Both Mech. & Elect. and Mag.	Mechanics only	Electricity and Magnetism only
First 45 min.	Sec. I, Mech. 35 questions this booklet, pp. 4-14	Sec. I, Mech. 35 questions this booklet, pp. 4-14	Sec. I, Elect. and Mag. 35 questions this booklet, pp. 16-26
2-minute interval		Survey Questions 7 questions (101-107) this booklet, pp. 28-29	Survey Questions 7 questions (101-107) this booklet, pp. 28-29
Second 45 min.	Sec. I, Elect. and Mag. 35 questions this booklet, pp. 16-26	Sec. II, Mech. 3 questions pink booklet, pp. 4-15	Sec. II, Elect. and Mag. 3 questions pink booklet, pp. 16-25
2-minute interval	Survey Questions 7 questions (101-107) this booklet, pp. 28-29		
Third 45 min.	Sec. II, Mech. 3 questions pink booklet, pp. 4-15		
Fourth 45 min.	Sec. II, Elec. and Mag. 3 questions pink booklet, pp. 16-25		

Separate grades are reported for Mechanics and for Electricity and Magnetism. Each section of each examination is 50 percent of the total grade; each question in a section has equal weight. Rulers or straightedges may be used in all parts of this examination. However, calculators may only be used in the two parts of Section II, NOT in Section I. Calculators may not be shared. A table of information that may be helpful is found on page 2 of this booklet.

This examination contains a total of 70 multiple-choice questions. If you are taking

- — ***Mechanics only*, please be careful to use the answer sheet ovals numbered 1-35.**
- — ***Electricity and Magnetism only*, please be careful to use the answer sheet ovals numbered 36-70.**
- — ***the entire examination* (Mechanics *and* Electricity and Magnetism), please be careful to use the answer sheet ovals numbered 1-70 on your answer sheet.**

Also, please be careful to use the ovals numbered 101-107 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

(A) ● (C) (D) (E)

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,	$\mu_0 = 4\pi \times 10^{-7}\text{ (T} \cdot \text{m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\text{ (T} \cdot \text{m)/A}$
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.

PHYSICS C

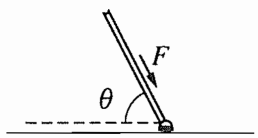
SECTION I, MECHANICS

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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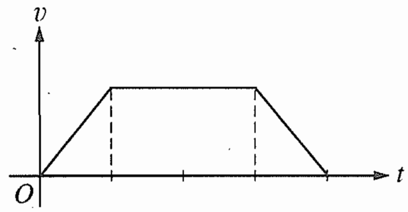
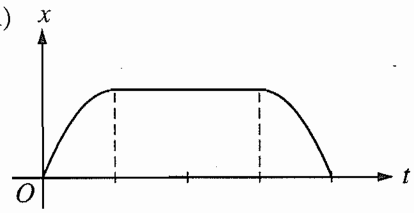
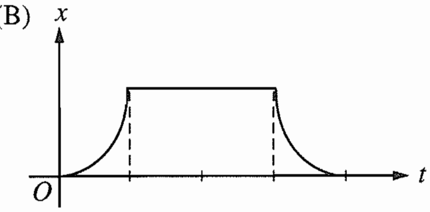
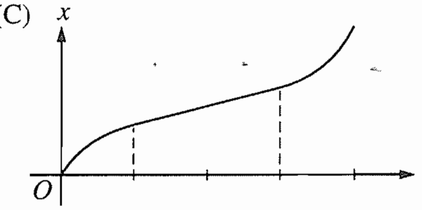
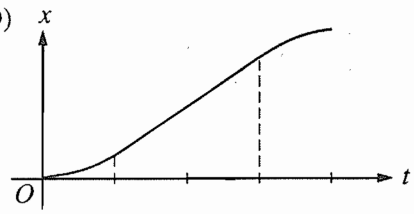


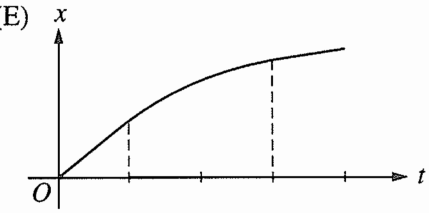
3. The graph above shows the velocity v as a function of time t for an object moving in a straight line. Which of the following graphs shows the corresponding displacement x as a function of time t for the same time interval?

(A) 

(B) 

(C) 

(D) 

(E) 

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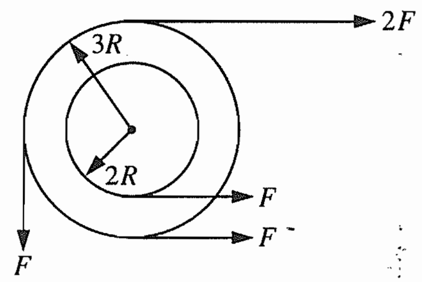
4. The position of a toy locomotive moving on a straight track along the x-axis is given by the equation $x = t^3 - 6t^2 + 9t$, where x is in meters and t is in seconds. The net force on the locomotive is equal to zero when t is equal to

(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) $\dfrac{M\omega^2 R^2}{2}$

(E) Zero

GO ON TO THE NEXT PAGE

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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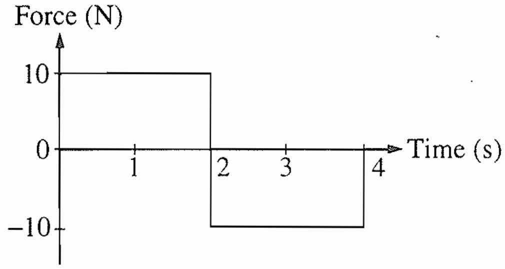
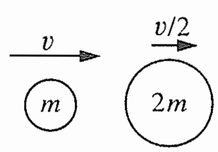


12. The graph above shows the force on an object of mass M as a function of time. For the time interval 0 to 4 s, the total change in the momentum of the object is

(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

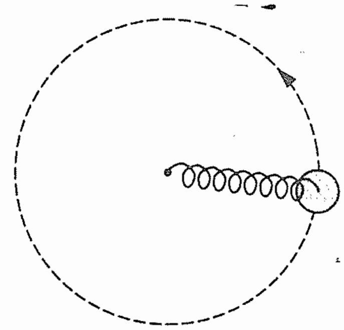


Top View

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?

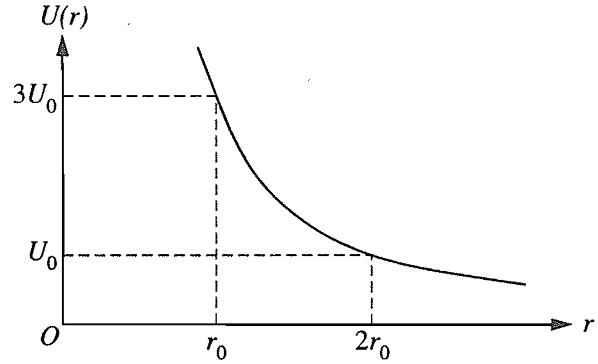
(A) 0.3 N
(B) 3 N
(C) 10 N
(D) 300 N
(E) 1,000 N

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

GO ON TO THE NEXT PAGE

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

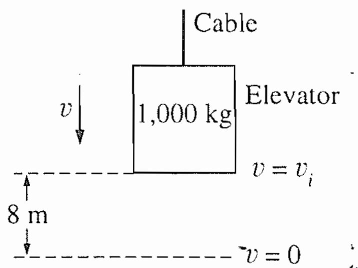
(D) $2br^{-1/2} + cr$

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

GO ON TO THE NEXT PAGE

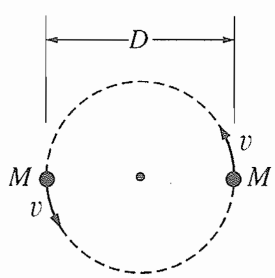
18. A frictionless pendulum of length 3 m swings with an amplitude of 10°. At its maximum displacement, the potential energy of the pendulum is 10 J. What is the kinetic energy of the pendulum when its potential energy is 5 J ?

(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

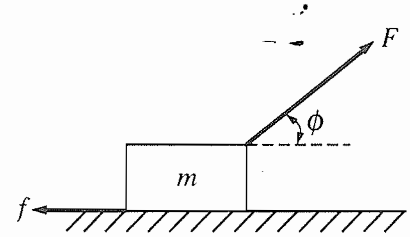
(A) 4 m/s
(B) 10 m/s
(C) 13 m/s
(D) 16 m/s
(E) 21 m/s



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) $\dfrac{F}{m}$

(B) $\dfrac{F\cos\phi}{m}$

(C) $\dfrac{F-f}{m}$

(D) $\dfrac{F\cos\phi - f}{m}$

(E) $\dfrac{F\sin\phi - mg}{m}$

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

(A) $\dfrac{f}{mg}$

(B) $\dfrac{mg}{f}$

(C) $\dfrac{mg - F\cos\phi}{f}$

(D) $\dfrac{f}{mg - F\cos\phi}$

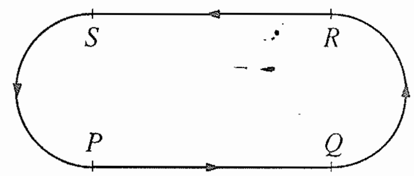
(E) $\dfrac{f}{mg - F\sin\phi}$

GO ON TO THE NEXT PAGE

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

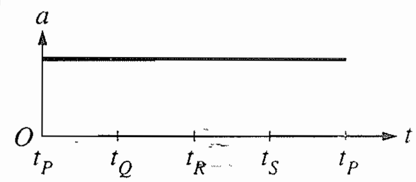
24. Two people are initially standing still on frictionless ice. They push on each other so that one person, of mass 120 kg, moves to the left at 2 m/s, while the other person, of mass 80 kg, moves to the right at 3 m/s. What is the velocity of their center of mass?

(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

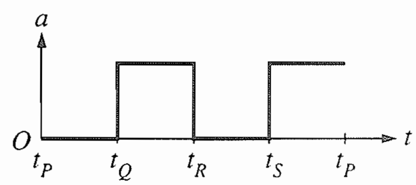


25. A figure of a dancer on a music box moves counterclockwise at constant speed around the path shown above. The path is such that the lengths of its segments, PQ, QR, RS, and SP, are equal. Arcs QR and SP are semicircles. Which of the following best represents the magnitude of the dancer's acceleration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

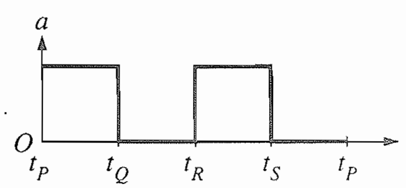
(A)



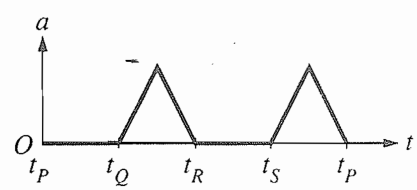
(B)



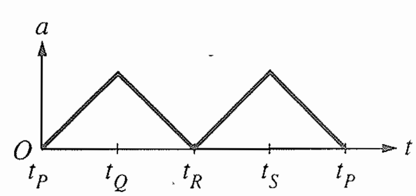
(C)



(D)



(E)



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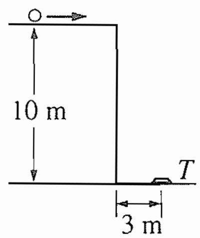


26. A target T lies flat on the ground 3 m from the side of a building that is 10 m tall, as shown above. A student rolls a ball off the horizontal roof of the building in the direction of the target. Air resistance is negligible. The horizontal speed with which the ball must leave the roof if it is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

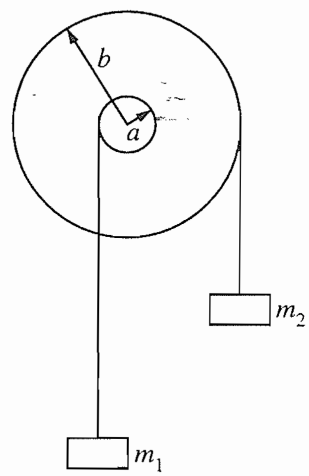
 (A) Zero

 (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) $b^2m_1 = a^2m_2$

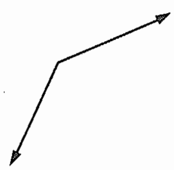
GO ON TO THE NEXT PAGE

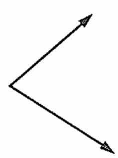
31. An object having an initial momentum that may be represented by the vector above strikes an object that is initially at rest. Which of the following sets of vectors may represent the momenta of the two objects after the collision?

(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) $\frac{\omega_f}{T}$

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

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

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

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

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

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

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

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

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

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

GO ON TO THE NEXT PAGE

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?

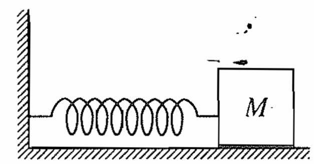
(A) $v = g(1 - e^{-bt})/b$

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

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

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

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

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

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

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
Free-Response Questions

Mechanics	45 minutes	3 required questions of equal weight on pages 4-15
Electricity and Magnetism	45 minutes	3 required questions of equal weight on pages 16-25

Section II is 50 percent of the total grade for each of the two examinations.

Mark one of the three boxes below to indicate which questions you are answering.

- ☐ Mechanics only
- ☐ Electricity and Magnetism only
- ☐ Both Mechanics and Electricity and Magnetism

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 indicate clearly 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 C
SECTION II

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}\text{ kg}$
	$= 931\text{ MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\text{ kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\text{ kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\text{ kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\text{ C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\text{ mol}^{-1}$
Universal gas constant,	$R = 8.31\text{ J/(mol}\cdot\text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\text{ J/K}$
Speed of light,	$c = 3.00 \times 10^8\text{ m/s}$
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,	$\mu_0 = 4\pi \times 10^{-7}\text{ (T}\cdot\text{m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\text{ (T}\cdot\text{m)/A}$
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,	$1\text{ atm} = 1.0 \times 10^5\text{ N/m}^2$
	$= 1.0 \times 10^5\text{ Pa}$
1 electron volt,	$1\text{ eV} = 1.60 \times 10^{-19}\text{ J}$
1 angstrom,	$1\text{ Å} = 1 \times 10^{-10}\text{ m}$

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

Angle	Sin	Cos	Tan
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.

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 C EQUATIONS FOR 1998

MECHANICS

$v = v_0 + at$

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

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

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

$\mathbf{F} = \frac{d\mathbf{p}}{dt}$

$\mathbf{J} = \int \mathbf{F}\, dt = \Delta \mathbf{p}$

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

$F_{fric} \le \mu N$

$W = \int \mathbf{F} \cdot d\mathbf{s}$

$K = \frac{1}{2} m v^2$

$P = \frac{dW}{dt}$

$\Delta U_g = mgh$

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

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

$\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$

$I = \int r^2 dm = \Sigma m r^2$

$\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$

$v = r\omega$

$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$

$K = \frac{1}{2} I \omega^2$

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

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

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

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

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

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

$F_G = -\frac{G m_1 m_2}{r^2}$

$U_G = -\frac{G m_1 m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
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
ω = angular speed
α = angular acceleration

ELECTRICITY AND MAGNETISM

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

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

$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$

$E = -\frac{dV}{dr}$

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

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

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

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

$C_p = \sum_i C_i$

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

$I = \frac{dQ}{dt}$

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

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

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$

$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$

$\mathbf{F} = \int I\, d\boldsymbol{\ell} \times \mathbf{B}$

$B_s = \mu_0 n I$

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

$\mathcal{E} = -\frac{d\phi_m}{dt}$

$\mathcal{E} = -L \frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
L = inductance
ℓ = length
n = number of loops of wire per unit length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux
κ = dielectric constant

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 1998

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

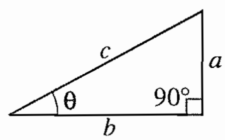
Parallelepiped
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r \ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

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



CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\cdot\frac{du}{dx}$$

$$\frac{d}{dx}(x^n) = nx^{n-1}$$

$$\frac{d}{dx}(e^x) = e^x$$

$$\frac{d}{dx}(\ln x) = \frac{1}{x}$$

$$\frac{d}{dx}(\sin x) = \cos x$$

$$\frac{d}{dx}(\cos x) = -\sin x$$

$$\int x^n dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^x dx = e^x$$

$$\int \frac{dx}{x} = \ln|x|$$

$$\int \cos x\, dx = \sin x$$

$$\int \sin x\, dx = -\cos x$$

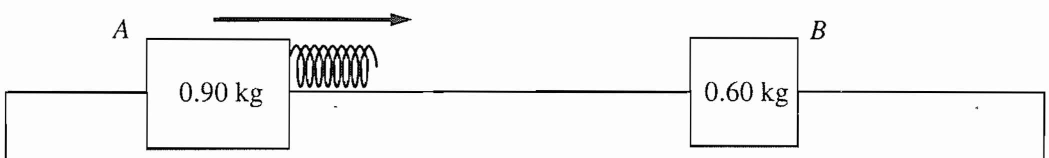
PHYSICS C

SECTION II, MECHANICS

Time—45 minutes

3 Questions

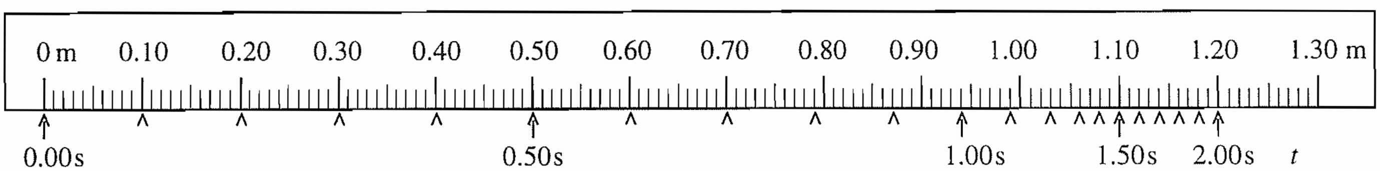
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



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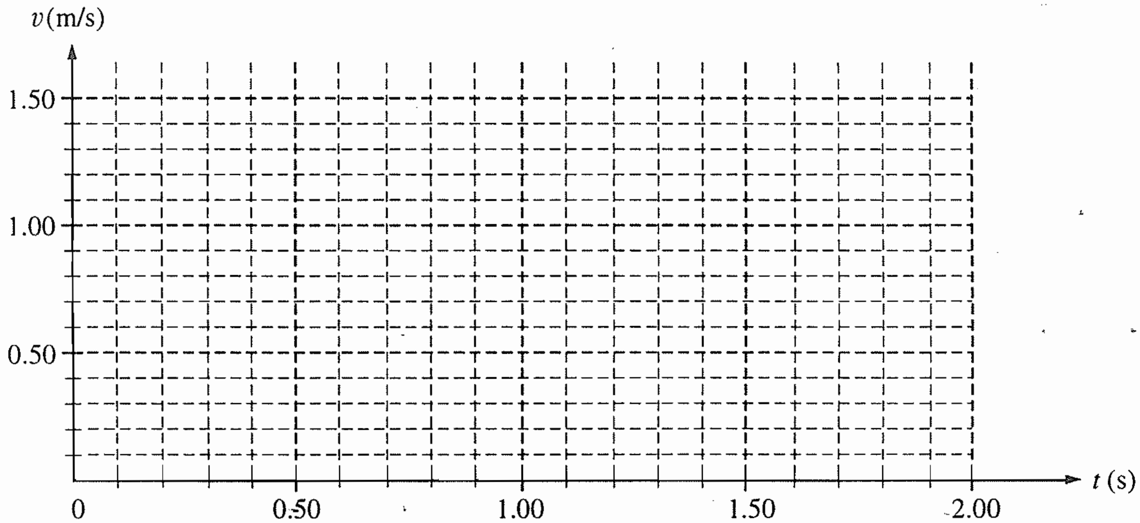
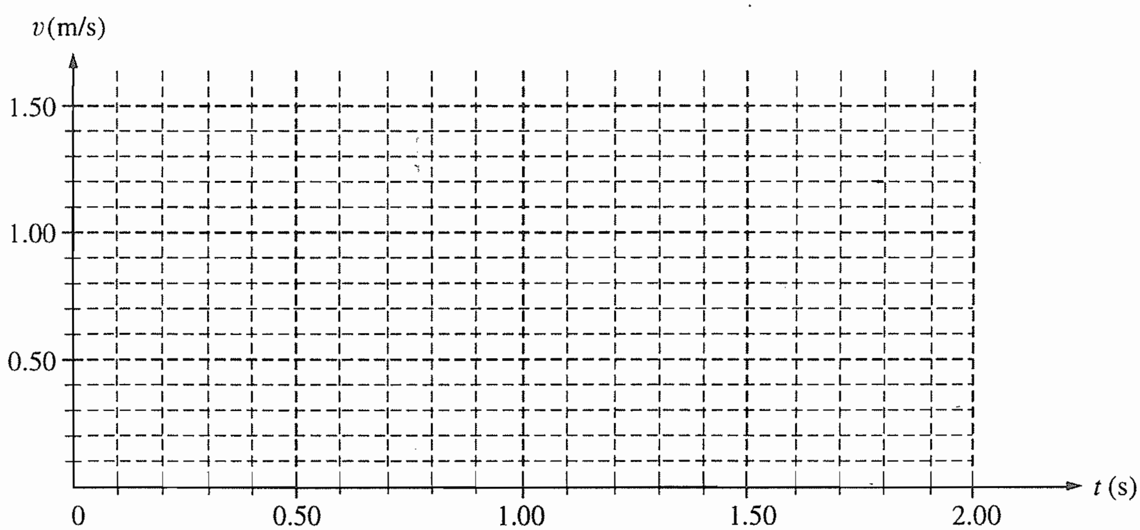
(b) On the axes below, sketch a graph, consistent with the data above, of the speed of glider A as a function of time t for the 2.00 s interval.



(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.



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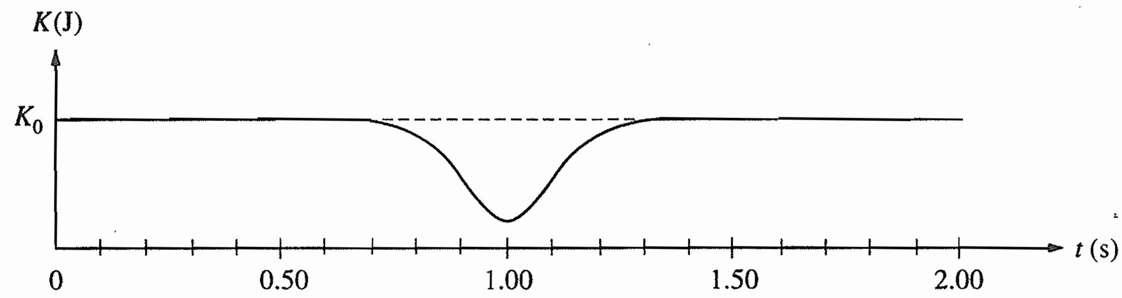
A graph of the total kinetic energy K for the two-glider system over the 2.00 s interval has the following shape. K_0 is the total kinetic energy of the system at time $t = 0$.

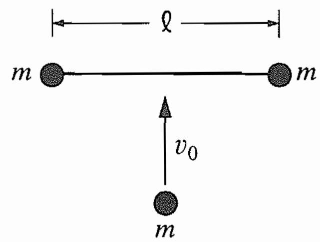


(d) i. Is the collision elastic? Justify your answer.

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

GO ON TO THE NEXT PAGE

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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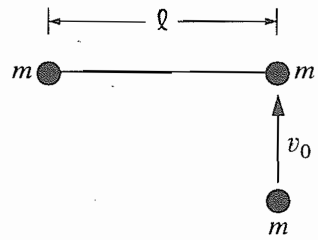


(b) The assembly is brought to rest, the clay lump removed, and the experiment is repeated as shown above, with the clay lump striking perpendicular to the rod but this time sticking to one of the spheres of the assembly.

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.

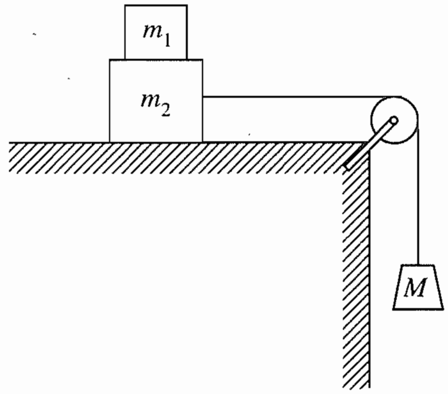
iii. Determine the speed of the center of mass immediately after the collision.

GO ON TO THE NEXT PAGE

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.

GO ON TO THE NEXT PAGE



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

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

$$\boxed{m_2}$$

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

$$\boxed{m_2}$$

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

$$\boxed{m_2}$$

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

GO ON TO THE NEXT PAGE

(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

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

ii. 1 point

For correct answer — 1 point

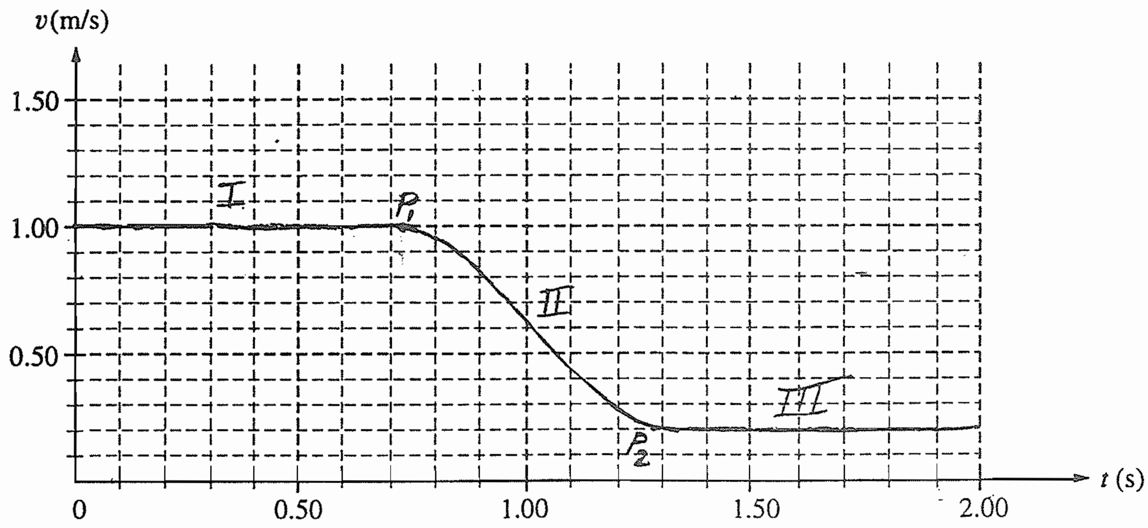
$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{0.99\,\text{m} - 0.87\,\text{m}}{1.10\,\text{s} - 0.90\,\text{s}} = 0.60\,\text{m/s}$$

iii. 1 point

For correct answer — 1 point

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

(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.

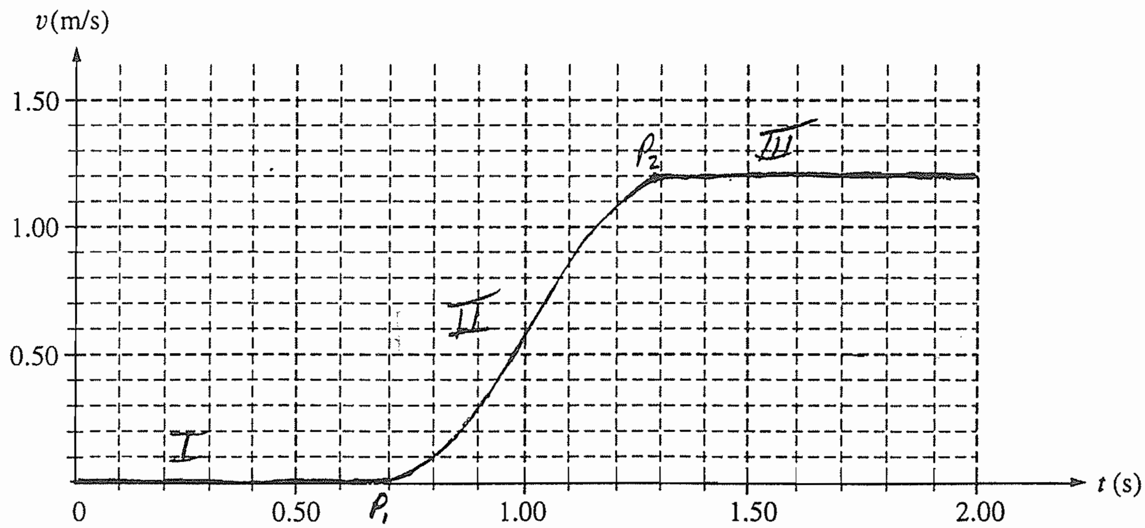
$$\frac{1}{2}m_A v_{Ai}^2 = \frac{1}{2}m_A v_{Af}^2 + \frac{1}{2}m_B v_B^2$$

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

For correct answer — 1 point

$v_B = 1.2\text{ m/s}$

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 — 1 point

Yes, the collision is elastic.

For any reasonable justification — 1 point

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.

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

ii. 1 point

For any reasonable explanation — 1 point

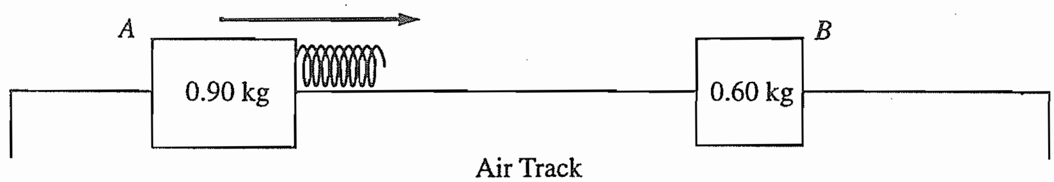
Examples:

The compressed spring stores maximum amount of kinetic energy.

At time t = 1 s, there is maximum kinetic energy stored as potential energy.

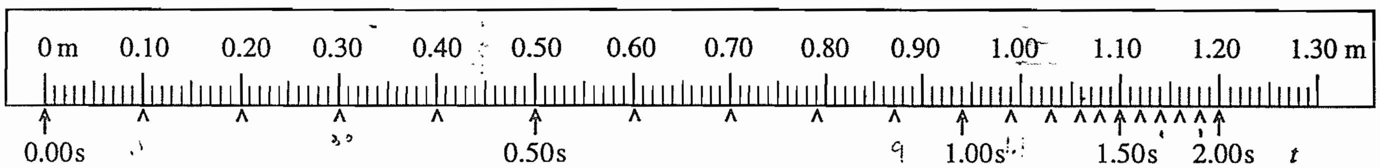
At time t = 1 s, the spring has maximum potential or elastic energy.

Excellent Student Response: 15 points



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 ∧ 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

$\bar{v} = d/t = \frac{.2m}{.2s} = 1\ m/s$

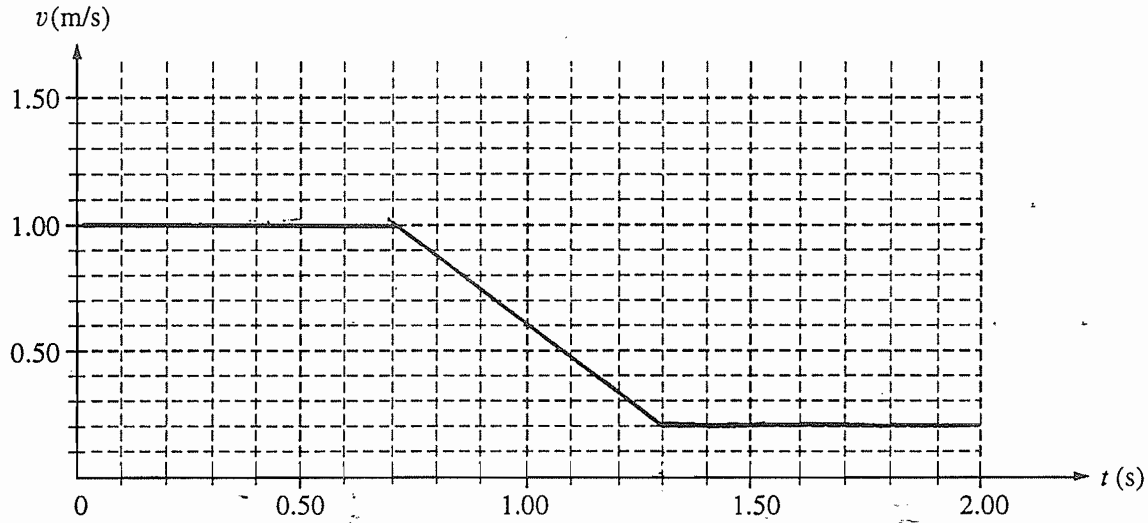
ii. 0.90 s to 1.10 s

$\bar{v} = d/t = \frac{.99m - .87m}{.2s} = \frac{.12m}{.2s} = .6\ m/s$

iii. 1.70 s to 1.90 s

$\bar{v} = d/t = \frac{1.18m - 1.14m}{.2s} = \frac{.04m}{.2s} = .2\ m/s$

(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.

A

$KE_i = \frac{1}{2}mv_i^2$
$= \frac{1}{2}(.9\,kg)(1\,m/s)^2$
$= .45\,J$

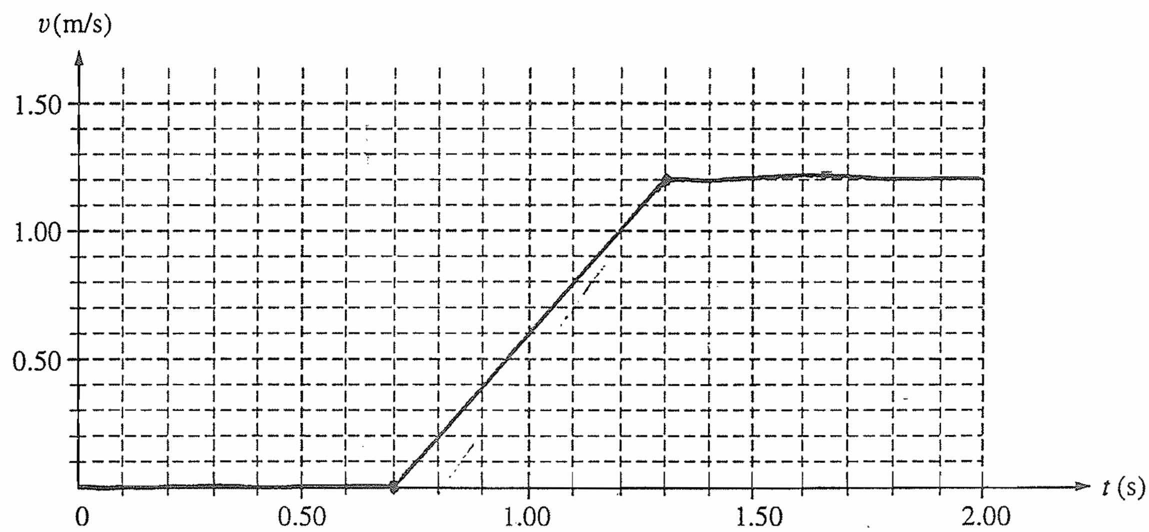
$KE_f = \frac{1}{2}mv_f^2$
$= \frac{1}{2}(.9\,kg)(.2\,m/s)^2$
$= .018\,J$

$\Delta KE = .45\,J - .018\,J = .432\,J$

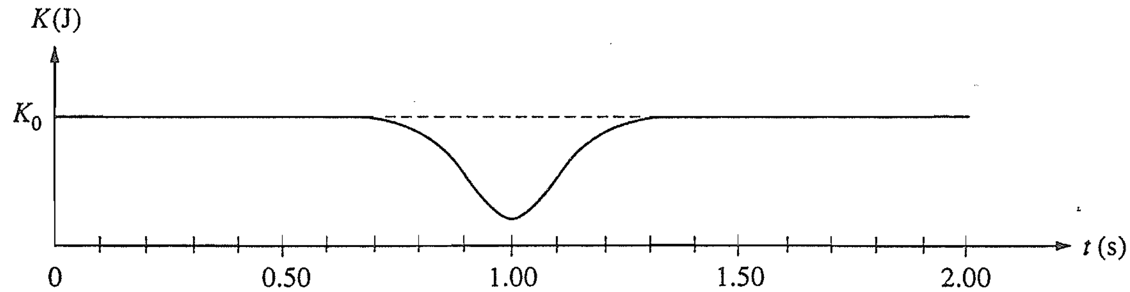
B

$KE = \frac{1}{2}mv^2$
$.432\,J = \frac{1}{2}(.6\,kg)v^2$
$1.44\,m^2/s^2 = v^2$
$1.2\,m/s = v$

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.

Yes the collision is elastic. This is so because momentum is conserved ($m_A v_i = m_A v_f + m_B v_f$) and so is Kinetic Energy. If this were an inelastic collision, then KE would not be conserved because it would be lost during the deformation of the objects and it would be converted into heat energy with all the rubbing the objects would do against each other,

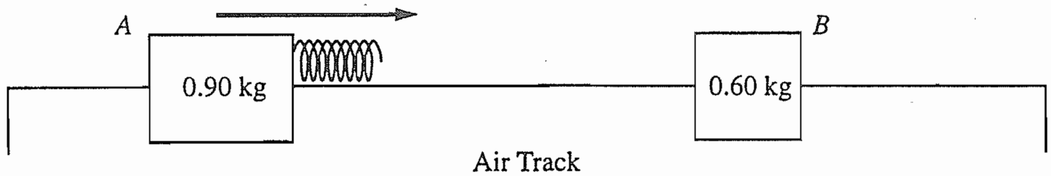
ii. Briefly explain why there is a minimum in the kinetic energy curve at $t = 1.00$ s.

That is the point at which the spring between the objects is completely compressed. Therefore the objects are barely moving, and most of their kinetic energy has gone into potential energy stored in the spring,

Commentary:

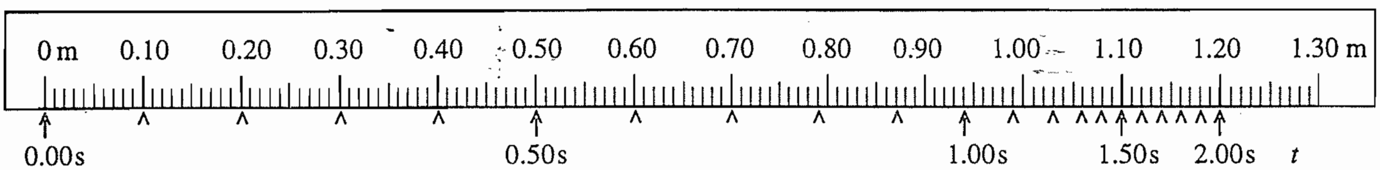
While this student does not explicitly make a statement of conservation of energy for part (c)i, it is implicit in the calculations that are shown. Both explanations for part (d) include the important ideas required.

Very Good Student Response: 13 points



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 ∧ 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

Ave sd. $= \dfrac{x_2 - x_1}{t_2 - t_1} = \dfrac{.3m - 0m}{.30s - .00s} = \dfrac{.3m}{.3s} = 1.00\ m/s$

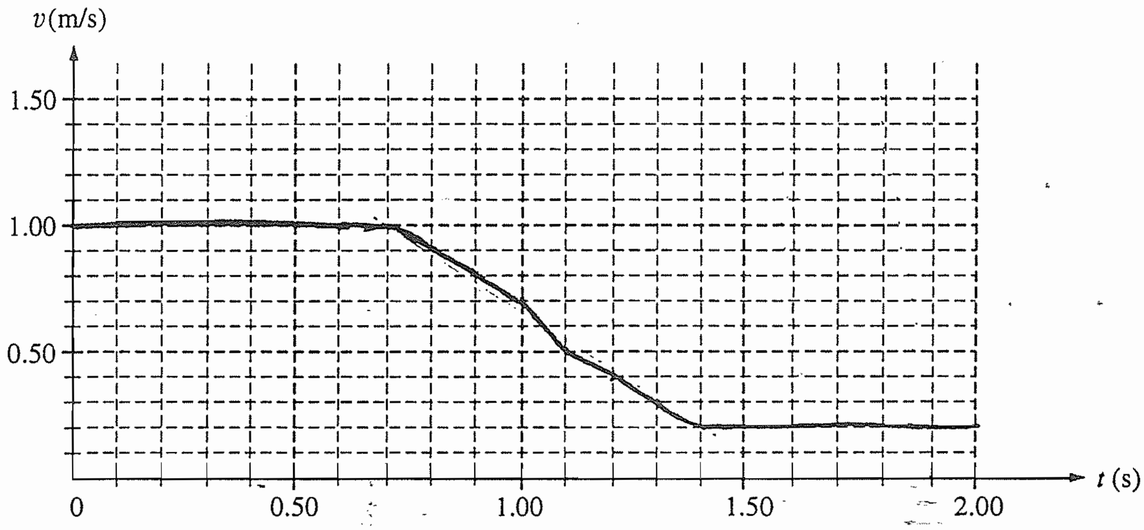
ii. 0.90 s to 1.10 s

$\dfrac{x_2 - x_1}{t_2 - t_1} = \dfrac{.99m - .87m}{1.10s - .90s} = 0.60\ m/s$

iii. 1.70 s to 1.90 s

$\dfrac{x_2 - x_1}{t_2 - t_1} = \dfrac{1.18m - 1.14m}{1.90s - 1.70s} = 0.20\ m/s$

(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.



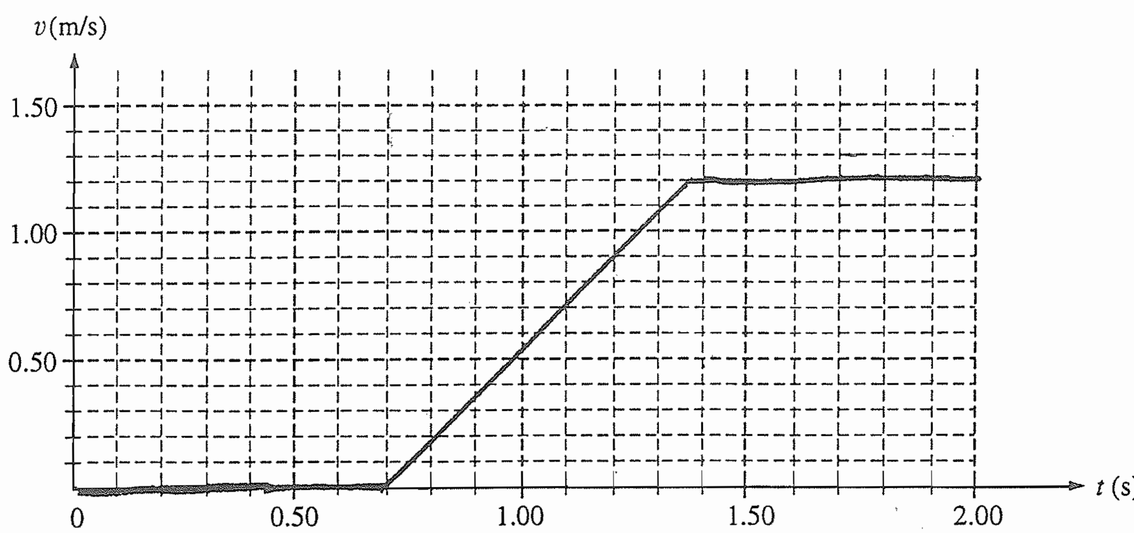
(c) i. Use the data to calculate the speed of glider B immediately after it separates from the spring.

$$m_A V_A + m_B V_B = m_A V_A + M_B V_B$$

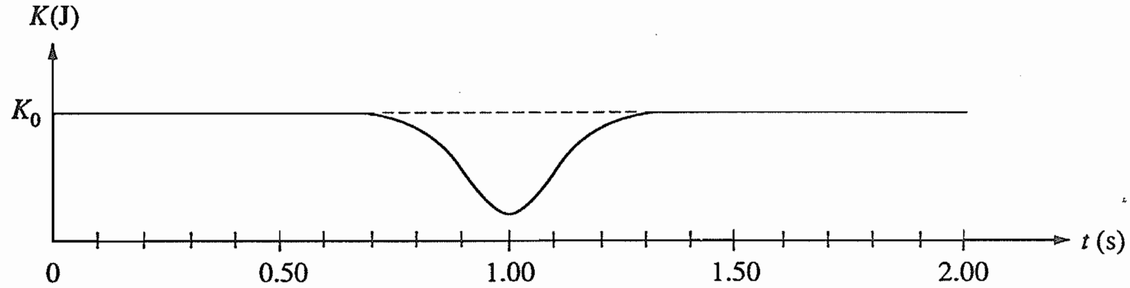
$$(.90\text{ kg})(1.00\text{ m/s}) + (.60\text{ kg})(0\text{ m/s}) = (.90\text{ kg})(.20\text{ m/s}) + (.60\text{ kg})(V_B)$$

$$V_B = 1.20\text{ m/s}$$

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.

Yes, both kinetic energy and momentum are conserved.

K before collision = K_0

K after collision = K_0

Masses of both gliders are constant.

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

Some of the kinetic energy of the gliders is temperarily converted to potential energy within the compressed spring. This potential energy is eventually converted back into kinetic energy.

Commentary:

This student does as well with the calculations and explanations as the previous paper, but point P_2 is incorrect in both graphs.

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

$$\Delta K = -\frac{m{v_0}^2}{3}$$

(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

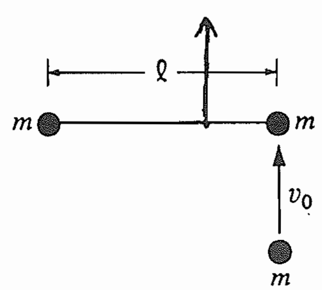
For correct substitutions into the center of mass equation — 1 point

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

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.

$L_{\text{before}} = L_{\text{after}}$

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 $L_{\text{before}} = L_{\text{after}}$,

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

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

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

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

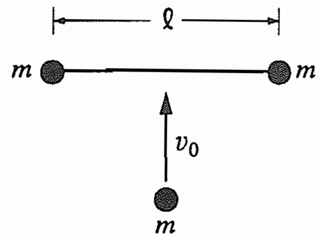
For correct answer — 1 point

$$\Delta K = -\frac{1}{4}m{v_0}^2$$

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

Excellent Student Response: 15 points

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.

$$m V_0 = (m + 2m) V_f$$

$$m V_0 = 3 m V_f$$

$$V_f = \frac{V_0}{3}$$

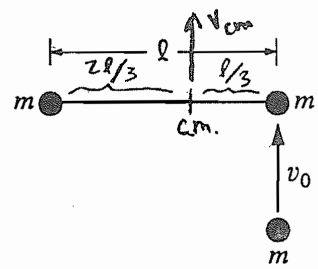
$$KE_f = \frac{1}{2}(3m) V_f^2 = \frac{1}{2}(3m)\left(\frac{V_0}{3}\right)^2 = \boxed{\frac{1}{6} m V_0^2}$$

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

$$\Delta KE = KE_f - KE_0$$

$$= \frac{1}{6} m V_0^2 - \frac{1}{2} m V_0^2$$

$$\boxed{\Delta KE = -\frac{1}{3} m V_0^2}$$



(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.) ← (since radii of spheres are neglible)

$$X_{cm} = \frac{(2m)\,l}{m+2m} = \frac{2ml}{3m} = \boxed{\frac{2}{3}l}$$

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.

$$mV_0 = (3m)\,V_{cm.f}$$

$$\boxed{V_{cm_f} = \frac{mV_0}{3m} = \frac{V_0}{3}}$$

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

$$L_o = L_f$$

$$r \times p_o = I\omega_f$$

$$m\left(\frac{\ell}{3}\right)v_o \sin 90^\circ = \left(m\left(\frac{2\ell}{3}\right)^2 + 2m\left(\frac{\ell}{3}\right)^2\right)\omega_f$$

$$\frac{m\ell v_o}{3} = \left(\frac{4m\ell^2}{9} + \frac{2m\ell^2}{9}\right)\omega_f$$

$$\frac{1}{3}\cancel{m}\cancel{\ell}v_o = \frac{2}{3}\cancel{m}\ell^{\cancel{2}}\omega_f$$

$$\boxed{\omega_f = \frac{v_o}{2\ell}}$$

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

$$\Delta KE = KE_f - KE_o$$

$$\Delta KE = \frac{1}{2}(3m)v_{cm_f}^2 + \frac{1}{2}I\omega_f^2 - \frac{1}{2}mv_o^2$$

$$= \frac{1}{2}(3m)\left(\frac{v_o}{3}\right)^2 + \frac{1}{2}\left(\frac{2}{3}m\ell^2\right)\left(\frac{v_o}{2\ell}\right)^2 - \frac{1}{2}mv_o^2$$

$$= \frac{1}{6}mv_o^2 + \frac{1}{12}mv_o^2 - \frac{1}{2}mv_o^2$$

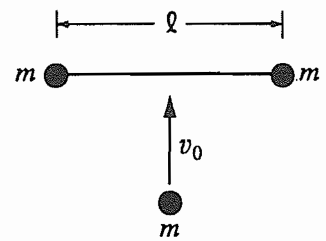
$$= \frac{1}{4}mv_o^2 - \frac{1}{2}mv_o^2 = \boxed{-\frac{1}{4}mv_o^2}$$

Commentary:

In addition to being completely correct, this solution is neat and well organized; the student shows an excellent understanding of the principles involved.

Very Good Student Response: 13 points

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.

$$\cancel{m}V_0 = 3\cancel{m}V_f$$

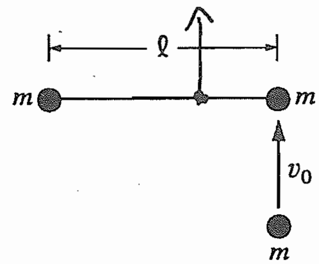
$$V_f = \frac{V_0}{3}$$

$$KE_{final} = \frac{1}{2}mv^2 = \frac{1}{2}\times 3m\times\left(\frac{V_0}{3}\right)^2 = \frac{1}{6}mV_0^2$$

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

$$KE_{initial} - KE_{final} = \Delta KE$$

$$\frac{1}{2}mV_0^2 - \frac{1}{6}mV_0^2 = \frac{1}{3}mV_0^2$$



(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.)

Center of mass = $\frac{m \times 0 + 2m \times \ell}{3m} = \frac{2}{3}\ell$ ~~from~~

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.

$mV_0 = 3mV_f$

$V_f = \frac{V_0}{3}$

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

$$I_{clay}\omega_{clay} = I_f \omega_f \qquad I_{clay} = m\left(\tfrac{1}{3}l\right)^2 = \frac{ml^2}{9}$$

$$\frac{ml^{\cancel{2}}}{9} \times \frac{V_0}{\frac{1}{3}\cancel{l}} = \left[2m\left(\tfrac{1}{3}l\right)^2 + m\left(\tfrac{2}{3}l\right)^2\right]\omega_f$$

$$\frac{mlV_0}{3} = \left[\frac{2ml^2}{9} + \frac{4ml^2}{9}\right]\omega_f$$

$$\frac{\cancel{m}\cancel{l}V_0}{\cancel{3}} = \frac{2\cancel{m}l^{\cancel{2}}}{\cancel{3}}\omega_f$$

$$\omega_f = \frac{V_0}{2l}$$

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

$$\Delta KE = \Delta KE_{linear} + \Delta KE_{angular}$$

$$\Delta KE_{angular} = \frac{1}{2}I_f\omega_f^2 \cancel{- \frac{1}{2}I_{clay}\omega_{clay}^2}$$

$$= \frac{1}{\cancel{2}} \times \frac{\cancel{2}ml^{\cancel{2}}}{3} \times \left(\frac{V_0}{2\cancel{l}}\right)^2 \cancel{- \frac{1}{2}m\left(\tfrac{1}{3}l\right)^2\left(\frac{V_0}{\frac{1}{3}l}\right)^2}$$

$$= \frac{mV_0^2}{12} \cancel{\;mV_0^2}$$

$$\Delta KE_{linear} = \frac{1}{2}mv^2 = \frac{1}{2} \times 3m \times \left(\frac{V_0}{3}\right)^2 = \frac{mV_0^2}{6}$$

$$\Delta KE = \frac{mV_0^2}{12} + \frac{mV_0^2}{6} = \frac{3mV_0^2}{12} = \frac{mV_0^2}{4}$$

Commentary:

This student shows a very good understanding of the problem. The answer to part (a)ii does not have the correct sign, and the student only calculates the final kinetic energy, not the total energy, in the last part.

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.

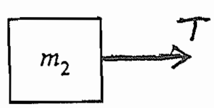
i.

$N_1 = m_1 g$ — 1 point

ii.

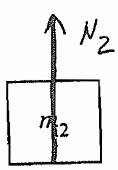
$f_1 = 0$ — 1 point

iii.



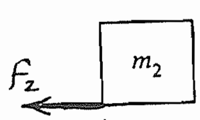
$T = Mg$ — 1 point

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
$f_{2(\max)} = \mu_{s2} N_2 = \mu_{s2}(m_1 + m_2)g$

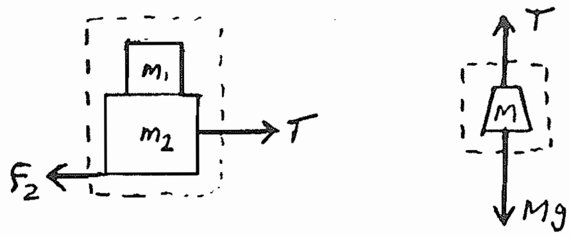
For equating this force to the tension $T = Mg$ — 1 point
$Mg = \mu_{s2}(m_1 + m_2)g$

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

Mech. 3 (continued)

Distribution of points

(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

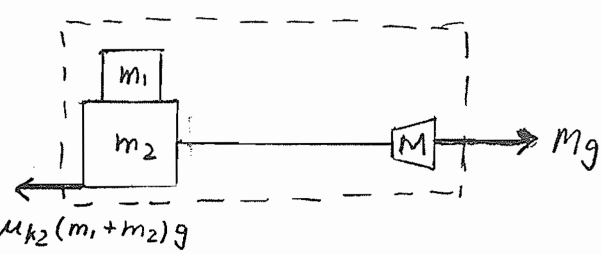
For example, solve each equation for T and set them equal.

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

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

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

(*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*

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

Mech. 3 (continued)

(d)

i. 2 points

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

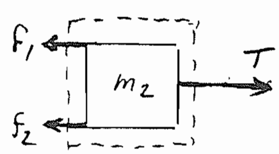
For correct value of f_1 — 1 point

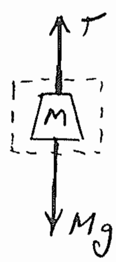
$$f_1 = \mu_{k1} m_1 g$$

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

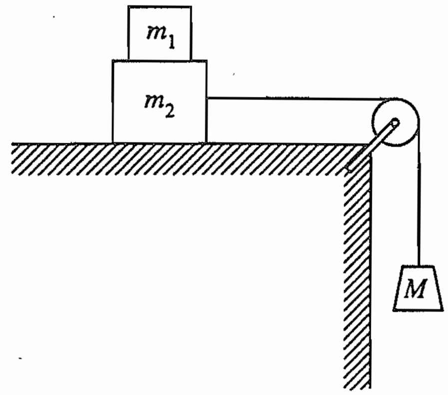
For example, solve each equation for T and set them equal.

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

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

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

Excellent Student Response: 15 points



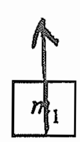
Mech. 3. Block 1 of mass m_1 is placed on block 2 of mass m_2, which is then placed on a table. A string connecting block 2 to a hanging mass M passes over a pulley attached to one end of the table, as shown above. The mass and friction of the pulley are negligible. The coefficients of friction between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

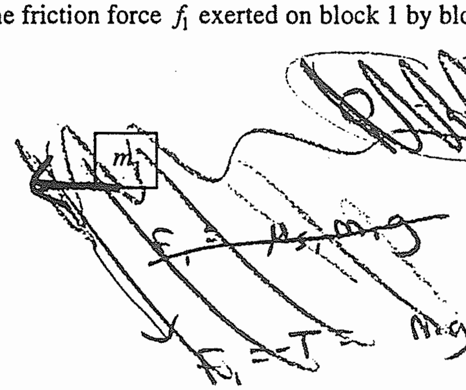
i. The normal force N_1 exerted on block 1 by block 2



$N_1 = m_1 g$

$m_1 g$

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



$\cancel{f_1 = \mu_{s1} m_1 g}$

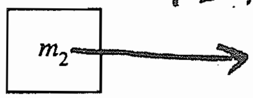
$\cancel{f_1 = T = Mg}$

0

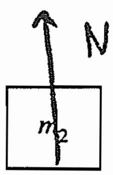
(No force to resist)

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

$T = Mg$



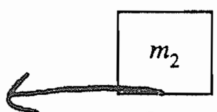
iv. The normal force N_2 exerted on block 2 by the tabletop



$N_2 = (m_1 + m_2)g$

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

$f = \mu F_N$



$f_2 = \mu_{s2}(m_1 + m_2)g$, at max M, otherwise

$f_2 = Mg$

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

$T = Mg = f_2 = \mu_{s2}(m_1 + m_2)g$

$M_{max} = \mu_{s2}(m_1 + m_2)$

(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.

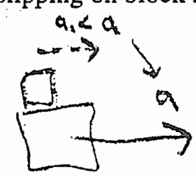
$Mg - T = Ma$ $\qquad$ $T - f_2 = F_{NET} = M_{net}\,a$

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

[illegible] $\qquad a = \cancel{\frac{T+f_2}{M+m_1+m_2}} = \boxed{\dfrac{Mg - \mu_{k2}(m_1+m_2)g}{m_1+m_2+M}}$

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

(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

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

$a_1 = \mu_{k1} g$

ii. The magnitude a_2 of the acceleration of block 2

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

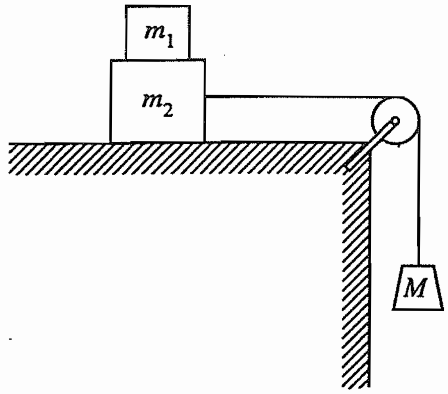
$Mg - T = Ma_2$

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

Commentary:

This is an excellent solution, showing a firm grasp of the principles involved.

Very Good Student Response: 12 points



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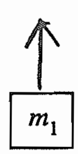
Express your answers in terms of the masses, coefficients of friction, and g, the acceleration due to gravity.

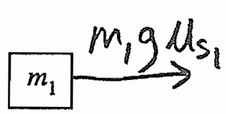
(a) Suppose that the value of M is small enough that the blocks remain at rest when released. For each of the following forces, determine the magnitude of the force and draw a vector on the block provided to indicate the direction of the force if it is nonzero.

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

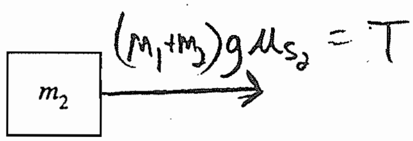


$N_1 = mg$

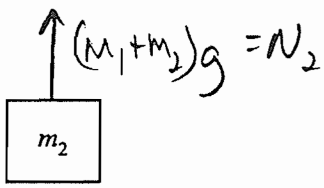
ii. The friction force f_1 exerted on block 1 by block 2



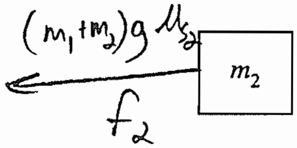
iii. The force T exerted on block 2 by the string



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.

$\Sigma F = ma = 0$ $\qquad$ $Mg - T = Ma = 0$

$m_2 a = 0 = T - (m_1+m_2)g\mu_{s2}$ $\qquad$ $Mg = T$

$$0 = Mg - (m_1+m_2)g\mu_{s2}$$

$$(m_1+m_2)g\mu_{s2} = Mg$$

$$\underline{M = (m_1+m_2)\mu_{s2}}$$

(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.

$$\Sigma F = ma$$

$$Ma = Mg - T \qquad (m_1+m_2)a = T - (m_1+m_2)g\mu_{k_2}$$

$$T = Mg - Ma \qquad (m_1+m_2)a = M(g-a) - (m_1+m_2)g\mu_{k_2}$$

$$\boxed{a = \frac{M(g-a) - (m_1+m_2)g\mu_{k_2}}{m_1+m_2}}$$

(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

$$\Sigma F = ma_1$$

$$m_1 a_1 = m_1 g \mu_{sk_1}$$

$$a_1 = g\mu_{sk_1}$$

ii. The magnitude a_2 of the acceleration of block 2

$$\Sigma F = m_2 a_2 \qquad Ma_2 = Mg - T$$

$$m_2 a_2 = T - (m_1+m_2)g\mu_{k_2} - m_1 g\mu_{k_1}$$

$$ma_2 = Mg - Ma_2 - (m_1+m_2)g\mu_{k_2} - m_1 g\mu_{k_1}$$

$$\boxed{a_2 = \frac{Mg - (m_1+m_2)g\mu_{k_2} - m_1 g\mu_{k_1}}{m_2 + M}}$$

Commentary:

This student makes some mistakes in part (a) and does not completely solve for the acceleration in part (c), but shows a good deal of understanding of the physics in this problem.

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.