



AP[®] Physics C: Mechanics 2012 Free-Response Questions

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TABLE OF INFORMATION DEVELOPED FOR 2012

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, $N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant, $R = 8.31 \text{ J}/(\text{mol}\cdot\text{K})$	Acceleration due to gravity at Earth's surface, $g = 9.8 \text{ m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23} \text{ J/K}$	
1 unified atomic mass unit, $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$	
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, $\mu_0 = 4\pi \times 10^{-7} \text{ (T}\cdot\text{m)}/\text{A}$	
Magnetic constant, $k' = \mu_0/4\pi = 1 \times 10^{-7} \text{ (T}\cdot\text{m)}/\text{A}$	
1 atmosphere pressure, $1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2 = 1.0 \times 10^5 \text{ Pa}$	

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 conventions are used in this exam.

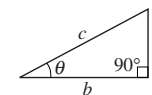
- I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
- II. The direction of any electric current is the direction of flow of positive charge (conventional current).
- III. For any isolated electric charge, the electric potential is defined as zero at an infinite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

ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

MECHANICS	ELECTRICITY AND MAGNETISM
$v = v_0 + at$ $x = x_0 + v_0 t + \frac{1}{2}at^2$ $v^2 = v_0^2 + 2a(x - x_0)$ $\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$ $\mathbf{F} = \frac{d\mathbf{p}}{dt}$ $\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$ $\mathbf{p} = m\mathbf{v}$ $F_{fric} \leq \mu N$ $W = \int \mathbf{F} \cdot d\mathbf{r}$ $K = \frac{1}{2}mv^2$ $P = \frac{dW}{dt}$ $P = \mathbf{F} \cdot \mathbf{v}$ $\Delta U_g = mgh$ $a_c = \frac{v^2}{r} = \omega^2 r$ $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$ $\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$ $I = \int r^2 dm = \Sigma mr^2$ $\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$ $v = r\omega$ $\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$ $K = \frac{1}{2}I\omega^2$ $\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$ $\mathbf{E} = \frac{\mathbf{F}}{q}$ $\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$ $E = -\frac{dV}{dr}$ $V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$ $U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$ $C = \frac{Q}{V}$ $C = \frac{\kappa\epsilon_0 A}{d}$ $C_p = \sum_i C_i$ $\frac{1}{C_s} = \sum_i \frac{1}{C_i}$ $I = \frac{dQ}{dt}$ $U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$ $R = \frac{\rho\ell}{A}$ $\mathbf{E} = \rho\mathbf{J}$ $I = Nev_d A$ $V = IR$ $R_s = \sum_i R_i$ $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ $P = IV$ $\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$
$a = \text{acceleration}$ $F = \text{force}$ $f = \text{frequency}$ $h = \text{height}$ $I = \text{rotational inertia}$ $J = \text{impulse}$ $K = \text{kinetic energy}$ $k = \text{spring constant}$ $\ell = \text{length}$ $L = \text{angular momentum}$ $m = \text{mass}$ $N = \text{normal force}$ $P = \text{power}$ $p = \text{momentum}$ $r = \text{radius or distance}$ $\mathbf{r} = \text{position vector}$ $T = \text{period}$ $U = \text{potential energy}$ $v = \text{velocity or speed}$ $W = \text{work done on a system}$ $x = \text{position}$ $\mu = \text{coefficient of friction}$ $\theta = \text{angle}$ $\tau = \text{torque}$ $\omega = \text{angular speed}$ $\alpha = \text{angular acceleration}$ $\phi = \text{phase angle}$	$A = \text{area}$ $B = \text{magnetic field}$ $C = \text{capacitance}$ $d = \text{distance}$ $E = \text{electric field}$ $\mathcal{E} = \text{emf}$ $F = \text{force}$ $I = \text{current}$ $J = \text{current density}$ $L = \text{inductance}$ $\ell = \text{length}$ $n = \text{number of loops of wire per unit length}$ $N = \text{number of charge carriers per unit volume}$ $P = \text{power}$ $Q = \text{charge}$ $q = \text{point charge}$ $R = \text{resistance}$ $r = \text{distance}$ $t = \text{time}$ $U = \text{potential or stored energy}$ $V = \text{electric potential}$ $v = \text{velocity or speed}$ $\rho = \text{resistivity}$ $\phi_m = \text{magnetic flux}$ $\kappa = \text{dielectric constant}$

ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

GEOMETRY AND TRIGONOMETRY	CALCULUS
Rectangle $A = bh$ Triangle $A = \frac{1}{2}bh$ Circle $A = \pi r^2$ $C = 2\pi r$ 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 $a^2 + b^2 = c^2$ $\sin \theta = \frac{a}{c}$ $\cos \theta = \frac{b}{c}$ $\tan \theta = \frac{a}{b}$	$\frac{df}{dx} = \frac{df}{du} \frac{du}{dx}$ $\frac{d}{dx}(x^n) = nx^{n-1}$ $\frac{d}{dx}(e^x) = e^x$ $\frac{d}{dx}(\ln x) = \frac{1}{x}$ $\frac{d}{dx}(\sin x) = \cos x$ $\frac{d}{dx}(\cos x) = -\sin x$ $\int x^n dx = \frac{1}{n+1}x^{n+1}, n \neq -1$ $\int e^x dx = e^x$ $\int \frac{dx}{x} = \ln x$ $\int \cos x dx = \sin x$ $\int \sin x dx = -\cos x$



2012 AP[®] PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

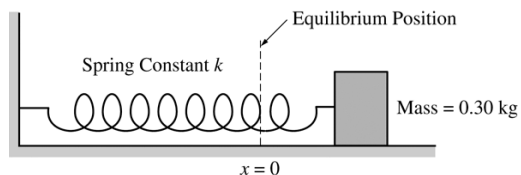
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

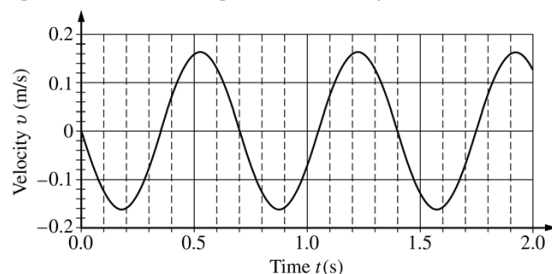
3 Questions

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.



Mech. 1.

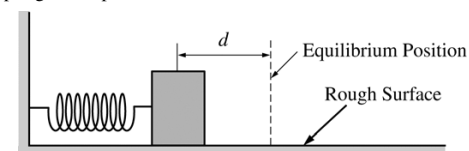
Experiment 1. A block of mass 0.30 kg is placed on a frictionless table and is attached to one end of a horizontal spring of spring constant k , as shown above. The other end of the spring is attached to a fixed wall. The block is set into oscillatory motion by stretching the spring and releasing the block from rest at time $t = 0$. A motion detector is used to record the position of the block as it oscillates. The resulting graph of velocity v versus time t is shown below. The positive direction for all quantities is to the right.



- Determine the equation for $v(t)$, including numerical values for all constants.
- Given that the equilibrium position is at $x = 0$, determine the equation for $x(t)$, including numerical values for all constants.
- Calculate the value of k .

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Experiment 2. The block and spring arrangement is now placed on a rough surface, as shown below. The block is displaced so that the spring is compressed a distance d and released from rest.

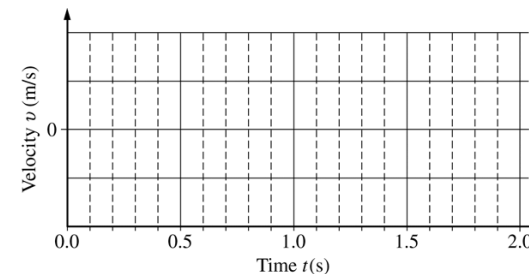


- On the dots below that represent the block, draw and label the forces (not components) that act on the block when the spring is compressed a distance $x = d/2$ and the block is moving in the direction indicated below each dot.

•
Toward
the equilibrium position

•
Away from
the equilibrium position

- Draw a sketch of v versus t in this case. Assume that there is a negligible change in the period and that the positive direction is still to the right.



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Mech. 2.

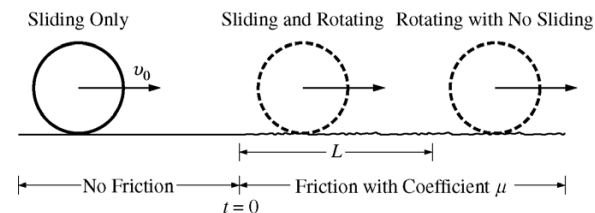
You are to perform an experiment investigating the conservation of mechanical energy involving a transformation from initial gravitational potential energy to translational kinetic energy.

- (a) You are given the equipment listed below, all the supports required to hold the equipment, and a lab table. On the list below, indicate each piece of equipment you would use by checking the line next to each item.

☐ Track	☐ Meterstick	☐ Set of objects of different masses
☐ Cart	☐ Electronic balance	☐ Lightweight low-friction pulley
☐ String	☐ Stopwatch	

- (b) Outline a procedure for performing the experiment. Include a diagram of your experimental setup. Label the equipment in your diagram. Also include a description of the measurements you would make and a symbol for each measurement.
- (c) Give a detailed account of the calculations of gravitational potential energy and translational kinetic energy both before and after the transformation, in terms of the quantities measured in part (b).
- (d) After your first trial, your calculations show that the energy increased during the experiment. Assuming you made no mathematical errors, give a reasonable explanation for this result.
- (e) On all other trials, your calculations show that the energy decreased during the experiment. Assuming you made no mathematical errors, give a reasonable physical explanation for the fact that the average energy you determined decreased. Include references to conservative and nonconservative forces, as appropriate.

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Mech. 3.

A ring of mass M , radius R , and rotational inertia MR^2 is initially sliding on a frictionless surface at constant velocity v_0 to the right, as shown above. At time $t = 0$ it encounters a surface with coefficient of friction μ and begins sliding and rotating. After traveling a distance L , the ring begins rolling without sliding. Express all answers to the following in terms of M , R , v_0 , μ , and fundamental constants, as appropriate.

- (a) Starting from Newton's second law in either translational or rotational form, as appropriate, derive a differential equation that can be used to solve for the magnitude of the following as the ring is sliding and rotating.
- The linear velocity v of the ring as a function of time t
 - The angular velocity ω of the ring as a function of time t
- (b) Derive an expression for the magnitude of the following as the ring is sliding and rotating.
- The linear velocity v of the ring as a function of time t
 - The angular velocity ω of the ring as a function of time t
- (c) Derive an expression for the time it takes the ring to travel the distance L .
- (d) Derive an expression for the magnitude of the velocity of the ring immediately after it has traveled the distance L .
- (e) Derive an expression for the distance L .

STOP

END OF EXAM