



CollegeBoard AP

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# AP<sup>®</sup> Physics C: Mechanics Exam

SECTION II

2007

**DO NOT OPEN THIS INSERT UNTIL YOU ARE TOLD TO DO SO.**

Write your answers in the pink Section II booklet. This green insert may be used for reference and/or scratch work as you answer the free-response questions, but no credit will be given for the work shown in the insert.

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TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS		UNITS		PREFIXES			
		Name	Symbol	Factor	Prefix	Symbol	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ $= 931 \text{ MeV}/c^2$	meter	m	$10^9$	giga	G	
Proton mass,	$m_p = 1.67 \times 10^{-27} \text{ kg}$	kilogram	kg	$10^6$	mega	M	
Neutron mass,	$m_n = 1.67 \times 10^{-27} \text{ kg}$	second	s	$10^3$	kilo	k	
Electron mass,	$m_e = 9.11 \times 10^{-31} \text{ kg}$	ampere	A	$10^{-2}$	centi	c	
Electron charge magnitude,	$e = 1.60 \times 10^{-19} \text{ C}$	kelvin	K	$10^{-3}$	milli	m	
Avogadro's number,	$N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	mole	mol	$10^{-6}$	micro	$\mu$	
Universal gas constant,	$R = 8.31 \text{ J}/(\text{mol}\cdot\text{K})$	hertz	Hz	$10^{-9}$	nano	n	
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23} \text{ J}/\text{K}$	newton	N	$10^{-12}$	pico	p	
Speed of light,	$c = 3.00 \times 10^8 \text{ m}/\text{s}$	pascal	Pa	VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES			
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$ $= 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$ $hc = 1.99 \times 10^{-25} \text{ J}\cdot\text{m}$ $= 1.24 \times 10^3 \text{ eV}\cdot\text{nm}$	joule	J				
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$	watt	W	$0^\circ$	0	1	0
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$	coulomb	C	$30^\circ$	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T}\cdot\text{m})/\text{A}$	volt	V	$37^\circ$	3/5	4/5	3/4
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7} (\text{T}\cdot\text{m})/\text{A}$	ohm	$\Omega$	$45^\circ$	$\sqrt{2}/2$	$\sqrt{2}/2$	1
Universal gravitational constant,	$G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg}\cdot\text{s}^2$	henry	H	$53^\circ$	4/5	3/5	4/3
Acceleration due to gravity at Earth's surface,	$g = 9.8 \text{ m}/\text{s}^2$	farad	F	$60^\circ$	$\sqrt{3}/2$	1/2	$\sqrt{3}$
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N}/\text{m}^2$ $= 1.0 \times 10^5 \text{ Pa}$	tesla	T	$90^\circ$	1	0	$\infty$
1 electron volt,	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	degree					
		Celsius	$^\circ\text{C}$				
		electron-volt	eV				

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.

## MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\Sigma \mathbf{F} = \mathbf{F}_{net} = ma$$

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

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

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

$$F_{fric} \leq \mu N$$

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

$$K = \frac{1}{2}mv^2$$

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

$$P = \mathbf{F} \cdot \mathbf{v}$$

$$\Delta U_g = mgh$$

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

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

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

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

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

$$v = r\omega$$

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

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

$$\omega = \omega_0 + \alpha t$$

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

$a$  = acceleration  
 $F$  = force  
 $f$  = frequency  
 $h$  = height  
 $I$  = rotational inertia  
 $J$  = impulse  
 $K$  = kinetic energy  
 $k$  = spring constant  
 $\ell$  = length  
 $L$  = angular momentum  
 $m$  = mass  
 $N$  = normal force  
 $P$  = power  
 $p$  = momentum  
 $r$  = radius or distance  
 $\mathbf{r}$  = position vector  
 $T$  = period  
 $t$  = time  
 $U$  = potential energy  
 $v$  = velocity or speed  
 $W$  = work done on a system  
 $x$  = position  
 $\mu$  = coefficient of friction  
 $\theta$  = angle  
 $\tau$  = torque  
 $\omega$  = angular speed  
 $\alpha$  = angular acceleration

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

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

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

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

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

$$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

## ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$$

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

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

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

$$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$$

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

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

$$I = Nev_d A$$

$$V = IR$$

$$R_s = \sum_i R_i$$

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

$$P = IV$$

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

$A$  = area  
 $B$  = magnetic field  
 $C$  = capacitance  
 $d$  = distance  
 $E$  = electric field  
 $\mathcal{E}$  = emf  
 $F$  = force  
 $I$  = current  
 $J$  = current density  
 $L$  = inductance  
 $\ell$  = 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  
 $r$  = distance  
 $t$  = time  
 $U$  = potential or stored energy  
 $V$  = electric potential  
 $v$  = velocity or speed  
 $\rho$  = resistivity  
 $\phi_m$  = magnetic flux  
 $\kappa$  = dielectric constant

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

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$$

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

$$B_s = \mu_0 nI$$

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

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

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

$$U_L = \frac{1}{2}LI^2$$

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

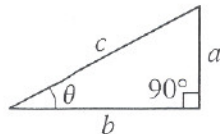
$b$  = base

$h$  = height

$\ell$  = length

$w$  = width

$r$  = radius



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

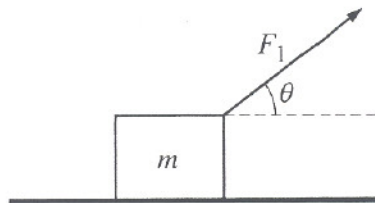
PHYSICS C: MECHANICS

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 block of mass  $m$  is pulled along a rough horizontal surface by a constant applied force of magnitude  $F_1$  that acts at an angle  $\theta$  to the horizontal, as indicated above. The acceleration of the block is  $a_1$ . Express all algebraic answers in terms of  $m$ ,  $F_1$ ,  $\theta$ ,  $a_1$ , and fundamental constants.

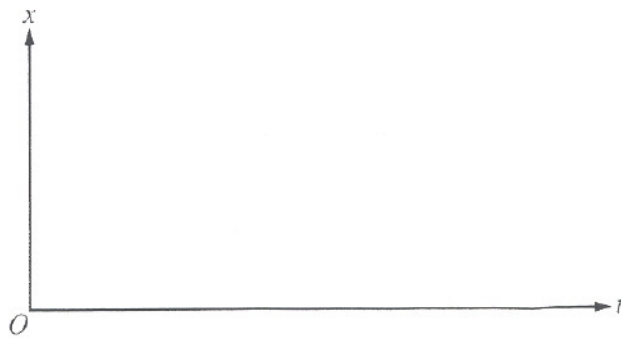
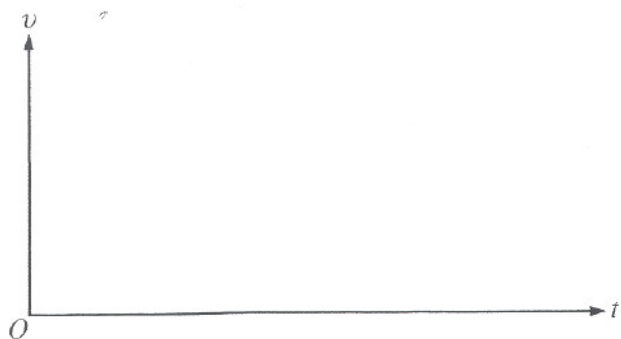
(a) On the figure below, draw and label a free-body diagram showing all the forces on the block.



(b) Derive an expression for the normal force exerted by the surface on the block.

(c) Derive an expression for the coefficient of kinetic friction  $\mu$  between the block and the surface.

(d) On the axes below, sketch graphs of the speed  $v$  and displacement  $x$  of the block as functions of time  $t$  if the block started from rest at  $x = 0$  and  $t = 0$ .



(e) If the applied force is large enough, the block will lose contact with the surface. Derive an expression for the magnitude of the greatest acceleration  $a_{\text{max}}$  that the block can have and still maintain contact with the ground.

Mech. 2.

In March 1999 the Mars Global Surveyor (GS) entered its final orbit about Mars, sending data back to Earth.

Assume a circular orbit with a period of  $1.18 \times 10^2$  minutes =  $7.08 \times 10^3$  s and orbital speed of  $3.40 \times 10^3$  m/s.

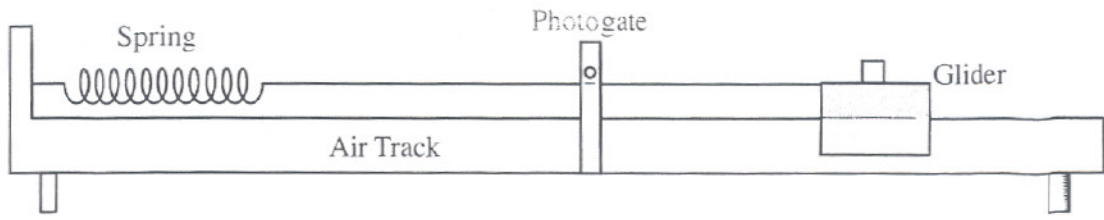
The mass of the GS is 930 kg and the radius of Mars is  $3.43 \times 10^6$  m.

- (a) Calculate the radius of the GS orbit.
- (b) Calculate the mass of Mars.
- (c) Calculate the total mechanical energy of the GS in this orbit.
- (d) If the GS was to be placed in a lower circular orbit (closer to the surface of Mars), would the new orbital period of the GS be greater than or less than the given period?

\_\_\_\_\_ Greater than          \_\_\_\_\_ Less than

Justify your answer.

- (e) In fact, the orbit the GS entered was slightly elliptical with its closest approach to Mars at  $3.71 \times 10^5$  m above the surface and its furthest distance at  $4.36 \times 10^5$  m above the surface. If the speed of the GS at closest approach is  $3.40 \times 10^3$  m/s, calculate the speed at the furthest point of the orbit.

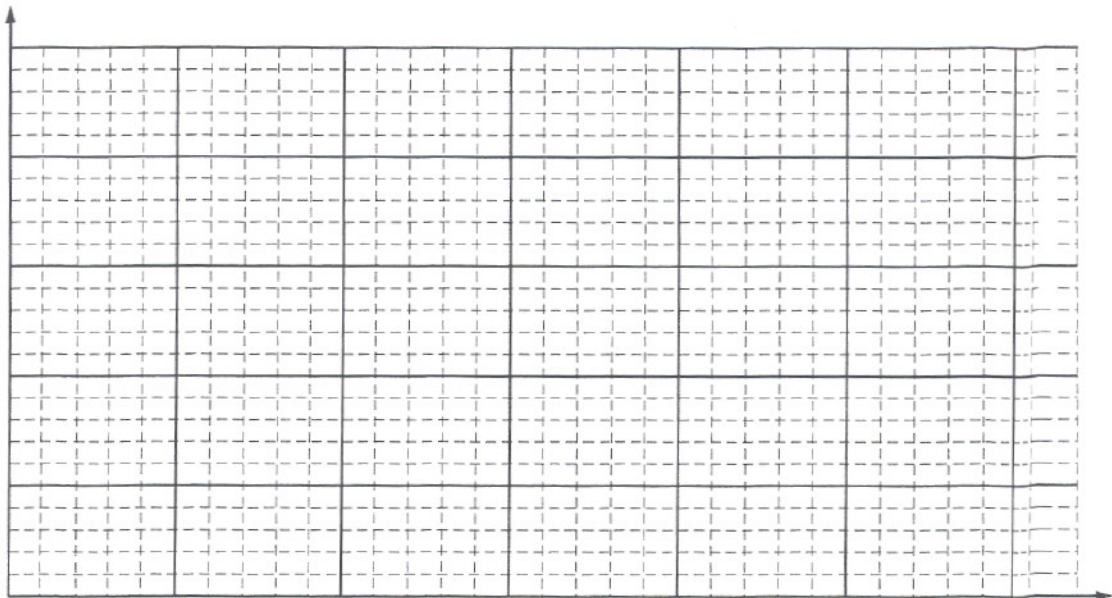


Mech. 3.

The apparatus above is used to study conservation of mechanical energy. A spring of force constant  $k$  N/m is held horizontal over a horizontal air track, with one end attached to the air track. A light string is attached to the other end of the spring and connects it to a glider of mass  $m$ . The glider is pulled to stretch the spring an amount  $x$  from equilibrium and then released. Before reaching the photogate, the glider attains its maximum speed and the string becomes slack. The photogate measures the time  $t$  that it takes the small block on top of the glider to pass through. Information about the distance  $x$  and the speed  $v$  of the glider as it passes through the photogate are given below.

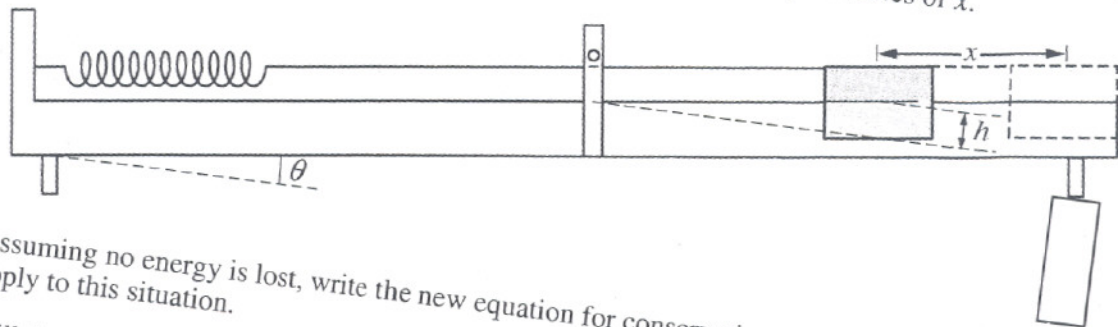
Trial #	Extension of the Spring $x$ (m)	Speed of Glider $v$ (m/s)	Extension Squared $x^2$ (m <sup>2</sup> )	Speed Squared $v^2$ (m <sup>2</sup> /s <sup>2</sup> )
1	$0.30 \times 10^{-1}$	0.47	$0.09 \times 10^{-2}$	0.22
2	$0.60 \times 10^{-1}$	0.87	$0.36 \times 10^{-2}$	0.76
3	$0.90 \times 10^{-1}$	1.3	$0.81 \times 10^{-2}$	1.7
4	$1.2 \times 10^{-1}$	1.6	$1.4 \times 10^{-2}$	2.6
5	$1.5 \times 10^{-1}$	2.2	$2.3 \times 10^{-2}$	4.8

- (a) Assuming no energy is lost, write the equation for conservation of mechanical energy that would apply to this situation.
- (b) On the grid below, plot  $v^2$  versus  $x^2$ . Label the axes, including units and scale.



(c)

- i. Draw a best-fit straight line through the data.
  - ii. Use the best-fit line to obtain the mass  $m$  of the glider.
- (d) The track is now tilted at an angle  $\theta$  as shown below. When the spring is unstretched, the center of the glider is a height  $h$  above the photogate. The experiment is repeated with a variety of values of  $x$ .



- i. Assuming no energy is lost, write the new equation for conservation of mechanical energy that would apply to this situation.
- ii. Will the graph of  $v^2$  versus  $x^2$  for this new experiment be a straight line?  
 Yes       No  
Justify your answer.