



AP[®] Physics C: Mechanics 2005 Free-Response Questions

The College Board: Connecting Students to College Success

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the association is composed of more than 4,700 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three and a half million students and their parents, 23,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT[®], the PSAT/NMSQT[®], and the Advanced Placement Program[®] (AP[®]). The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

Copyright © 2005 by College Board. All rights reserved. College Board, AP Central, APCD, Advanced Placement Program, AP, AP Vertical Teams, Pre-AP, SAT, and the acorn logo are registered trademarks of the College Entrance Examination Board. Admitted Class Evaluation Service, CollegeEd, Connect to college success, MyRoad, SAT Professional Development, SAT Readiness Program, and Setting the Cornerstones are trademarks owned by the College Entrance Examination Board. PSAT/NMSQT is a registered trademark of the College Entrance Examination Board and National Merit Scholarship Corporation. Other products and services may be trademarks of their respective owners. Permission to use copyrighted College Board materials may be requested online at: <http://www.collegeboard.com/inquiry/cbpermit.html>.

Visit the College Board on the Web: www.collegeboard.com.

AP Central is the official online home for the AP Program and Pre-AP: apcentral.collegeboard.com.

TABLE OF INFORMATION FOR 2005

CONSTANTS AND CONVERSION FACTORS		UNITS		PREFIXES		
		Name	Symbol	Factor	Prefix	Symbol
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$			10^9	giga	G
	$= 931 \text{ MeV}/c^2$	meter	m	10^6	mega	M
Proton mass,	$m_p = 1.67 \times 10^{-27} \text{ kg}$	kilogram	kg	10^3	kilo	k
Neutron mass,	$m_n = 1.67 \times 10^{-27} \text{ kg}$	second	s	10^{-2}	centi	c
Electron mass,	$m_e = 9.11 \times 10^{-31} \text{ kg}$	ampere	A	10^{-3}	milli	m
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19} \text{ C}$	kelvin	K	10^{-6}	micro	μ
Avogadro's number,	$N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	mole	mol	10^{-9}	nano	n
Universal gas constant,	$R = 8.31 \text{ J}/(\text{mol} \cdot \text{K})$	hertz	Hz	10^{-12}	pico	p
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23} \text{ J/K}$	newton	N	VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES		
Speed of light,	$c = 3.00 \times 10^8 \text{ m/s}$	pascal	Pa			
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$	joule	J	θ	$\sin \theta$	$\cos \theta$
	$hc = 1.99 \times 10^{-25} \text{ J} \cdot \text{m}$	watt	W	0°	0	1
	$= 1.24 \times 10^3 \text{ eV} \cdot \text{nm}$	coulomb	C	30°	1/2	$\sqrt{3}/2$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$	volt	V	45°	$\sqrt{2}/2$	$\sqrt{2}/2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$	ohm	Ω	60°	$\sqrt{3}/2$	1
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T} \cdot \text{m})/\text{A}$	henry	H	90°	1	∞
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7} (\text{T} \cdot \text{m})/\text{A}$	farad	F			
Universal gravitational constant,	$G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2$	tesla	T			
Acceleration due to gravity at the Earth's surface,	$g = 9.8 \text{ m/s}^2$	degree	$^\circ$			
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2$	Celsius	$^\circ\text{C}$			
	$= 1.0 \times 10^5 \text{ Pa}$	electron-volt	eV			
1 electron volt,	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$					

The following conventions are used in this examination.

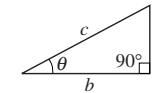
- I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
- II. The direction of any electric current is the direction of flow of positive charge (conventional current).
- III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2004 and 2005

MECHANICS	ELECTRICITY AND MAGNETISM
$v = v_0 + at$ $x = x_0 + v_0t + \frac{1}{2}at^2$ $v^2 = v_0^2 + 2a(x - x_0)$ $\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$ $\mathbf{F} = \frac{d\mathbf{p}}{dt}$ $\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$ $\mathbf{p} = m\mathbf{v}$ $F_{fric} \leq \mu N$ $W = \int \mathbf{F} \cdot d\mathbf{r}$ $K = \frac{1}{2}mv^2$ $P = \frac{dW}{dt}$ $P = \mathbf{F} \cdot \mathbf{v}$ $\Delta U_g = mgh$ $a_c = \frac{v^2}{r} = \omega^2 r$ $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$ $\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$ $I = \int r^2 dm = \Sigma mr^2$ $\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$ $v = r\omega$ $\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$ $K = \frac{1}{2}I\omega^2$ $\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$ $\mathbf{F}_s = -k\mathbf{x}$ $U_s = \frac{1}{2}kx^2$ $T = \frac{2\pi}{\omega} = \frac{1}{f}$ $T_s = 2\pi\sqrt{\frac{m}{k}}$ $T_p = 2\pi\sqrt{\frac{\ell}{g}}$ $\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$ $U_G = -\frac{Gm_1m_2}{r}$	$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$ $\mathbf{E} = \frac{\mathbf{F}}{q}$ $\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$ $E = -\frac{dV}{dr}$ $V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$ $U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$ $C = \frac{Q}{V}$ $C = \frac{\kappa\epsilon_0 A}{d}$ $C_p = \sum_i C_i$ $\frac{1}{C_s} = \sum_i \frac{1}{C_i}$ $I = \frac{dQ}{dt}$ $U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$ $R = \frac{\rho\ell}{A}$ $V = IR$ $R_s = \sum_i R_i$ $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ $P = IV$ $\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$ $\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$ $\mathbf{F} = \int I d\boldsymbol{\ell} \times \mathbf{B}$ $B_s = \mu_0 nI$ $\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$ $\mathcal{E} = -\frac{d\phi_m}{dt}$ $\mathcal{E} = -L\frac{dI}{dt}$ $U_L = \frac{1}{2}LI^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2004 and 2005

GEOMETRY AND TRIGONOMETRY	CALCULUS
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 $a^2 + b^2 = c^2$ $\sin \theta = \frac{a}{c}$ $\cos \theta = \frac{b}{c}$ $\tan \theta = \frac{a}{b}$	$A = \text{area}$ $C = \text{circumference}$ $V = \text{volume}$ $S = \text{surface area}$ $b = \text{base}$ $h = \text{height}$ $\ell = \text{length}$ $w = \text{width}$ $r = \text{radius}$ $\frac{df}{dx} = \frac{df}{du} \frac{du}{dx}$ $\frac{d}{dx}(x^n) = nx^{n-1}$ $\frac{d}{dx}(e^x) = e^x$ $\frac{d}{dx}(\ln x) = \frac{1}{x}$ $\frac{d}{dx}(\sin x) = \cos x$ $\frac{d}{dx}(\cos x) = -\sin x$ $\int x^n dx = \frac{1}{n+1}x^{n+1}, n \neq -1$ $\int e^x dx = e^x$ $\int \frac{dx}{x} = \ln x$ $\int \cos x dx = \sin x$ $\int \sin x dx = -\cos x$



2005 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

PHYSICS C

Section II, MECHANICS

Time—45 minutes

3 Questions

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

Mech. 1.

A ball of mass M is thrown vertically upward with an initial speed of v_0 . It experiences a force of air resistance given by $\mathbf{F} = -k\mathbf{v}$, where k is a positive constant. The positive direction for all vector quantities is upward. Express all algebraic answers in terms of M , k , v_0 , and fundamental constants.

- (a) Does the magnitude of the acceleration of the ball increase, decrease, or remain the same as the ball moves upward?

_____ increases _____ decreases _____ remains the same

Justify your answer.

- (b) Write, but do NOT solve, a differential equation for the instantaneous speed v of the ball in terms of time t as the ball moves upward.

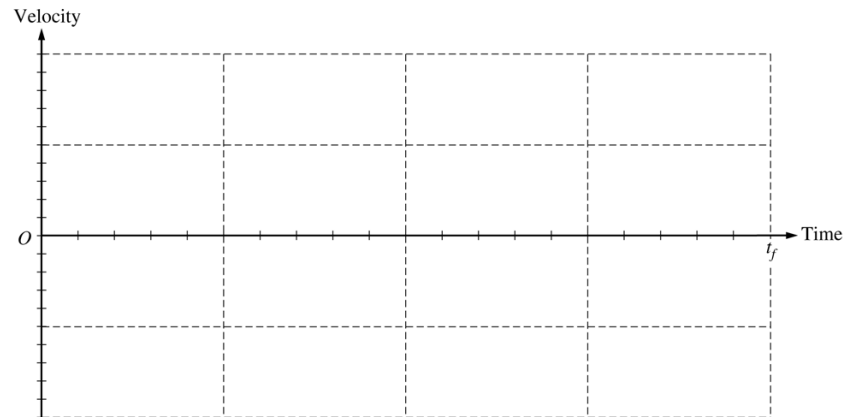
- (c) Determine the terminal speed of the ball as it moves downward.

- (d) Does it take longer for the ball to rise to its maximum height or to fall from its maximum height back to the height from which it was thrown?

_____ longer to rise _____ longer to fall

Justify your answer.

- (e) On the axes below, sketch a graph of velocity versus time for the upward and downward parts of the ball's flight, where t_f is the time at which the ball returns to the height from which it was thrown.



Copyright © 2005 by College Entrance Examination Board. All rights reserved.
Visit apcentral.collegeboard.com (for AP professionals) and www.collegeboard.com/apstudents (for AP students and parents).

GO ON TO THE NEXT PAGE.

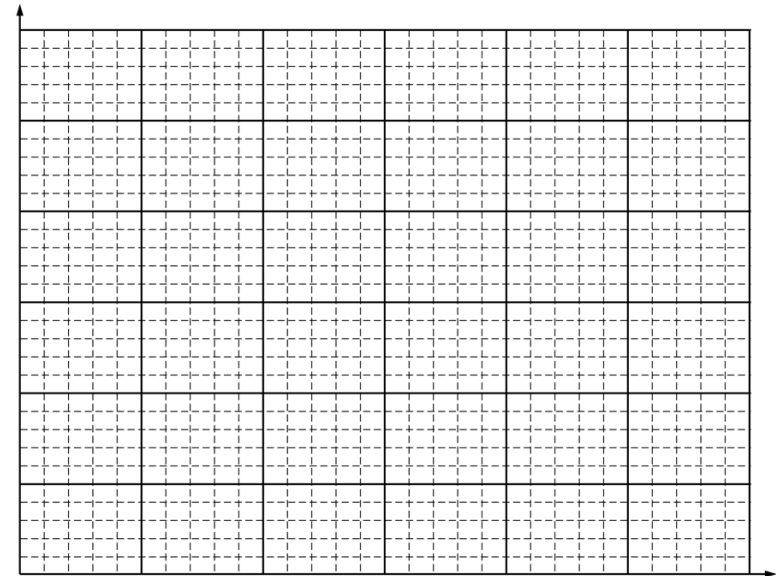
2005 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

Mech. 2.

A student is given the set of orbital data for some of the moons of Saturn shown below and is asked to use the data to determine the mass M_S of Saturn. Assume the orbits of these moons are circular.

Orbital Period, T (seconds)	Orbital Radius, R (meters)		
8.14×10^4	1.85×10^8		
1.18×10^5	2.38×10^8		
1.63×10^5	2.95×10^8		
2.37×10^5	3.77×10^8		

- (a) Write an algebraic expression for the gravitational force between Saturn and one of its moons.
- (b) Use your expression from part (a) and the assumption of circular orbits to derive an equation for the orbital period T of a moon as a function of its orbital radius R .
- (c) Which quantities should be graphed to yield a straight line whose slope could be used to determine Saturn's mass?
- (d) Complete the data table by calculating the two quantities to be graphed. Label the top of each column, including units.
- (e) Plot the graph on the axes below. Label the axes with the variables used and appropriate numbers to indicate the scale.

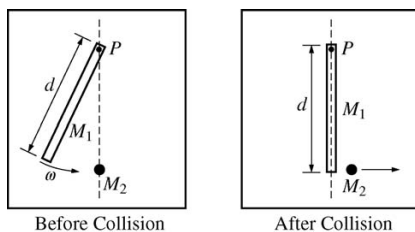


- (f) Using the graph, calculate a value for the mass of Saturn.

Copyright © 2005 by College Entrance Examination Board. All rights reserved.
Visit apcentral.collegeboard.com (for AP professionals) and www.collegeboard.com/apstudents (for AP students and parents).

GO ON TO THE NEXT PAGE.

2005 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

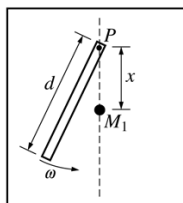


TOP VIEWS

Mech. 3.

A system consists of a ball of mass M_2 and a uniform rod of mass M_1 and length d . The rod is attached to a horizontal frictionless table by a pivot at point P and initially rotates at an angular speed ω , as shown above left. The rotational inertia of the rod about point P is $\frac{1}{3}M_1d^2$. The rod strikes the ball, which is initially at rest. As a result of this collision, the rod is stopped and the ball moves in the direction shown above right. Express all answers in terms of M_1 , M_2 , ω , d , and fundamental constants.

- Derive an expression for the angular momentum of the rod about point P before the collision.
- Derive an expression for the speed v of the ball after the collision.
- Assuming that this collision is elastic, calculate the numerical value of the ratio M_1/M_2 .



Before Collision

- A new ball with the same mass M_1 as the rod is now placed a distance x from the pivot, as shown above. Again assuming the collision is elastic, for what value of x will the rod stop moving after hitting the ball?

END OF SECTION II, MECHANICS