AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2017

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

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle 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. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

Form I
Form Code 4NBP4-S

80

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	$1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/(4\pi) = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = {v_{x0}}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

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

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

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

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_N\right|$

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

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

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

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

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

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

$x = x_{\max} \cos(\omega t + \phi)$

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

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

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

$\left|\vec{F}_G\right| = \frac{G m_1 m_2}{r^2}$

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

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0} \left|\frac{q_1 q_2}{r^2}\right|$

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

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

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

$C = \frac{\kappa \varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

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

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

$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C (\Delta V)^2$

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

$\vec{E} = \rho\vec{J}$

$I = Nev_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

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

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \bullet d\vec{A}$

$\varepsilon = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\varepsilon = -L\frac{dI}{dt}$

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

Rectangular Solid

$V = \ell wh$

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

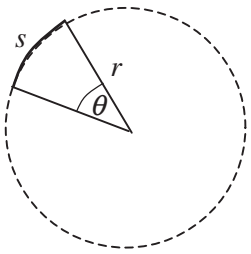
$a^2 + b^2 = c^2$

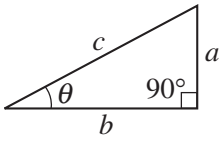
$\sin\theta = \frac{a}{c}$

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

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

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





CALCULUS

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

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

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

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

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

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

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

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

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$\vec{A}\bullet\vec{B} = AB\cos\theta$

$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

PHYSICS C: MECHANICS

SECTION I

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 circle on the answer sheet.

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

1. A plane starts at rest on a straight runway. For the first 30 s, the plane's acceleration a is given as a function of time t by the equation $a = \beta t^2$, where $\beta = 1/90\ \text{m/s}^4$ and t is in seconds.

   What is the plane's speed at t = 30 s ?

   (A) 10 m/s
   (B) 30 m/s
   (C) 100 m/s
   (D) 150 m/s
   (E) 300 m/s

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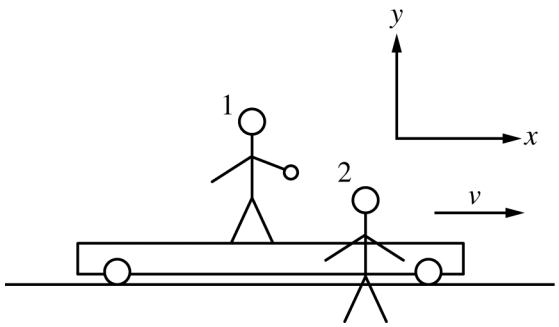
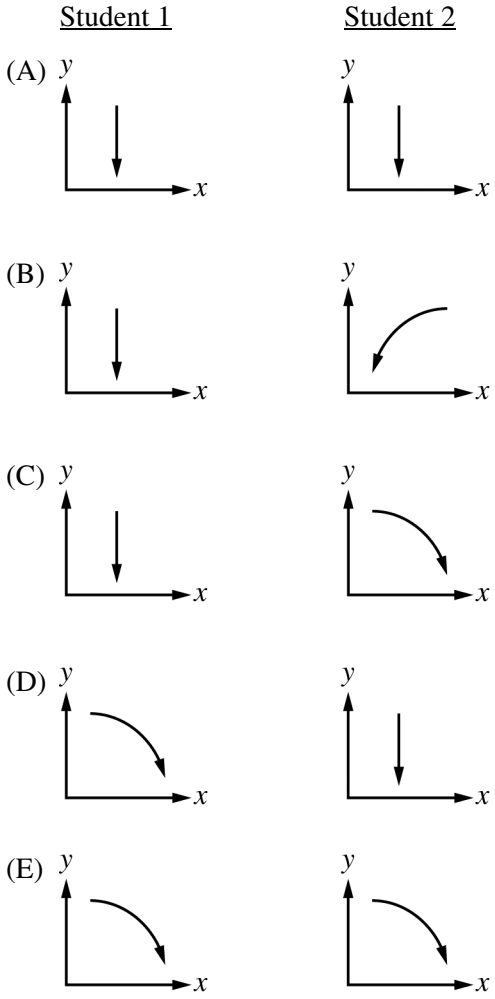


2. Student 1 is standing on a cart holding a small stone, while student 2 is standing at rest on the ground, as shown in the figure above. The cart is moving at a constant speed v in the $+x$-direction, as indicated by the coordinate system shown. Student 1 drops the stone precisely when passing student 2. Which of the following best represents the path of the falling stone relative to student 1 and the path of the falling stone relative to student 2 ?



3. A particle of mass 2.0 kg is moving in the xy-plane at a constant speed of 0.80 m/s in the $+x$-direction along the line $y = 4$ m. As the particle travels from $x = -3$ m to $x = +3$ m, the magnitude of its angular momentum with respect to the origin is

(A) not constant
(B) 0
(C) 4.8 kg•m^2/s
(D) 6.4 kg•m^2/s
(E) 8.0 kg•m^2/s

4. Suppose that a spherical star spinning at an initial angular velocity ω suddenly collapses to half of its original radius without any loss of mass. Assume the star has uniform density before and after the collapse. What will the angular velocity of the star be after the collapse?

(A) $\omega/4$
(B) $\omega/2$
(C) ω
(D) 2ω
(E) 4ω

5. Two identical, unlabeled boxes are transported to an orbiting space station. The astronauts know that one box is filled with a light sample of ants for an experiment, and the other is filled with heavy tools for repairs. How can the astronauts tell, without opening the boxes, which box has the tools?

(A) Weigh each box on a spring scale. The box with the tools will have a higher reading.
(B) Shake each box. The box with the tools will be harder to move back and forth.
(C) Push each box. The box with the tools will travel farther before it stops.
(D) Place each box on opposite sides of a balance. The box on the side that goes down lower will be the box with the tools.
(E) Toss each box straight up. The box with the tools will go higher before coming back down.

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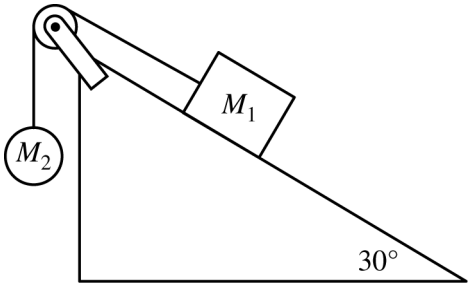

6. A block of mass M_1 is connected by a string to a sphere of mass M_2. The block is on a frictionless plane inclined at an angle of 30°, as shown in the figure above. The string passes over a pulley of negligible mass and friction, and the sphere hangs freely. Which of the following is always true if the block is accelerating down the incline?

(A) $M_1 < M_2$
(B) $M_1 = M_2$
(C) $M_1 < M_2\left(\sin 30^\circ\right)$
(D) $M_1\left(\sin 30^\circ\right) < M_2$
(E) $M_1\left(\sin 30^\circ\right) > M_2$

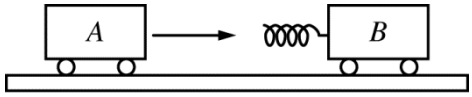

Figure 1

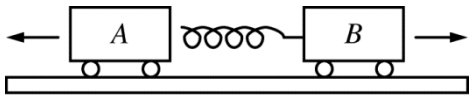

Figure 2

7. Two carts of equal mass are on a horizontal surface with negligible friction. Cart *A* is approaching cart *B*, which is at rest, as shown in Figure 1 above. Attached to cart *B* is a spring that is initially compressed. At the moment cart *A* collides with cart *B*, the spring is released and pushes on cart *A*, as shown in Figure 2 above. Which of the following correctly states what happens to the kinetic energy and the momentum of the two-cart system as a result of the collision compared to those quantities before the collision?

	Kinetic energy	Magnitude of Momentum
(A)	Increases	Decreases
(B)	Increases	Stays the same
(C)	Increases	Increases
(D)	Stays the same	Increases
(E)	Stays the same	Stays the same

8. A ball of mass m is dropped from rest from a height h and collides elastically with the floor, rebounding to its original height. What is the magnitude of the average force applied by the floor on the ball during the time the ball is in contact with the floor?

(A) Zero
(B) mg
(C) $2mg$
(D) $4mg$
(E) It cannot be determined without knowing the length of time that the ball is in contact with the floor.

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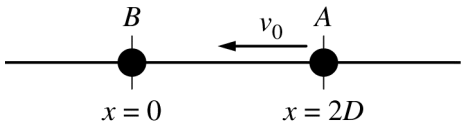
GO ON TO THE NEXT PAGE.

Questions 9-10



Particle A and particle B, each of mass M, move along the x-axis exerting a force on each other. The potential energy of the system of two particles associated with the force is given by the equation $U = \beta/r^2$, where r is the distance between the two particles and β is a positive constant. At time $t = 0$, particle A is located at $x = 2D$ with an initial speed of v_0 to the left, and particle B is at rest at the origin, as shown in the figure above.

9. At time $t = T_1$, particle A is observed to be traveling with speed $2v_0/3$ to the left. The speed and direction of motion of particle B is

   (A) $2v_0/3$ to the left
   (B) $v_0/3$ to the left
   (C) $v_0/3$ to the right
   (D) $2v_0/3$ to the right
   (E) $5v_0/3$ to the right

10. Which of the following equations could be used to find r_{MIN}, the minimum distance between the masses as particle A approaches particle B?

   (A) $\dfrac{\beta}{4D^2} + Mv_0^2 = \dfrac{\beta}{r_{MIN}^2} + M\left(\dfrac{v_0}{2}\right)^2$

   (B) $\dfrac{\beta}{4D^2} + \dfrac{1}{2}Mv_0^2 = \dfrac{\beta}{r_{MIN}^2} + M\left(\dfrac{v_0}{2}\right)^2$

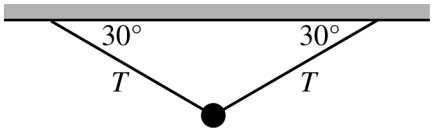
   (C) $\dfrac{\beta}{4D^2} + \dfrac{1}{2}Mv_0^2 = \dfrac{\beta}{r_{MIN}^2} + \dfrac{1}{2}Mv_0^2$

   (D) $\dfrac{\beta}{4D^2} + \dfrac{1}{2}Mv_0^2 = \dfrac{\beta}{r_{MIN}^2}$

   (E) $\dfrac{\beta}{4D^2} + Mv_0^2 = \dfrac{\beta}{r_{MIN}^2}$

11. A 2 kg object is released from rest from a height of 3 m above Earth's surface. How much kinetic energy does the object have when it reaches a height of 1 m?

   (A) 2.5 J
   (B) 10 J
   (C) 20 J
   (D) 30 J
   (E) 40 J



12. A sphere of mass m hangs from two strings that each make an angle of 30° with the horizontal, as shown in the figure above. What is the tension T in one of the strings?

   (A) $mg/6$
   (B) $mg/4$
   (C) $mg/2$
   (D) mg
   (E) $3mg/2$

13. A skier is traveling down a slope that is inclined 30° above the horizontal. The coefficient of kinetic friction between the skier and the slope is 0.10. Which of the following best describes the acceleration of the skier?

   (A) It is zero.
   (B) It is about $4.0\ \text{m/s}^2$.
   (C) It is about $9.0\ \text{m/s}^2$.
   (D) It is about $10\ \text{m/s}^2$.
   (E) It cannot be determined without knowing the mass of the skier.

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GO ON TO THE NEXT PAGE.

Questions 14-16

A ball of mass 2.0 kg is thrown vertically upward from the top of a building. The ball's velocity v is given as a function of time t by the equation $v(t) = R - St$, where $R = 5$ m/s and $S = 10$ m/s^2. The positive direction is upward.

14. What is the ball's acceleration at time $t = 1$ s?

(A) -10 m/s^2
(B) -5 m/s^2
(C) 0
(D) 5 m/s^2
(E) 10 m/s^2

15. At what time does the ball reach its maximum height above the building?

(A) 0.2 s
(B) 0.4 s
(C) 0.5 s
(D) 1.0 s
(E) 2.0 s

16. If the ball reaches the ground at $t = 2.0$ s, what is the height of the building?

(A) 5 m
(B) 10 m
(C) 15 m
(D) 20 m
(E) 30 m

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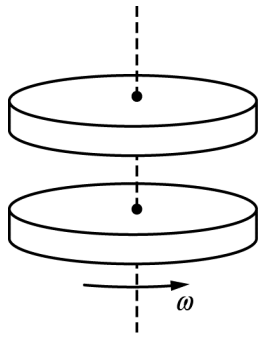
Questions 17-19



A solid disk of mass *M* and radius *R* is freely rotating horizontally in a counterclockwise direction with angular speed ω about a vertical axis through its center with negligible friction. The rotational inertia of the disk is $MR^2/2$. A second identical disk is at rest and suspended above the first disk with the centers of the two disks aligned, as shown in the figure above. There is no contact between the disks. The second disk is dropped onto the first disk, and after a short time they rotate counterclockwise with the same angular speed ω_f.

17. Which of the following properties of the two-disk system must be conserved between the time the second disk is dropped on the first disk and the time that the two disks begin rotating with the same speed?

(A) Kinetic energy only
(B) Angular momentum only
(C) Both kinetic energy and angular momentum
(D) Neither kinetic energy nor angular momentum
(E) It cannot be determined without knowing the nature of the forces between the two disks.

18. The interval of time Δt is the elapsed time from the moment of first contact between the two disks until they are both spinning at the same angular velocity. Which of the following expressions gives the magnitude of the average torque that the first disk exerts on the second disk?

(A) $MR^2\omega_f$
(B) $\dfrac{MR^2\omega_f}{\Delta t}$
(C) $\dfrac{MR^2\omega_f}{2\Delta t}$
(D) $\dfrac{2MR^2\omega_f}{\Delta t}$
(E) It cannot be determined without knowing the nature of the forces between the two disks.

19. The two disks are now shifted so that the axis of rotation goes through a point on the edge of the disks. The rotational inertia of the two-disk system is now

(A) $2MR^2$
(B) $3MR^2$
(C) $4MR^2$
(D) $5MR^2$
(E) $10MR^2$

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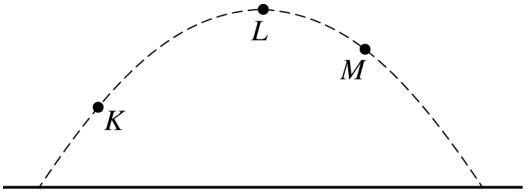


20. A student throws a metal sphere, which follows the path shown above. If air resistance is negligible, which of the following is a correct relationship between the magnitudes of the accelerations a_K, a_L, and a_M at the three points shown?

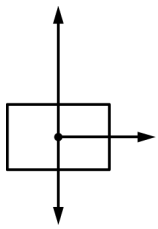
(A) $a_K = a_L = a_M$
(B) $a_K = a_L > a_M$
(C) $a_K = a_M > a_L$
(D) $a_K > a_L = a_M$
(E) $a_K > a_M > a_L$

21. A cannonball is shot from the top of a 30 m high hill at a velocity of 25 m/s and at an angle of 40° above the horizontal and lands on the ground below. The speed of the cannonball at the top of its path is most nearly

(A) 0
(B) 16 m/s
(C) 19 m/s
(D) 25 m/s
(E) 29 m/s

22. A 1500 kg car is pushing a 4000 kg truck. The car and truck are accelerating at 2.0 m/s^2. Assuming that the frictional force on the truck is negligible, what force is the truck exerting on the car?

(A) 0 N
(B) 3000 N
(C) 5000 N
(D) 8000 N
(E) 11,000 N



23. The figure above shows the directions and relative magnitudes of all three forces that are acting on an object. Which of the following best shows the direction of the object's acceleration?

(A) 

(B) 

(C) 

(D) 

(E)

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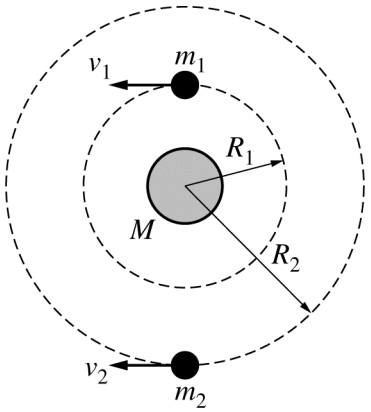
Questions 24-26



Note: Figure not drawn to scale.

Two satellites of masses m_1 and m_2 orbit a planet of mass M in circular orbits. The satellites travel in opposite directions with speeds v_1 and v_2, as shown in the figure above. Their orbital radii are R_1 and R_2, respectively. Assume that $M >> m_2 > m_1$.

24. The ratio of the speeds v_1/v_2 is

(A) $\sqrt{R_2/R_1}$
(B) $\sqrt{R_1/R_2}$
(C) $\sqrt{m_2/m_1}$
(D) $\sqrt{m_1/m_2}$
(E) 1

25. The magnitude of the angular momentum of the two-satellite system is best represented by

(A) $|m_1v_1 + m_2v_2|$
(B) $|m_1v_1 - m_2v_2|$
(C) $|m_1v_1R_1 + m_2v_2R_2|$
(D) $|m_1v_1R_1 - m_2v_2R_2|$
(E) $|m_1v_1/R_1 + m_2v_2/R_2|$

26. If U_1 is the potential energy of the planet-satellite system containing the satellite of mass m_1 and U_2 is the potential energy of the planet-satellite system containing the satellite of mass m_2, which of the following expressions best represents the ratio U_1/U_2 ?

(A) $\frac{m_1R_1}{m_2R_2}$
(B) $\frac{m_2R_2}{m_1R_1}$
(C) $\frac{m_1R_2}{m_2R_1}$
(D) $\frac{m_2R_1}{m_1R_2}$
(E) $\frac{m_1R_2^2}{m_2R_1^2}$

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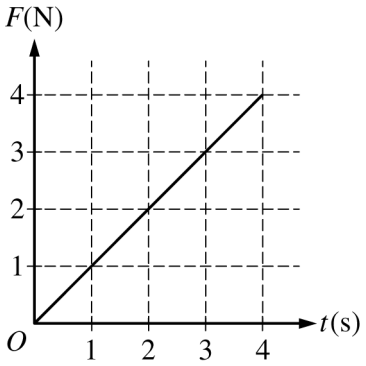
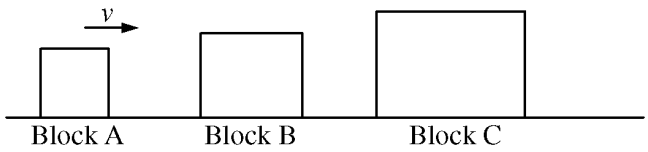


27. The graph above shows a variable force F that acts on an object as it moves along a straight line as a function of time t. What is the change in momentum of the object from $t = 2$ s to $t = 4$ s ?

(A) 1 kg•m/s
(B) 2 kg•m/s
(C) 4 kg•m/s
(D) 6 kg•m/s
(E) 8 kg•m/s



28. Blocks A, B, and C are aligned along a straight line on a horizontal frictionless surface. The masses of the blocks are M, $2M$, and $3M$, respectively. Block A is initially moving to the right along the same line at a speed v, as shown in the figure above. Blocks B and C are initially at rest. Block A collides with and sticks to block B. The two blocks then collide with and stick to block C. What is the speed of block C after the collisions?

(A) 0
(B) $v/6$
(C) $v/3$
(D) $v/2$
(E) $6v$

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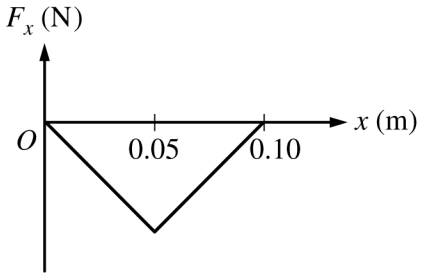


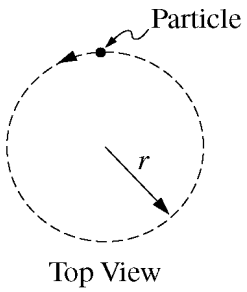
29. The graph above shows a conservative force F_x as a function of position x acting on an object in a closed system. If this is the only force acting on the object, what happens to the potential energy of the system as the object moves from 0 m to 0.10 m?

(A) It increases only.
(B) It decreases only.
(C) It increases and then decreases.
(D) It decreases and then increases.
(E) It does not change.

30. How does the work required to accelerate a particle from 10 m/s to 20 m/s compare to that required to accelerate it from 20 m/s to 30 m/s?

(A) It is less.
(B) It is the same.
(C) It is greater.
(D) It cannot be determined without knowing the magnitude of the force exerted on the particle.
(E) It cannot be determined without knowing the mass of the particle.

Questions 31-32



A particle of mass m moves counterclockwise around a horizontal circle of radius r, as shown above. The angular speed of the particle is given as a function of time t by $\omega(t) = bt$, where b is a positive constant and $t \geq 0$.

31. Which of the following best describes the acceleration vector for the particle at the moment shown in the diagram?

(A) It is directed toward the left.
(B) It is directed toward the bottom of the page.
(C) It is directed toward the top of the page.
(D) It has components directed toward the right and toward the bottom of the page.
(E) It has components directed toward the left and toward the bottom of the page.

32. What is the magnitude of the angular momentum of the particle about the center of the circle as a function of time?

(A) mbt/r
(B) $mbrt$
(C) mbr^2t
(D) mb^2rt^2
(E) $mb^2r^2t^2$

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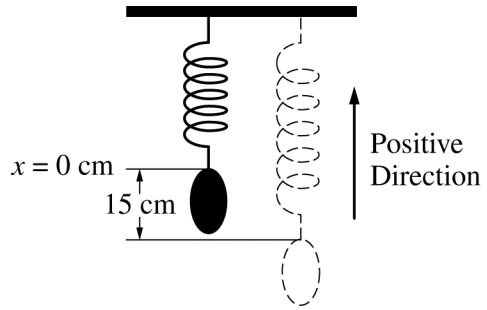
Questions 33-35



An object is initially hanging in equilibrium from a vertical spring. The object is pulled down 15 cm from its equilibrium position, as illustrated above, and released at time $t = 0$. The object then oscillates with a period of 2.0 s. Let $x = 0$ be the equilibrium position and let the positive direction be upward.

33. What is the position of the object at $t = 3.0$ s?

(A) 15 cm
(B) 7.5 cm
(C) 0 cm
(D) −7.5 cm
(E) −15 cm

34. What is the total distance traveled by the object during the first 2.0 s of its motion?

(A) 90 cm
(B) 75 cm
(C) 60 cm
(D) 45 cm
(E) 30 cm

35. Which of the following statements is true of the magnitude of the acceleration of the object at time $t = 1.0$ s?

(A) It is equal to zero.
(B) It is equal to g.
(C) It has its minimum value that is not zero.
(D) It has its maximum value.
(E) It has a value between zero and its maximum value.

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S T O P

END OF MECHANICS SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2017

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

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4NBP4-S

80

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	$1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/(4\pi) = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = {v_{x0}}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

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

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

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

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_N\right|$

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

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

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

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

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

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

$x = x_{\max} \cos(\omega t + \phi)$

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

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

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

$\left|\vec{F}_G\right| = \frac{G m_1 m_2}{r^2}$

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

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0} \left|\frac{q_1 q_2}{r^2}\right|$

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

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

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

$C = \frac{\kappa \varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

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

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

$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C (\Delta V)^2$

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

$\vec{E} = \rho\vec{J}$

$I = Nev_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

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

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \bullet d\vec{A}$

$\varepsilon = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\varepsilon = -L\frac{dI}{dt}$

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

Rectangular Solid

$V = \ell wh$

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

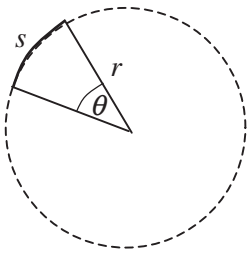
$a^2 + b^2 = c^2$

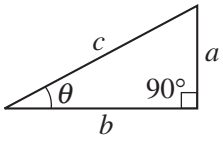
$\sin\theta = \frac{a}{c}$

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

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

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





CALCULUS

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

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

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

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

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

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

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

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

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$\vec{A}\bullet\vec{B} = AB\cos\theta$

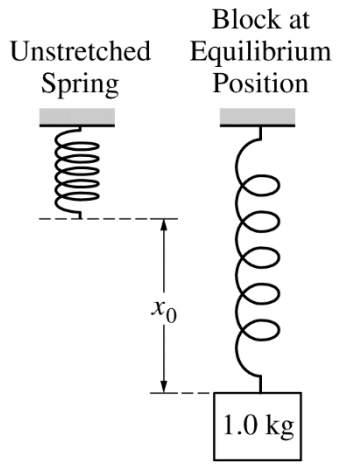
$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

THIS PAGE MAY BE USED FOR SCRATCH WORK.

GO ON TO THE NEXT PAGE.

PHYSICS C: MECHANICS
SECTION II
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.



1. A spring of negligible mass and with a spring constant of $50\ \text{N/m}$ is hung vertically, as shown above in the figure on the left. A block of mass 1.0 kg is attached to the spring and slowly lowered a distance x_0 until it hangs at rest at the equilibrium position, as shown above in the figure on the right.

   (a) On the dot below that represents the block, draw and label the forces (not components) that act on the block when it is at the equilibrium position shown. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

   (b) Calculate the distance x_0 that the spring is stretched from its original length to the equilibrium position.

Question 1 continues on the next 2 pages.

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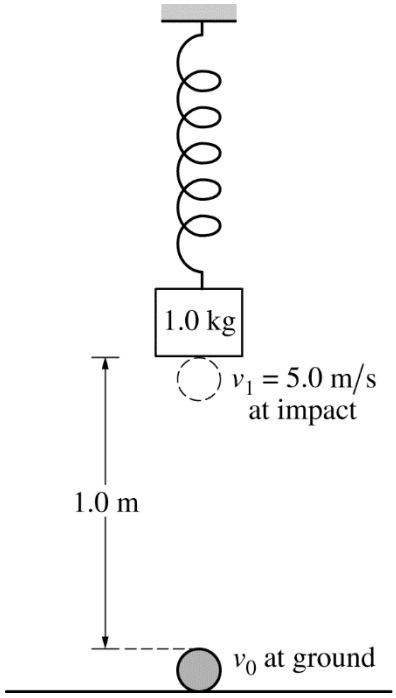

While the 1.0 kg block is in equilibrium, a 0.20 kg ball of clay is launched with speed v_0 vertically from the ground 1.0 meter below the hanging block. The clay has speed $v_1 = 5.0$ m/s when it collides with the block.

(c) Calculate the speed v_0.

Upon impact, the clay sticks to the 1.0 kg block.

(d)

i. Calculate the speed of the block immediately after the collision.

ii. Calculate the kinetic energy lost in the collision.

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iii. Determine the period of oscillation for the block-clay-spring system.

(e) When the oscillating block-clay-spring system reaches its maximum speed after the collision, will the spring be stretched from its original length by a distance greater than, less than, or equal to x_0 ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

(f) The collision is repeated using a rubber ball with the same mass as the ball of clay. The rubber ball is launched vertically with the same speed v_0. The collision between the rubber ball and the block is elastic. Will the speed of the block immediately after colliding with the rubber ball be greater than, less than, or equal to the speed of the block you calculated in part (d)i ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

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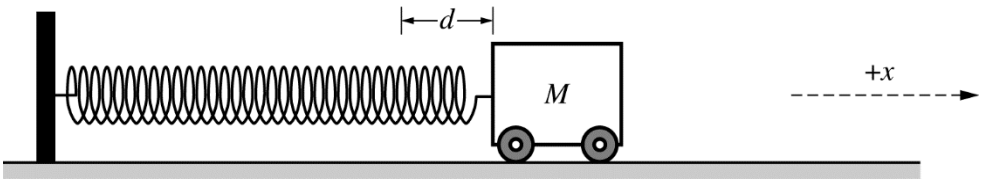
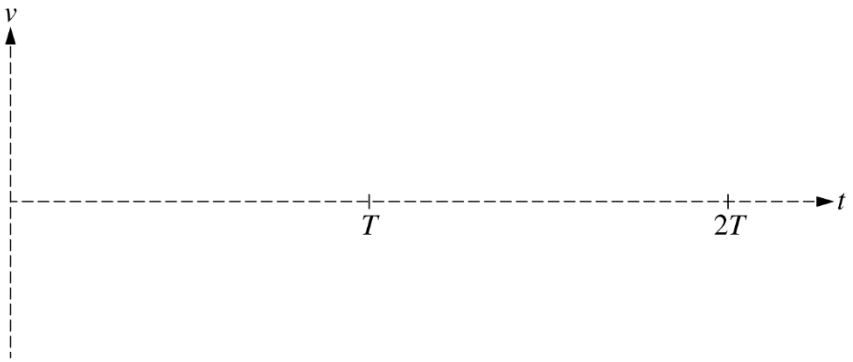


2. A cart of mass M is on a level, horizontal track. The cart is attached to one end of an ideal spring, and the other end of the spring is attached to a vertical support. The spring has a spring constant k. The cart is pulled to the right, stretching the spring a distance d, as shown above, and released from rest at time $t = 0$. The cart-spring system begins to oscillate, and the position x of the cart as a function of time t is given by the equation $x(t) = d\cos(\omega t)$, where x is in meters, ω is in rad/s, and t is in seconds. Assume the mass of the cart's wheels to be negligible.

   (a) Derive an equation for the velocity of the cart v as a function of time t.

   (b) On the axes below, sketch a graph of the velocity v of the cart as a function of time t for two complete oscillations. On the graph, T represents the time for one complete oscillation. Explicitly label asymptotes, maxima, or minima with algebraic expressions, as appropriate.



   (c) Express all answers in part (c) in terms of ω, t, M, d, k, and physical constants, as appropriate.

      i. Determine an expression for the kinetic energy K of the system as a function of time t.

      ii. Determine an expression for the potential energy U of the system as a function of time t.

      iii. Using the equations from parts (c)i and (c)ii, show that the rate of change of the total energy of the system dE/dt is zero.

Question 2 continues on the next 2 pages.

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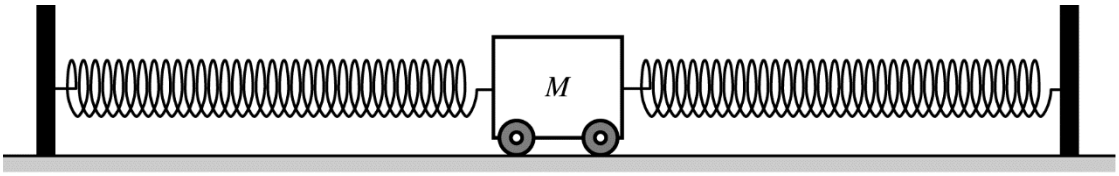


Figure 1

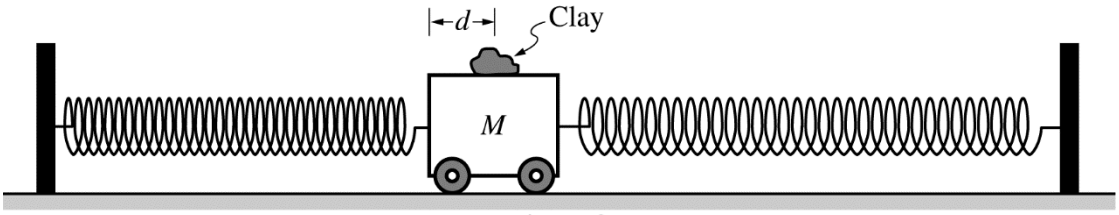
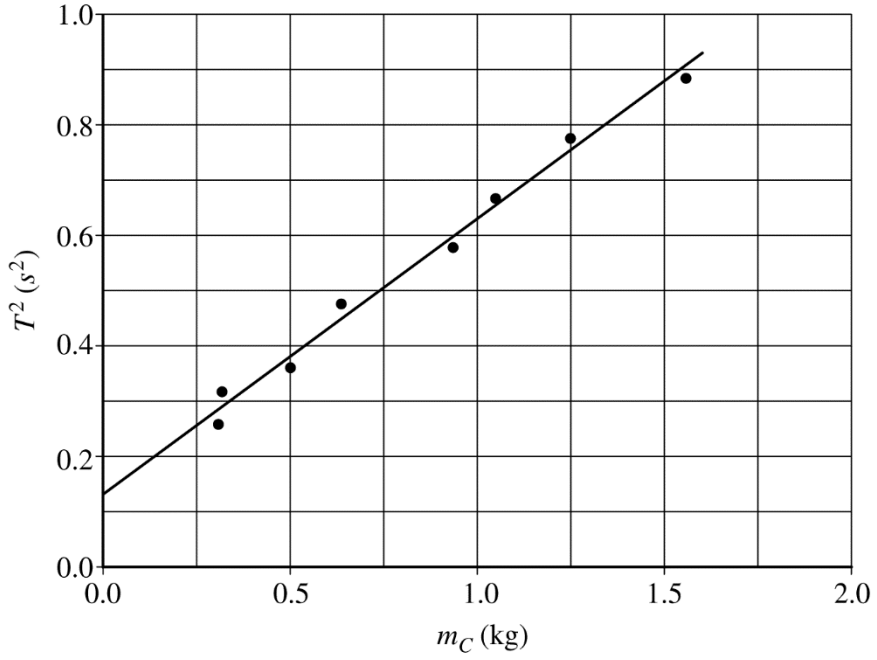


Figure 2

Two springs identical to the spring above are attached to each side of the cart of unknown mass *M*, as shown in Figure 1 above. The cart is on a level, horizontal track of negligible friction. A piece of clay is added to the top of the cart so that it will stick to the cart. The cart is displaced to the left a distance *d* and released from rest, as shown in Figure 2 above. The period of oscillation is recorded. This procedure is repeated for several different pieces of clay of different masses. In each trial, the cart is displaced the same distance *d*. The data are shown below on the linear graph of T^2 as a function of m_C, where *T* is the period of oscillation and m_C represents the mass of the clay.



(d) From the graph, determine the following.

i. *k*, the spring constant of each spring

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ii. M, the mass of the cart

(e) The experiment is repeated, but in a second set of trials, the cart is pulled back a distance D, where $D > d$. Describe any changes that will occur for the straight line on the graph in part (d).

Justify your answer.

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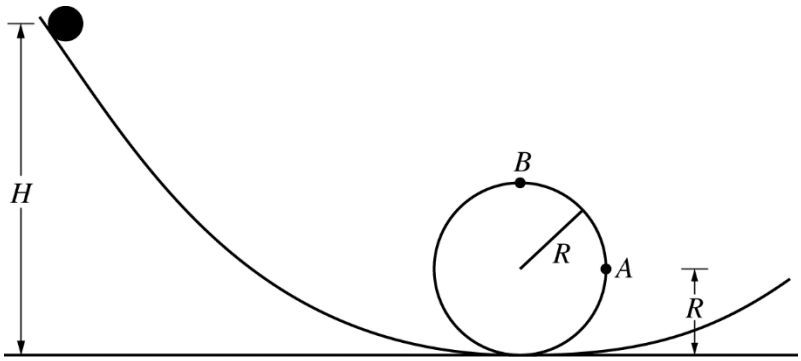
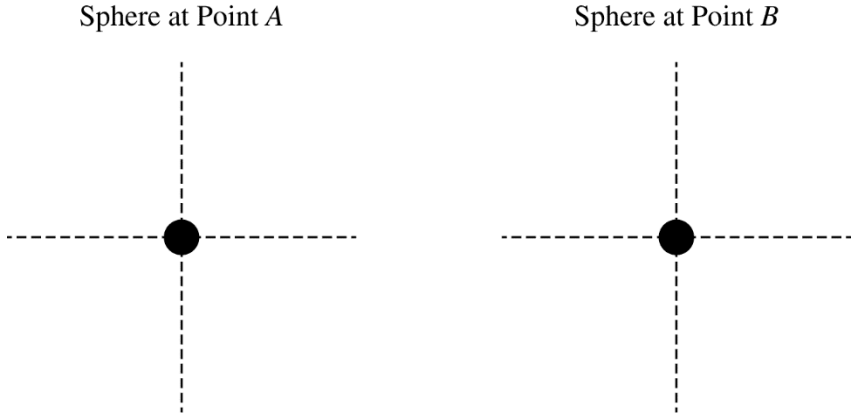


3. A sphere of mass m and radius r is released from rest at the top of a curved track of height H. The sphere travels down the curved track and around a loop of radius R. The sphere rolls without slipping during the entire motion. Point A on the loop is at height R, and point B is at the top of the loop. The rotational inertia of the sphere is $2mr^2/5$. Express all of your answers in parts (a) through (d) in terms of m, r, H, R, and physical constants, as appropriate. Assume $r << R$.

   (a) On the dots below, which represent the sphere, draw and label the forces (not components) that are exerted on the sphere at point A and at point B, respectively. Each force must be represented by a distinct arrow starting on and pointing away from the dot.



   (b)

      i. Derive an expression for the speed of the sphere at point A.

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ii. Derive an expression for the normal force the track exerts on the sphere at point *A*.

(c) Calculate the ratio of the rotational kinetic energy to the translational kinetic energy of the sphere at point *A*.

(d) The minimum release height necessary for the sphere to travel around the loop and not lose contact with the loop at point B is H_{MIN}. The sphere is replaced with a hoop of the same mass and radius. Will the value of H_{MIN} increase, decrease, or stay the same?

____ Increase ____ Decrease ____ Stay the same

Justify your answer.

Question 3 continues on the next page.

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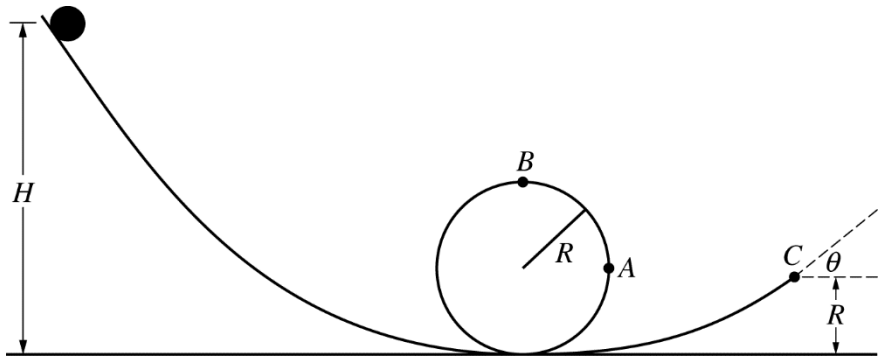

The sphere is again released from a known height H and eventually leaves the track at point C, which is a height R above the bottom of the loop, as shown in the figure above. The track makes an angle of θ above the horizontal at point C. Express your answer in part (e) in terms of m, r, H, R, θ, and physical constants, as appropriate.

(e) Calculate the maximum height above the bottom of the loop that the sphere will reach.

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END OF EXAM

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