

AP[®] Physics C: Mechanics 2008 Free-Response Questions

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TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS						
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19} \text{ C}$					
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, 1 eV = 1.60×10^{-19} J					
Electron mass, $m_e = 9.11 \times 10^{-31} \text{ kg}$	Speed of light, $c = 3.00 \times 10^8 \text{ m/s}$					
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, $R = 8.31 \text{ J/(mol}\cdot\text{K})$	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,	$\boldsymbol{\epsilon}_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$					
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,	$\mu_0 = 4\pi \times 10^{-7} \text{ (T-m)/A}$					
Magnetic constant,	$k' = \mu_0 / 4\pi = 10^{-7} \text{ (T-m)/A}$					
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2 = 1.0 \times 10^5 \text{ Pa}$					

	meter,	m	mole,	mol	watt,	W	farad,	F
LINUT	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	Т
UNIT SYMBOLS	second,	S	newton,	Ν	volt,	V	degree Celsius,	°C
SIMBOLS	ampere,	А	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	Κ	joule,	J	henry,	Н		

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
sin $ heta$	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 0	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	8

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.

MECHANICS

-	
$v = v_0 + at$	a = acceleration F = force
$x = x_0 + v_0 t + \frac{1}{2}at^2$	f = frequency h = height
$v^2 = v_0^2 + 2a(x - x_0)$	I = rotational inertial J = impulse
$\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$	K = kinetic energy k = spring constant
$\mathbf{F} = \frac{d\mathbf{p}}{dt}$	ℓ = length L = angular moment m = mass
$\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$	N = normal force P = power
$\mathbf{p} = m\mathbf{v}$	p = momentum r = radius or distant
$F_{fric} \le \mu N$	\mathbf{r} = position vector T = period
$W = \int \mathbf{F} \cdot d\mathbf{r}$	t = time U = potential energ
$K = \frac{1}{2}mv^2$	v = velocity or spec W = work done on a x = position
$P = \frac{dW}{dt}$	$\mu = \text{coefficient of f}$ $\theta = \text{angle}$
$P = \mathbf{F} \cdot \mathbf{v}$	τ = torque ω = angular speed
$\Delta U_g = mgh$	α = angular speed α = angular acceler
$a_c = \frac{v^2}{r} = \omega^2 r$	$\mathbf{F}_s = -k\mathbf{x}$
$\tau = \mathbf{r} \times \mathbf{F}$	$U_s = \frac{1}{2}kx^2$
$\sum \tau = \tau_{net} = I\alpha$ $I = \int r^2 dm = \sum mr^2$	_
$I = \int r^2 dm = \sum mr^2$	$T = \frac{2\pi}{\omega} = \frac{1}{f}$
$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$	$T_s = 2\pi \sqrt{\frac{m}{k}}$
$v = r\omega$	π 2 ℓ
$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$	$T_p = 2\pi \sqrt{\frac{\ell}{g}}$
$K = \frac{1}{2}I\omega^2$	$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$
$\omega = \omega_0 + \alpha t$	$U_G = -\frac{Gm_1m_2}{r}$
$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	r

-		
cceleration	$-1 q_1 q_2$	A =
orce	$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$	B =
requency	0 7	C =
eight	$\mathbf{E} = \frac{\mathbf{F}}{q}$	d =
otational inertia	$\mathbf{E} = \frac{1}{q}$	E =
npulse		<i>E</i> =
inetic energy	$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$	F =
pring constant	$J \epsilon_0$	<i>I</i> =
ngth	dV	J =
ngular momentum	$E = -\frac{dV}{dr}$	L =
ass	ur ur	$\ell =$
ormal force	$1 \Sigma q_i$	<i>n</i> =
ower	$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$	
omentum		N =
dius or distance	$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$	_
osition vector	$\int O_E - q v - 4\pi\epsilon_0 r$	P =
eriod		<i>Q</i> =
me	$C = \frac{Q}{V}$	q =
otential energy	V	R =
elocity or speed	κεΩΑ	<i>r</i> =
ork done on a system	$C = \frac{\kappa \epsilon_0 A}{d}$	t =
osition		U =
pefficient of friction	$C_p = \sum_i C_i$	V =
ngle	l	<i>υ</i> =
orque	$1 - \Sigma^{1}$	ρ =
ngular speed	$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$	$\phi_m =$
ngular acceleration		κ =
	$I = \frac{dQ}{dt}$	
	dt	
-k x	$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$	∮B
	$O_c = \frac{1}{2}QV = \frac{1}{2}CV$	J
$\frac{1}{2}kx^2$		$d\mathbf{B} =$
2	$R = \frac{\rho\ell}{A}$	а р -
π 1	A	_
$\frac{\pi}{p} = \frac{1}{f}$	$\mathbf{E} = \rho \mathbf{J}$	F =
	I Mari A	D _
$\pi \sqrt{\frac{m}{k}}$	$I = Neo_d A$	$B_s =$
\mathbb{V}_k	V = IR	
Ø		<i>_m</i> =
$2\pi\sqrt{\frac{\ell}{g}}$	$R_{s} = \sum_{i} R_{i}$	
V S	L L	<i>E</i> =
Gm_1m_2	$\frac{1}{1} = \Sigma \frac{1}{1}$	
$-\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$	$R_{p} \xrightarrow{i} R_{i}$	<i>E</i> =
$-\frac{Gm_1m_2}{r}$	P = IV	U_L =
r	$\mathbf{F}_{M} = q\mathbf{v} \times \mathbf{B}$	$\sim L$
	$\mathbf{F} = \frac{1}{A}$ $\mathbf{E} = \rho \mathbf{J}$ $I = Nev_d A$ $V = IR$ $R_s = \sum_i R_i$ $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ $P = IV$ $\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$	

area magnetic field capacitance distance electric field emf force current current density inductance length number of loops of wire per unit length number of charge carriers per unit volume power charge point charge resistance distance time potential or stored energy electric potential velocity or speed resistivity = magnetic flux dielectric constant $\cdot d\ell = \mu_0 I$ $=\frac{\mu_0}{4}\frac{I\,d\ell \times \mathbf{r}}{2}$

ELECTRICITY AND MAGNETISM

$$4\pi r^{3}$$

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

$$B_{s} = \mu_{0} n I$$

$$\phi_{m} = \int \mathbf{B} \cdot d\mathbf{A}$$

$$\boldsymbol{\varepsilon} = -\frac{d\phi_{m}}{dt}$$

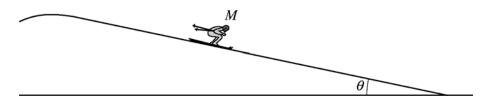
$$\boldsymbol{\varepsilon} = -L \frac{dI}{dt}$$

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

CALCULUS **GEOMETRY AND TRIGONOMETRY** Rectangle A = area $\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$ C = circumferenceA = bhV = volumeTriangle $\frac{d}{dx}(x^n) = nx^{n-1}$ S = surface area $A = \frac{1}{2}bh$ b = base $\frac{d}{dx}(e^x) = e^x$ h = heightCircle $\ell = \text{length}$ $\frac{d}{dx}(\ln x) = \frac{1}{x}$ w = width $A = \pi r^2$ r = radius $C = 2\pi r$ $\frac{d}{dx}(\sin x) = \cos x$ Parallelepiped $V = \ell w h$ $\frac{d}{dx}(\cos x) = -\sin x$ Cylinder $V = \pi r^2 \ell$ $\int x^{n} dx = \frac{1}{n+1} x^{n+1}, \, n \neq -1$ $S = 2\pi r\ell + 2\pi r^2$ $\int e^x dx = e^x$ Sphere $V = \frac{4}{3}\pi r^3$ $\int \frac{dx}{x} = \ln|x|$ $S = 4\pi r^2$ $\int \cos x \, dx = \sin x$ **Right Triangle** $\int \sin x \, dx = -\cos x$ $a^2 + b^2 = c^2$ $\sin\theta = \frac{a}{c}$ a 90° $\cos\theta = \frac{b}{c}$ $\tan \theta = \frac{a}{b}$

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 the pink booklet in the spaces provided after each part, NOT in this green insert.



Mech. 1.

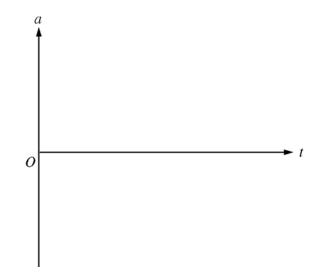
A skier of mass *M* is skiing down a frictionless hill that makes an angle θ with the horizontal, as shown in the diagram. The skier starts from rest at time t = 0 and is subject to a velocity-dependent drag force due to air resistance of the form F = -bv, where v is the velocity of the skier and b is a positive constant. Express all algebraic answers in terms of M, b, θ , and fundamental constants.

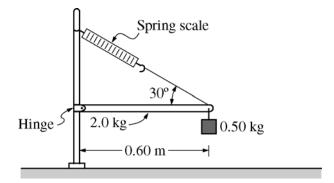
(a) On the dot below that represents the skier, draw a free-body diagram indicating and labeling all of the forces that act on the skier while the skier descends the hill.



- (b) Write a differential equation that can be used to solve for the velocity of the skier as a function of time.
- (c) Determine an expression for the terminal velocity v_T of the skier.
- (d) Solve the differential equation in part (b) to determine the velocity of the skier as a function of time, <u>showing all your steps</u>.

(e) On the axes below, sketch a graph of the acceleration a of the skier as a function of time t, and indicate the initial value of a. Take downhill as positive.

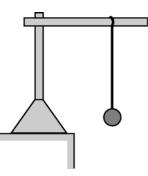




Mech. 2.

The horizontal uniform rod shown above has length 0.60 m and mass 2.0 kg. The left end of the rod is attached to a vertical support by a frictionless hinge that allows the rod to swing up or down. The right end of the rod is supported by a cord that makes an angle of 30° with the rod. A spring scale of negligible mass measures the tension in the cord. A 0.50 kg block is also attached to the right end of the rod.

- (a) On the diagram below, draw and label vectors to represent all the forces acting on the rod. Show each force vector originating at its point of application.
- (b) Calculate the reading on the spring scale.
- (c) The rotational inertia of a rod about its center is $\frac{1}{12}ML^2$, where *M* is the mass of the rod and *L* is its length. Calculate the rotational inertia of the rod-block system about the hinge.
- (d) If the cord that supports the rod is cut near the end of the rod, calculate the initial angular acceleration of the rod-block system about the hinge.

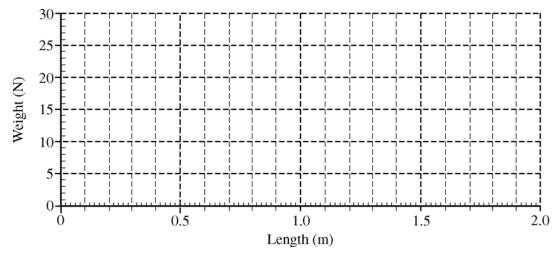


Mech. 3.

In an experiment to determine the spring constant of an elastic cord of length 0.60 m, a student hangs the cord from a rod as represented above and then attaches a variety of weights to the cord. For each weight, the student allows the weight to hang in equilibrium and then measures the entire length of the cord. The data are recorded in the table below:

Weight (N)	0	10	15	20	25
Length (m)	0.60	0.97	1.24	1.37	1.64

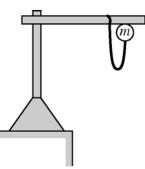
(a) Use the data to plot a graph of weight versus length on the axes below. Sketch a best-fit straight line through the data.



(b) Use the best-fit line you sketched in part (a) to determine an experimental value for the spring constant k of the cord.

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The student now attaches an object of unknown mass m to the cord and holds the object adjacent to the point at which the top of the cord is tied to the rod, as represented above. When the object is released from rest, it falls 1.5 m before stopping and turning around. Assume that air resistance is negligible.

- (c) Calculate the value of the unknown mass m of the object.
- (d) i. Calculate how far down the object has fallen at the moment it attains its maximum speed.
 - ii. Explain why this is the point at which the object has its maximum speed.
 - iii. Calculate the maximum speed of the object.

END OF EXAM